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Editorial

Mass fish kills catalyse improved water and fisheries management

Craig A. Boys [A,B,E], *Thomas S. Rayner*[A,B], *Simon M. Mitrovic*[C], *Katherine E. Doyle*[B], *Lee. J. Baumgartner* [B] *and John D. Koehn* [B,D]

[A]New South Wales Department of Primary Industries, Port Stephens Fisheries Institute, Taylors Beach Road, Taylors Beach, NSW 2316, Australia. Email: craig.boys@dpi.nsw.gov.au; tom.rayner@dpi.nsw.gov.au

[B]Institute for Land Water and Society, Charles Sturt University, PO Box 789, Albury, NSW 2640, Australia. Email: kadoyle@csu.edu.au; lbaumgartner@csu.edu.au

[C]School of Life Sciences, University of Technology Sydney, Ultimo, NSW 2007, Australia. Email: simon.mitrovic@uts.edu.au

[D]Applied Aquatic Ecology, Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, 123 Brown Street, Heidelberg, Vic. 3084, Australia. Email: john.koehn@dse.vic.gov.au

[E]Corresponding author. Email: craig.boys@dpi.nsw.gov.au

Abstract. Mass fish kills capture the world's attention and their frequency is increasing worldwide. The sudden death of many millions of native fish in the Darling–*Baaka* River in Australia in 2018–19 was a catalyst for the 11 articles in this special issue. Collectively, they advance our understanding of how to manage these events, dealing with: ecological impacts and recovery; technologies and approaches for prediction, preparedness and response; and the role of the public in preparing and responding to these catastrophic events.

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Introduction

Mass fish kills capture the world's attention. They bring otherwise-cryptic declines of freshwater biodiversity into the spotlight, raising public concern over our collective capacity to protect and recover highly altered aquatic ecosystems. Fish kills can be caused by a variety of natural and human-induced stressors that push fish beyond their physiological limits, and their occurrence is increasing worldwide (La and Cooke 2011).

In the Southern Hemisphere summer of 2018–19, millions of native fish succumbed to a catastrophic death event in a 30-km stretch of Australia's Darling–*Baaka* River (Australian Academy of Science 2019). Many other smaller events also occurred across inland and coastal rivers of the continent's south-east (New South Wales Department of Primary Industries 2020). The Darling–*Baaka* River fish kill affected a range of iconic species, especially large individuals (1 m in length and weighing ≥20 kg) of threatened Murray cod or *goodoo* (*Maccullochella peelii*), a popular target of anglers, and the culturally and ecologically significant bony herring or *nhaampa* (*Nematalosa erebi*).

Widespread and intense media coverage of the fish kill prompted a strong public response and increased scrutiny of water management decisions and practices. This pressure prompted several enquiries examining the causes of the event (Australian Academy of Science 2019; Vertessy *et al.* 2019). It also inspired fisheries scientists and managers to convene a special session at the 2019 Australian Society of Fish Biology Conference in Canberra. The aim was to share experiences of the Darling–*Baaka* River fish kill, capture data surrounding the event and ask, 'Can these mass fish kills provide a catalyst for improved water and fisheries management?'

Focus of this special issue

The challenge of managing fish kills is certainly not unique to Australia. Climate change, coupled with the ever-increasing pressure on our freshwater resources, will mean that these adverse events will continue to be confronted across the globe (Hughes 2003; La and Cooke 2011). The desire to share experiences of the Darling–*Baaka* River with a broader international audience gave rise to this special issue of *Marine and Freshwater Research*, 'Fish Kills in Freshwaters', with the objective of improving the way we manage fish kills in freshwater systems globally. The knowledge generated from the 11 articles collectively advance our understanding around the ecological impacts and recovery from fish kills; technologies and approaches for prediction, preparedness and response; and the often-ignored social impacts on communities and the role the

public can play in preparing and responding to these catastrophic events. Specifically:

- The articles by Sheldon *et al.* (2022) and Stocks *et al.* (2022) provide an important historical record of the death of millions of fish in the Lower Darling–*Baaka* River in 2018–19. Sheldon *et al.* (2022) draw upon their own investigative work and that of others to summarise the proximate and ultimate causes of the deaths. The authors provide a timely critique on how rivers are managed and outline recommendations that have implications for policy makers in a changing climate. Stocks *et al.* (2022) detail the results of fish community surveys 18 months after the deaths, showing populations under continued stress and emphasising the importance of investing in ongoing monitoring and recovery measures.
- Pera *et al.* (2022) report on lake mesocosm experiments that highlight reduced dissolved oxygen effects from decaying carp (*Cyprinus carpio*), and a linear relationship between the biomass level of dead carp and rising nutrient levels (total nitrogen and total phosphorus), chlorophyll-*a* and phytoplankton biovolume. These results demonstrate how critical timely clean-up efforts are in avoiding cascading detrimental effects on water quality, which may further exacerbate ecological damage.
- Davie and Pera (2022) introduce a promising new method for predicting when and where fish kills may occur. The Fish Health Indicator is a geographic information system-based tool combining meteorological forecasts with river flow and algal biomass data to identify river reaches where deteriorating water quality conditions may be conducive to mass fish kills. With further validation and refinement, the indicator could provide managers with an early warning signal to help coordinate preventative actions that reduce the likelihood or severity of fish kills.
- Boys *et al.* (2022) review a suite of mechanical and chemical options available to mitigate the impacts of hypoxia-driven fish kill events. These technologies work by promoting mixing or aeration to prevent stratification, and subsequent destratification, of waterbodies that can lead to hypoxia, or to create small 'pockets' of oxygenated refugia for fish. A shortlist of recommended options is provided, along with a decision support tool to assist with deploying the most effective technologies.
- Many of the technologies outlined in Boys *et al.* (2022) require further field evaluation for efficacy, environmental risk and cost-effectiveness. Baldwin *et al.* (2022) present field trial results, evaluating a range of aerator designs used during the 2018–19 fish kills. The performance and limitations of the different aerators are outlined, along with recommendations that can improve the way they are used in future events.
- Studies by Zampatti *et al.* (2022) and Thiem *et al.* (2022) use otolith microstructure and chemistry to explore the ages, provenance and large-scale movements of three potamodromous species that perished in the 2018–19 Lower Darling–*Baaka* fish kills, namely the golden perch (*Macquaria ambigua*), Murray cod and silver perch (*Bidyanus bidyanus*). Their research shows that restoring resilient populations of these species will require reinstating the hydrological and hydraulic factors associated with spawning, recruitment and dispersal, while removing barriers to large-scale movements that have disconnected different natal regions.
- Stuart and Sharpe (2022) describe a model to design environmental flows that support spawning and recruitment of Murray cod. The model uses a hydrological dataset to design a managed flow event, aimed at reinstating components of the natural flow regime that have been historically lost due to river regulation and water extraction. Not only can ecohydraulic models like this improve current water management policies, but they can also be used to facilitate population recovery following large fish kills.
- Although scientists and managers often count the costs of large fish kills in economic terms, the cultural and social impacts are rarely acknowledged. Ellis *et al.* (2022) bring a new perspective, examining the effect that the death of millions of fish had on the Baakandji (the Traditional Owners and First Nations people of the Darling–*Baaka* River) and others in the local community. The authors document heartfelt accounts of loss, despair and helplessness, compounded by frustration at not having a role in water management and policy making. This paper suggests how a greater understanding and incorporation of various knowledge systems (and enhanced community and agency cooperation) could significantly improve the ways in which rivers and fish kills are managed.
- Koehn (2022) concludes this special issue with a call to action. Historically, the assessment and reporting of kills has been poor and the true costs (economic, ecological and social) have not been properly quantified. Without a philosophical change in our approach to dealing with fish kills worldwide, we are destined to perpetuate the same mistakes. This paper provides 15 key recommendations that could make a significant improvement in our ability to manage future fish kills and build freshwater ecosystems that are more resilient to these events.

Conclusion

Mass fish kills evoke a range of human emotions and responses. They strike at the heart of our relationship with rivers, their biota and our long-term custodianship of these environments. They also provide an opportunity to reconsider how we best meet our ethical responsibilities to repair the natural functions of aquatic ecosystems. In this way, mass fish kills do provide a catalyst for improved water and fisheries management, by stimulating the development of new and innovative approaches. Retrospectively examining fish kills for both their causes and consequences ultimately deepens our capacity to respond as a community. It is therefore important to document the stories of those scientists and managers directly involved in preventing and responding to fish kills, as well as those in the general community who are left to live with the long-lasting consequences.

With each mass fish kill event, the technologies and approaches we deploy between and during events need to be constantly reviewed and renewed, to ensure we can mitigate, or manage, future events more effectively. The resilience and recovery of our freshwater ecosystems also need to be supported by management decisions that are grounded in state-of-the-art ecological knowledge. The body of work in this special issue

represents a clear path forward and demonstrates that mass fish kill events can catalyse improved water and fisheries management, with global implications. However, as outlined in Koehn (2022), there is still much to be done if we are to avoid future disasters, manage them better when they do occur and adequately invest in actions that will restore the losses.

Conflicts of interest

Craig A. Boys, Simon M. Mitrovic, Katherine E. Doyle and Lee. J. Baumgartner were guest editors of this special issue and, along with John D. Koehn, co-authored several articles cited in this editorial. The authors played no role in the review or editorial handling of this article, or any of the articles that they authored as part of this issue.

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