Rehabilitating the Snowy River: The influence of environmental flow releases on dissolved organic carbon supply and utilisation

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Preface

This thesis consists of six chapters. Chapters 2 to 5 have been written as separate articles that have either been published or are in preparation for submission to peer reviewed scientific journals. These papers are included as or close to their published or submitted form, and as a result, some repetition occurs. To prevent unnecessary duplication, a single reference list has been provided at the end of this thesis.

This thesis is a compilation of my original work, carried out with guidance from my academic and industry supervisors. I conceptualised this research, carried out the majority of the data collection and analysis, and wrote the manuscripts. The details of the publications arising from this thesis are provided below, and co-author contributions have been specified.

Chapter 2: Rohlfs, A., Mitrovic, S. M., Williams, S. and Coleman, D. 2015. Can tributary in-flows improve DOC regime recovery in a snowmelt river regulated by a large reservoir? *Marine and Freshwater Research*. 67 (9), pp 1338-1345, doi:10.1071/MF14230

S. M. Mitrovic provided conceptual advice, guidance and field assistance.

S. Williams provided conceptual advice and guidance, and facilitated the provision of experimental flow releases.

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Chapter 3: Rohlfs A., Mitrovic, S. M., Williams, S., Hitchcock, J. N. and Rees, G. N. 2016. Dissolved organic carbon delivery from managed flow releases in a montane snowmelt river. *Aquatic Sciences*, 78 (4), pp 793-807, doi:10.1007/s00027-016-0472-5

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Chapter 4: Rohlfs, A., Mitrovic, S. M., Williams, S., Rees, G. N., Lim, R. and Werry, L. 2016. Functional responses to environmental flows: does resource delivery from pulsed dam releases influence microbial metabolism? Freshwater Biology. In prep.

S. M. Mitrovic provided conceptual advice, guidance and field assistance.

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S. M. Mitrovic provided conceptual advice and guidance.

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R. Lim provided conceptual advice and technical guidance with mesocosm design and set up.

R. Carney provided assistance with sample and data analysis.

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Other publications produced during my candidature but not forming part of this thesis:

Hitchcock, J. N., Mitrovic, S. M., Hadwen, W.L., Roelke, D.L., Growns, I. O. and **Rohlfs, A.** 2016. Terrestrial dissolved organic carbon subsidises estuarine zooplankton: an *in-situ* mesocosm study. *Limnology and Oceanography,* vol. 61, issue 1, pp 254-267

Hitchcock, J. N., Mitrovic, S. M., Hadwen, W.L., Growns, I. O. and **Rohlfs, A.** 2014. Zooplankton responses to freshwater inflows and organic matter pulses in a wave-dominated estuary. *Marine and Freshwater Research.* In press. doi: 10.1071/MF15297

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List of Abbreviations

ALPHA	α-1,4-glucosidase
BETA	β-1,4-glucosidase
BU	Butyl esterase
CR	Community respiration
DOC	Dissolved organic carbon
EEA	Extracellular enzyme activities
ETS	Electron transport system
FI	Fluorescence index
GPP	Gross primary productivity
INT	Iodonitrotetrazolium
LEU	Leucine amino-pepidase
NO_x	Oxides of nitrogen
PCO	Principal coordinates analysis
PHOS	Alkaline Phosphatase
SMS	Snowy Mountains Hydroelectric Scheme
SFRMM	Snowy Flow Response Monitoring and Modelling program
SRIF	Snowy River Increased Flows
SRP	Soluble reactive phosphorus
TN	Total nitrogen
TP	Total phosphorus
XYL	β-xylosidase

Abstract

Environmental flows are the quantity, timing and quality of water flow required to sustain and protect ecosystem and social values. Environmental flows delivered as managed water releases from large reservoirs often form the basis of rehabilitation programs in regulated rivers, and may benefit the aquatic food web by mobilising basal food resources, including dissolved organic carbon (DOC). However, the linkages between managed water releases, organic carbon delivery and microbial metabolic responses remain poorly understood. This thesis aimed to examine and compare the influence of dam and tributary water releases on DOC transport and microbial utilisation using field monitoring and manipulative mesocosm studies in the Snowy River in south-east Australia.

Field monitoring revealed positive, linear relationships between DOC concentration and discharge in the unregulated tributary that were absent directly downstream of the dam, and re-emerged below the tributary confluence. Variability in tributary DOC concentration was dampened downstream of a weir facilitating diversions of tributary water. These water diversions prevented approximately 80% of annual tributary DOC export from reaching the main stem. Tributary water releases supplied rapid pulses of terrestrial DOC to the regulated main stem, whereas dam releases produced low, constant DOC concentrations, and mobilised a mixture of terrestrial and microbial DOC.

The mesocosm studies showed that benthic microbial communities can respond rapidly to hydrologically-driven variations in DOC and nutrient regimes, providing a potential mechanism through which environmental flows may trigger increased rates of microbial processing. In the field mesocosm study, rapid, short duration increases in benthic metabolic respiration occurred following exposure to high-flow dam release waters. A manipulative laboratory study simulating different DOC regimes on benthic substrates found that a faster terrestrial DOC input rate facilitates stronger effects on microbial enzyme expression and bacterial taxonomic structure relative to press and control treatments.

This thesis contributes to a more comprehensive understanding of organic carbon supply and utilisation in regulated rivers, as well as the ecological mechanisms linking resource supply regime and biotic processes. These results reveal the considerable scope for

dissolved organic matter in river flows to be actively managed through environmental water delivery. In particular, these results support the wider implementation of tributary environmental water releases in river rehabilitation programs.