

**A multi-scale investigation into the effects of
permanent inundation on the flood pulse, in
ephemeral floodplain wetlands of the River Murray.**



The Murray-Darling Junction during the drought of 1914
Photo, taken by Sydney Milne, was kindly donated by his son Robin Milne for use in this thesis.

Cathy Francis B.Sc. Hons.

University of Canberra
Murray-Darling Freshwater Research Centre
Cooperative Research Centre for Freshwater Ecology

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 2005

Acknowledgements

I would like to thank my supervisors, Dr. Ben Gawne and Associate Professor Martin Thoms, for the support both provided, particularly in the write-up stage of my PhD when your encouragement, and the comments you provided on the drafts of my thesis, were invaluable and greatly appreciated.

I must also thank the managers responsible for the wetlands I worked on, including Bruce Weir and Peter Schram (SA Field and Game Association), David Leslie and Paul Childs (NSW State Forests) and Paul Lloyd (Murray Wetlands Working Group), all of whom provided me with great encouragement and assistance! And, of course, it would not have been possible to complete all my field work without my many volunteer field helpers: my main-stays Dad, Iain Ellis, Brendan Ebner, Sarah Cartwright and Fiona Betts, as well as Paul Rat, Kate Gerber, Nick Lapse and local TAFE students – Mick, Nick and Russell. Special thanks to you Dad, for “volunteering” at times when it was impossible to find anyone else to help, clearly it was quite hard-work ...



Thanks also to the staff of the ‘water lab’ (University of Canberra), particularly Anne Taylor, for advice and assistance provided, and to Piers Brissenden (University of Adelaide) for kindly allowing me to use the Zoology Department facilities while I was based in Adelaide for a short period. Ross Cunningham also provided invaluable statistical advice and analyses.

And last, but most certainly not least, I would like to sincerely thank my family and friends. Mum and Dad, without your endless support (and patience) I would not have been able to complete this thesis (not in this life-time anyway), which I would like to dedicate to my Gramps, George. To all my lovely friends, thanks for your encouragement, motivation, company and for keeping me sane - special thanks to my dear friends Kylie and Alex for providing all of these things in abundance.

This project was supported by funding from the Murray-Lower Darling River Management Board and the Lower Murray-Darling Catchment Management Committee, the University of Canberra and the Cooperative Research Centre for Freshwater Ecology (CRCFE).

Abstract

Using a multi-scale experimental approach, the research undertaken in this thesis investigated the role of the flood pulse in ephemeral floodplain wetlands of the River Murray, in order to better understand the impact of river regulation (and permanent inundation) on these wetlands.

An ecosystem-based experiment was conducted on the River Murray floodplain, to compare changes in nutrient availability and phytoplankton productivity in three ephemeral wetlands (over a drying/re-flooding cycle) with three permanently inundated wetlands. In the ephemeral wetlands, both drying and re-flooding phases were associated with significant increases in nutrient availability and, in some cases, phytoplankton productivity. It was demonstrated that the 'flood pulse', as described by the Flood Pulse Concept (FPC), can occur in ephemeral wetlands in dryland river-floodplain systems, although considerable variation in the nature of the pulse existed amongst these wetlands. Results of this experiment suggest that factors such as the degree of drying and length of isolation during the dry phase, the rate of re-filling, timing of re-flooding and the number of drying/re-flooding cycles may be potentially important in producing the variation observed.

Permanent inundation of ephemeral wetlands effectively removed these periods of peak nutrient availability and phytoplankton productivity, resulting in continuously low levels (of nutrient availability and phytoplankton productivity). It was concluded that alteration of the natural hydrological cycle in this way can significantly reduce nutrient availability, primary production and secondary production, essentially changing the structure and function, the ecology, of these wetlands. Equally, the results of this experiment indicate that some of the changes resulting from river regulation and permanent inundation can be somewhat reversed, within a relatively short period of time, given re-instatement of a more natural hydrological regime.

A mesocosm experiment was used to examine the influence of the dry phase, specifically the effect of the degree of wetland drying, on patterns of nutrient availability and primary productivity comprising the flood pulse. Compared to permanent inundation, re-flooding of completely desiccated sediments increased carbon (C) and nitrogen (N) availability while partial drying generally decreased, or had little

effect on, C and N availability after re-flooding. However, degree of drying had little effect on phosphorus availability or rates of primary production measured after re-flooding, and it is possible that these two factors are related. Partial drying reduced rates of community respiration after re-flooding, possibly a reflection of the reduced carbon concentrations measured in these mesocosms in this phase of the experiment. Degree of drying also influenced the macrophyte community (measured after three months of flooding), with plant biomass generally decreasing and species diversity increasing as the degree of drying increased (with the exception of complete sediment desiccation which had lasting negative effects on both macrophyte biomass and species diversity).

The results of the ecosystem and mesocosm experiments were utilised, in addition to results collected from the same experiment conducted at two smaller scales (minicosms and microcosms), to assess whether the effects of hydrological regime on nutrient availability at the 'wetland' scale could be replicated in smaller-scale experiments. None of the smaller-scaled experiments included in this investigation were able to replicate the specific response to hydrological regime recorded at the ecosystem scale, however the mesocosm experiment did produce results that were more similar to those at the ecosystem scale than those produced by the mini and microcosm experiments. The results of this study indicated that extrapolation of results from small-scale experiments should be undertaken with caution, and confirmed that a multi-scale approach to ecological research is wise, where large-scale field experimentation and/or monitoring provides a check on the accuracy, and hence relevance, of conclusions reached via mesocosm experiments.

Table of Contents

Certificate of authorship of thesis	ii
Copyright	iii
Acknowledgements	iv
Abstract	vi
List of Tables	xi
List of Figures	xii
Chapter 1: Introduction	1
1.1 River regulation	1
1.2 The flood pulse concept	4
1.3 Experimental scale	7
1.4 Research aims and thesis structure	9
Chapter 2: Examining the nature of the flood pulse in ephemeral floodplain wetlands of the River Murray - An ecosystem-scale experiment	11
2.1 Introduction	11
2.2 Materials and methods	18
2.2.1 Experimental design	18
2.2.2 Study sites	20
2.2.3 Sampling regime	24
2.2.4 Parameters	32
2.2.5 Data analysis	34
2.2 Results	35
2.3.1 Permanent inundation	37
2.3.2 The dry phase	37
2.3.3 The re-flooding phase	42
2.4 Discussion	52
2.4.1 The flood pulse	52

2.4.2	The effects of permanent inundation	56
Chapter 3: Degree of drying – impacts on nutrient availability and community metabolism after re-flooding, a mesocosm experiment		
		59
3.1	Introduction	59
3.2	Materials and methods	64
3.2.1	Experimental design	64
3.2.2	Sampling regime	65
3.2.3	Parameters	66
3.2.4	Data analysis	71
3.3	Results	72
3.3.1	The dry phase	72
3.3.2	The re-flooding phase	76
3.4	Discussion	91
3.4.1	Degree of drying and the flood pulse – Nutrient availability	91
3.4.2	Degree of drying and the flood pulse – Community metabolism	95
3.4.3	Degree of drying and the flood pulse – Macrophyte community	97
3.4.4	In summary	98
Chapter 4: The effect of experimental scale on nutrient availability following drying and re-flooding of floodplain wetland sediments		
4.1	Introduction	100
4.2	Materials and methods	106
4.2.1	Ecosystem experiment	108
4.2.2	Mesocosm experiment	108
4.2.3	Minicosm experiment	108
4.2.4	Microcosm experiment	109
4.2.5	Data analysis	110
4.3	Results	112
4.3.1.	Ecosystem experiment	112

4.3.2. Mesocosm experiment	113
4.3.3. Minicosm experiment	113
4.3.4. Microcosm experiment	116
4.3.5. Comparison between experimental scales	122
4.4 Discussion	124
4.4.1 Ecosystem vs smaller-scale experiments	124
4.4.2 In summary	129
Chapter 5: General summary	
5.1 The potential for patterns and processes in floodplain wetlands of the River Murray to be reproduced at smaller experimental scales	132
5.2 Changes in nutrient availability and primary productivity during drying and following re-flooding in ephemeral floodplain wetlands of the River Murray, including application of the Flood Pulse Concept to dryland river-floodplain systems	135
5.3 The effects of permanent inundation on the 'flood pulse' in ephemeral floodplain wetlands of the River Murray	138
References	142

List of Tables

Chapter 2

Table 1: Mussel Lagoons and Chambers Creek Wetland, dates sampled (p 25)

Table 2: Moira Lake and Barmah Lake, dates sampled (p 26)

Table 3: Croppers Lagoon and Lake Moodemere, dates sampled (p 28)

Chapter 3

Table 4: Results of analysis of dissolved organic carbon (DOC) and total carbon (TC) concentrations following re-flooding of mesocosms (p 77)

Table 5: Results of the general linear mixed model analysis of ammonia (NH_4^+), nitrate + nitrite (NO_x^-) and total nitrogen (TN) concentrations following re-flooding of mesocosms (p 80)

Table 6: Results of the general linear mixed model analysis of ortho-phosphate (PO_4^{3-}) and total phosphorus (TP) concentrations following re-flooding of mesocosms (p 84)

Table 7: Results of the general linear mixed model analysis of Community Respiration over 24 hours (CR_{24}), Gross Primary Productivity (GPP) and Productivity:Respiration ratio (P:R) following re-flooding of mesocosms (p 87)

Chapter 4

Table 8: A summary of the experimental scales utilized in studies concerning nutrient dynamics and/or phytoplankton productivity in wetland systems exposed to drying and re-flooding (p 105)

Table 9: Results of two-way ANOVA (with replication) for NH_4^+ , NO_x^- , TN, PO_4^{3-} and TP concentrations following re-flooding of minicosms (p 114)

Table 10: Results of two-way ANOVA (with replication) for NH_4^+ , NO_x^- , TN, PO_4^{3-} and TP concentrations following re-flooding of the treatment microcosms (p 116)

Table 11: A comparison of patterns and processes observed in experiments conducted at the ecosystem, mesocosm, minicosm and microcosm scales (p 122)

Table 12: PO_4^{3-} and TP concentrations measured in the study site (Barmah Lake) and reported for other wetlands located on the River Murray floodplain (p 125)

List of Figures

Chapter 2

Figure 1: The nitrogen cycle in wetland systems, indicating the affects of oxygen availability in different sediment layers (p 16)

Figure 2: The phosphorus cycle in wetland systems, indicating interactions with the iron cycle (p 17)

Figure 3: Maps of (a) eastern Australia indicating the Murray-Darling Basin, (b) the Murray-Darling Basin indicating the River Murray, and (c) the River Murray indicating the location of wetland pairs included in the experiment (p 19)

Figure 4: (a) Big Mussel Lagoon prior to re-flooding, (b) Little Mussel Lagoon and Big Mussel Lagoon, approximately 24 hours after re-flooding commenced, and (c) Big Mussel Lagoon post re-flooding (p 29)

Figure 5: Chambers Creek wetland (p 29)

Figure 6: Moira Lake: (a) prior to re-flooding, and (b) post re-flooding (p 30)

Figure 7: Barmah Lake (p 30)

Figure 8: Croppers Lagoon: (a) prior to re-flooding, and (b) post re-flooding (p 31)

Figure 9: Lake Moodemere (p 31)

Figure 10: Average water depth (cms) on each sampling date at (a) Big and Little Mussel Lagoons and Chambers Creek Wetland, (b) Moira and Barmah Lakes and (c) Croppers Lagoon and Lake Moodemere (p 36)

Figure 11 (a – d): Changes in average concentrations of (a) TC, (b) DOC, (c) TN and (d) NH_4^+ in Moira and Barmah Lakes over two drying/re-flooding cycles (p 40)

Figure 11 (e – h): Changes in average concentrations of (e) NO_x^- , (f) TP, (g) PO_4^{3-} , and (h) chlorophyll *a* in Moira and Barmah Lakes over two drying/re-flooding cycles (p 41)

Figure 12 (a – d): Average concentrations of (a) TC, (b) DOC, (c) TN and (d) NH_4^+ in Big Mussel and Little Mussel Lagoons, Chambers Creek Wetland and the River Murray 1 day prior to re-flooding and 1 day, 1 week, 1 month and 3 months after re-flooding of Mussel Lagoons (p 45)

Figure 12 (e – h): Average concentrations of (e) NO_x^- , (f) TP, (g) PO_4^{3-} and (h) chlorophyll *a* in Big Mussel and Little Mussel Lagoons, Chambers Creek Wetland and the River Murray 1 day prior to re-flooding and 1 day, 1 week, 1 month and 3 months after re-flooding of Mussel Lagoons (p 46)

Figure 13 (a – d): Average concentrations of (a) TC, (b) DOC, (c) TN and (d) NH_4^+ in Croppers Lagoon, Lake Moodemere and the River Murray 1 day prior to re-flooding and 1 day, 1 week, 1 month and 3 months after re-flooding of Croppers Lagoon (p 50)

Figure 13 (e – h): Average concentrations of (e) NO_x^- , (f) TP, (g) PO_4^{3-} and (h) chlorophyll a in Croppers Lagoon, Lake Moodemere and the River Murray 1 day prior to re-flooding and 1 day, 1 week, 1 month and 3 months after re-flooding of Croppers Lagoon (p 51)

Chapter 3

Figure 14: Treatments 1 – 4 and the Control at the end of the 'dry phase': (a) Treatment 1; (b) Treatment 2; (c) Treatment 3; (d) Treatment 4; (e) Control (p 67)

Figure 15: The closed system designed to measure community metabolism in this experiment (p69)

Figure 16 (a – d): Average concentrations of (a) DOC, (b) TC, (c) NH_4^+ and (d) NO_x^- recorded in treatment 1, treatment 2, treatment 3, treatment 4, and control mesocosms during the dry phase (p74)

Figure 16 (e – g): Average concentrations of (e) TN, (f) PO_4^{3-} , and (g) TP recorded in treatment 1, treatment 2, treatment 3, treatment 4, and control mesocosms during the dry phase (p75)

Figure 17: Average conductivity ($\text{mS}\cdot\text{cm}^{-1}$) recorded in treatment 1, treatment 2, treatment 3, treatment 4, and control mesocosms over the re-flooding phase (p 77)

Figure 18: For the three month period following re-flooding, (a, b) average DOC and TC concentrations (respectively) for each treatment; and (c, d) changes in average DOC and TC concentrations (respectively) over time for treatment 1, treatment 2, treatment 3, treatment 4, and control mesocosms (p 79)

Figure 19: For the three month period after re-flooding, (a, b, c) average NH_4^+ , NO_x^- and TN concentrations (respectively) for each treatment; and (d, e, f) changes in average NH_4^+ , NO_x^- and TN concentrations (respectively) over time for treatment 1, treatment 2, treatment 3, treatment 4, and control mesocosms (p 83)

Figure 20: For the three month period after re-flooding, (a, b) average PO_4^{3-} and TP concentrations (respectively) for each treatment; and (c, d) changes in average PO_4^{3-} and TP concentrations (respectively) over time for treatment 1, treatment 2, treatment 3, treatment 4, and control mesocosms (p 86)

Figure 21: For the three month period after re-flooding, (a, b, c) average CR₂₄, GPP and P:R (respectively) for each treatment; and (d, e, f) changes in average CR₂₄, GPP and P:R (respectively) over time for treatment 1, treatment 2, treatment 3, treatment 4, and control mesocosms (p 89)

Figure 22: (a) Biomass and (b) species richness of the aquatic fauna harvested from mesocosms at the end of the experiment, averaged for each treatment (p 90)

Chapter 4

Figure 23: Experimental units for the (a) ecosystem experiment (Barmah Lake), (b) mesocosm experiment, (c) minicosm experiment and (d) microcosm experiment (p 107)

Figure 24 (a – f): Average NH₄⁺, NO_x⁻ and TN concentrations (natural log transformed) recorded in Treatments and Controls after re-flooding in the (a – c) ecosystem and (d – f) mesocosm experiments (p 119)

Figure 24 (g – l): Average NH₄⁺, NO_x⁻ and TN concentrations (natural log transformed) recorded in Treatments and Controls after re-flooding in the (g – i) minicosm and (j – l) microcosm experiments (p 120)

Figure 25 (a – h): Average PO₄³⁻ and TP concentrations (natural log transformed) recorded in Treatments and Controls after re-flooding in the (a – b) ecosystem, (c – d) mesocosm, (e – f) minicosm and (g – h) microcosm experiments (p 121)