The landscape-scale structure and functioning of floodplains

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B. App. Sci. Hons

A thesis submitted for the degree of PhD in Applied Science,

University of Canberra

September 2004

To Sammy and Dan

without whom this would be meaningless

Abstract

Floodplains are amongst the most productive and biodiverse ecosystems. The structure and functioning of floodplains is controlled by the interaction of intermittent inundation with the floodplain landscape. These interactions create highly complex and dynamic ecosystems that are difficult to study at large scales. Consequently, most research of floodplains has been conducted at small spatial and temporal scales. Inundation of floodplains can extend over many square kilometres, however, which unifies the floodplain landscape into an integrated ecosystem operating at the landscape scale. The lack of data and poor understanding of the landscape-scale structure and functioning of floodplains limits the possibility of managing floodplains sustainably as pressure for exploitation of their resources increases.

This thesis quantifies the landscape-scale relationship between the frequency and patterns of inundation, the composition and structure of the landscape, and the functioning of the floodplain landscape in terms of the distribution and dynamics of plant growth vigour over an area of approximately 376,000 ha on the Lower Balonne Floodplain; highly biodiverse, semi-arid floodplain ecosystem that straddles the state border between New South Wales and Queensland approximately 500 km inland from the eastern coast of Australia. Mean annual rainfall at St.George, to the north of the study area, is approximately 400–450 mm per year, and median annual evaporation is approximately 2000 mm per year. Plants and animals on the floodplain are therefore heavily dependent upon flooding for survival.

This project is based on the analysis of 13 Landsat Thematic Mapper satellite images captured over a 10-year period during which land and water resource development increased substantially. There is now concern that development activities have affected the functioning of the floodplain to the detriment of the natural environment and

agricultural productivity. The impacts from these activities on the functioning of the floodplain are not yet known, however.

Inundation of the Lower Balonne Floodplain was mapped using a two-part process involving a band ratio to identify deep clear water, and a change detection analysis to identify areas of shallower inundation. This analysis shows that, in contrast with most floodplains, the main flowpath of the Lower Balonne Floodplain runs along its central axis away from river channels, which flow along the floodplain's outer edges. Inundation propagates from the centre of the floodplain out towards river channels as flood discharge volumes increase.

Variations in the spatial pattern of inundated patches within the inundated extent create distinctive aquatic habitat and connectivity conditions at different flow levels. These can be described in terms of three connectivity phases: (I) Disconnected, in which isolated patches of inundation occur at low flows and river channels are hydrologically dislocated from the floodplain; (II) Interaction, where increased hydrological connectivity between inundated patches, and between the floodplain and the river channels at moderate flows, may enable significant exchange of materials, organisms and energy; and (III) Integration, in which almost the entire floodplain landscape is connected by open water during large magnitude floods.

There is an abrupt transition in inundation patterns as flows increase between 60,000 ML day^{-1} and 65,000 ML day^{-1} (ARI 2 to 2.3 years) in which inundation patterns transform from being relatively disconnected into a highly integrated network of patches. These patterns may have significant consequences for the structure and functioning of the floodplain. Increases in flows across this small range may therefore mark an important ecological flow threshold on this system. Water resource development impacts have changed the relative frequency of flows on the Lower

Balonne Floodplain, which will probably affect the sequence of connectivity phases over time. The most likely impact of these changes will be to create a floodplain that is drier overall than under natural flow conditions, and that has a smaller and wetter area of high inundation frequency.

The relationship between inundation and the structure of the floodplain landscape was examined by comparing a landcover map showing the distribution and character of 10 landcover types to the inundation frequency maps. Landcover types were mapped from a multi-date Reference Image composite of seven images captured over a period of 10 years. The Reference Image improves landcover discrimination by at least 14% over classification of a single-date image, and has an overall accuracy between 82.5% and 85% at the landscape-scale. The Reference Image shows that the landscape of the Lower Balonne Floodplain is a highly fragmented mosaic of diverse landcover types distributed in association with inundation frequency. Stratifying the floodplain into zones of frequent and rare inundation shows that frequently inundated areas have a less fragmented but less diverse landscape structure than rarely inundated areas. Assessment of the functioning of each landcover types within the floodplain ecosystem, based on landscape pattern metric analysis, indicates that the function of landcover types also changes between inundation frequency zones. Most importantly, these changes include a transformation of the matrix landcover type, which controls the character and dynamics of the ecosystem overall, from Open Grassland to Coolibah Open Woodland in the frequently inundated zone.

The landscape structure of the Lower Balonne Floodplain has been affected by development impacts, which include clearing of native vegetation, isolation of parts of the floodplain from natural inundation events by the construction of levee banks and drainage channels, and grazing impacts. Changes to the inundation regime may also affect the structure of the floodplain landscape. Over the long term, these changes are likely to create a larger area of Open Grassland and a smaller area of Coolibah Open Woodland as the zone of frequent inundation becomes smaller and wetter.

To examine the functioning of the floodplain ecosystem, the inundation maps were compared to remotely sensed indexes of plant growth vigour at the landscape and landcover-type scales. The dynamics of plant growth vigour over time are influenced by factors operating at the regional, landscape and patch scales. Evaporation is the major control of growth vigour levels at the landscape scale, but each landcover type has a distinctive pattern of growth vigour dynamics that is related to its composition and location, and possibly its landscape structure. The association between the spatial distribution of plant growth vigour and inundation frequency is non-linear, with the highest growth vigour occurring where inundation occurs approximately once per year. This indicates a subsidy-stress interaction with water in which plant growth vigour is limited by soil anoxia in areas of frequent or long term inundation, and by drought stress in rarely inundated areas.

A landscape-scale model of growth vigour dynamics, founded on the principles of Hierarchical Patch Dynamics and Landscape Ecology, was created from growth vigour measurements of each landcover type over time. This model was used to examine possible impacts of development activities on the functioning of the floodplain ecosystem. This model shows that the response of plant growth vigour development activities can be complex and subtle, and include a change in mean long-term growth vigour and an increased susceptibility to drought. The model also indicates that periods of high growth vigour can occur in substantially altered floodplain ecosystems. The model was also used to explore the levels of landcover change that might cause a threshold change in the functioning of the ecosystem, which may substantially alter the

disturbance-response characteristics of the floodplain ecosystem. The model indicates a threshold change when the extent of Open Grassland is reduced by 30% of its extent in 1993, in which plant growth vigour response to disturbance is virtually inverted from that observed in the images. The temporal variability of plant growth vigour levels increases as the extent of Open Grassland is further reduced.

This thesis makes a number of important contributions to our understanding of floodplain structure and functioning. It includes the development of new techniques suited to studying large diverse and complex landscapes at the landscape scale from satellite images, and provides quantitative data describing the links between the structure of floodplain landscapes and their functioning at the landscape scale. This work improves the understanding of floodplain ecosystems by integrating models of floodplain structure and functioning, which have been developed largely from smaller-scale studies of temperate and tropical floodplains, with landscape-scale measurements of this semi-arid system. This thesis also has implications for the Lower Balonne Floodplain by improving the level of information about this important ecosystem and providing baseline data against which the condition of the floodplain can be assessed in future.

Certificate of Authorship of Thesis

Except where indicated in footnotes, quotations and the bibliography, I certify that I am the sole author of the thesis submitted today entitled 'The Landscape-Scale Structure and Functioning of Floodplains'. I further certify that to the best of my knowledge the thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis. The material in the thesis has not been the basis of an award of any other degree or diploma except where due reference is made in the text of the thesis. The thesis complies with University requirements for a thesis as set out in

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Preface

A preliminary version of part of this work was published in:

Sims, N. C. and Thoms, M. C. (2002) What happens when floodplains wet themselves: vegetation response to inundation on the Lower Balonne Floodplain. **In:** *Proceedings of the IAHS Symposium on the Structure, Function and Management Implications of Fluvial Sedimentary Systems*, *Alice Springs, September 2002.*International Association of Hydrological Sciences.p 195-202.

This paper is included in this thesis as Appendix A.

Acknowledgements

This project has been long and many people have helped along the way. In particular I would like to thank Assoc. Prof. Martin Thoms, for his support, advice and encouragement for the duration of this work. Many thanks also to Dr Simon Benger for his encouragement and assistance with the remote sensing work in particular. This project was funded in part by a grant from Environment Australia and the Australian Research Council.

I am very grateful to Dr Ralph Ogden, who helped with fieldwork, the development of this project, and provided useful advice at other times. Many thanks to all members of the Lower Balonne Advisory Committee for their support and advice. Thanks to Les and Leith Boully for providing accommodation during fieldwork, and to the residents of the Lower Balonne Floodplain for giving me access to their properties and showing me how the floodplain works. Peter Liston gave me the map of Australia. Earth Resource Mapping Pty Ltd provided the ER Mapper image processing software. Kenji Walter, Gypsy Bhalla and others at Agrecon helped me with image analysis. Ann Milligan helped with editing. Thanks to all staff at the CRCFE for being enthusiastic, happy and smart, especially Richard Norris for employing me and Simon Linke for keeping me in touch with music. Thanks to all members of the River and Floodplain group at UC, especially Heather for personifying integrity and Craig for showing me the real power of the digital camera. Many thanks to Dogboy, for being a good mate and reminding me to finish this thesis. I thank the Broomheads for their kind thoughts. Many thanks to my colleagues at CSIRO for their generous support and assistance during the later stages of this project. I still blame Dr Paul Downey for starting all of this.

Many thanks to Mum for inspiring me to keep going, and to Dad for always giving me the right advice. Thanks to Ian, Margaret and Sarah for their great generosity, support and encouragement. My bro Jase is a great hero of mine, but stop smoking and wear your seatbelt!

Most importantly I owe so much to Samantha, my champion and greatest supporter, who has been so patient. I look forward to us spending lots of time together from now on. To Dan, I hope this encourages you to do great things.

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