Appendices






Appendix 1

Project presentations

Underlined names refer to speaker of multi-author talks

2006

Glenn Wilson. *Managing environmental flows in an agricultural landscape: the Lower Gwydir floodplain*. Cotton Catchment Communities CRC Environment Program meeting, Tamworth, NSW. (January)

Glenn Wilson. *Research to underpin environmental flow decisions for the Lower Gwydir floodplain*. Environmental Contingency Allowance Operations Advisory Committee, Moree, NSW. (February)

Glenn Wilson. *Research to underpin environmental flow decisions for northern floodplain rivers*. Condamine Alliance, Toowoomba, Qld. (March)

Glenn Wilson. *Managing environmental flows in an agricultural landscape: the Lower Gwydir floodplain*. Project Steering Committee meeting 1, Moree, NSW. (June)

Glenn Wilson. *Research to underpin environmental flow decisions for the Lower Gwydir floodplain*. National Water Commission, Canberra, ACT (July)

Paul Frazier & Glenn Wilson. *Research to underpin environmental flow decisions for northern floodplain rivers*. Australian Cotton Conference, Gold Coast, Qld. (August)

Glenn Wilson. *Managing environmental water delivery to floodplain aquatic habitats of Australia's northern Murray-Darling Basin.* Freshwater Research Unit, University of Cape Town, Cape Town, South Africa. (November)

2007

Peter Berney. *Vegetation dynamics in response to the wetting regime and grazing in the Lower Gwydir Wetlands*. Department of Ecosystem Management, University of New England, Armidale, NSW. (April)

Glenn Wilson, Tobias Bickel, Julia Sisson & Peter Berney. *Managing environmental flows in the Lower Gwydir.* Gwydir Environmental Contingency Allowance Operations Advisory Committee, Moree, NSW. (August)

Peter Berney, Glenn Wilson & Darren Ryder. *Investigating the impacts of an altered flow regime on the floodplain vegetation of the Lower Gwydir Wetlands*. 2007 School of Environmental and Rural Science Post-graduate student conference, Coffs Harbour, NSW. (July)

Peter Berney, Glenn Wilson & Darren Ryder. *Gwydir Wetlands: Environmental flows, grazing and biodiversity*. 2007 Cotton CRC Conference, Narrabri, NSW. (August)

Peter Berney, Glenn Wilson & Darren Ryder. *Vegetation response to an environmental flow in the Lower Gwydir Wetlands, NSW*. 2007 Ecological Society of Australia conference, Perth, WA. (November)

2008

Peter Berney. *Managing environmental flows in an agricultural landscape: the Lower Gwydir floodplain. Vegetation dynamics in response to the wetting regime and grazing*. Project Steering Committee meeting 2, Moree, NSW. (February)

Tobias Bickel, Glenn Wilson & Julia Sisson. *Managing environmental flows in an agricultural landscape: the Lower Gwydir floodplain. Water chemistry, invertebrates and fish*. Project Steering Committee meeting 2, Moree, NSW. (February)

Glenn Wilson. *Fish, river flows and floodplain wetlands in the northern Murray-Darling Basin*. University of New England School of Environmental and Rural Science, Armidale, NSW. (June)

Glenn Wilson. *Introduction to the Forum*. The Lower Gwydir: Surface Flows and the Ecology of Streams and Wetlands. A Forum to Inform the Local Community and Guide Management. Moree, NSW. (July)

Peter Berney, Glenn Wilson & Darren Ryder. *Vegetation in the Lower Gwydir Wetlands: the relative influence of flooding and grazing.* The Lower Gwydir: Surface Flows and the Ecology of Streams and Wetlands. A Forum to Inform the Local Community and Guide Management. Moree, NSW. (July)

Tobias Bickel, Glenn Wilson & Julia Sisson. *Managing environmental flows in the Lower Gwydir: invertebrates, fish and water quality.* The Lower Gwydir: Surface Flows and the Ecology of Streams and Wetlands. A Forum to Inform the Local Community and Guide Management. Moree, NSW. (July)

Wendy Merritt*, Sue Powell* & Glenn Wilson. *Vegetation in the Lower Gwydir Wetlands: the relative influence of flooding and grazing.* The Lower Gwydir: Surface Flows and the Ecology of Streams and Wetlands. A Forum to Inform the Local Community and Guide Management. Moree, NSW. (July) *Australian National University.

Jeff Kelleway*, Debashish Mazumder**, Yoshi Kobayashi*, Lisa Knowles*, Neil Saintilan* & Glenn Wilson. Using stable isotopes to construct aquatic food webs of the Lower Gwydir Wetlands. The Lower Gwydir: Surface Flows and the Ecology of Streams and Wetlands. A Forum to Inform the Local Community and Guide Management. Moree, NSW. (July) *NSW

Department of Environment and Climate Change. **Australian Nuclear Science and Technology Organisation.

Glenn Wilson, Tobias Bickel, Peter Berney & Julia Sisson. *Managing environmental flows in an agricultural landscape: The Lower Gwydir floodplain*. The Water Group, Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra, ACT. (August)

Glenn Wilson, Tobias Bickel, Peter Berney & Julia Sisson. *Managing environmental flows in an agricultural landscape: The Lower Gwydir floodplain*. The Fenner School of Environment and Society, The Australian National University, Canberra, ACT. (August)

Glenn Wilson, Tobias Bickel & Julia Sisson. *Environmental Flow Releases – effects on the Lower Gwydir fish community.* Australian Society of Fish Biology Conference and Workshop, Sydney, NSW. (September)

Tobias Bickel, Glenn Wilson & Julia Sisson. *Managing environmental flows in an agricultural landscape: The Lower Gwydir floodplain*. Cotton Catchment Communities CRC Science Forum, Narrabri, NSW. (October)

Peter Berney, Glenn Wilson & Darren Ryder. *The impact of flows and grazing on plant communities in the Gwydir Wetlands*. Cotton CRC 2008 Conference, Narrabri, NSW. (October)

Glenn Wilson, Jennifer Spencer and Elizabeth Heagney. *Responses of fish and waterbirds to flow variability in the Gwydir wetlands*. Conference on Ecological Response Modelling in the Murray-Darling Basin, Sydney, NSW. (November)

Glenn Wilson, Tobias Bickel, Peter Berney & Julia Sisson. *Ecological responses to flow variability in the Lower Gwydir terminal wetland system, Australia's northern Murray-Darling Basin*. Harry Oppenheimer Okavango Research Centre, Maun, Botswana. (November)

Peter Berney, Glenn Wilson & Darren Ryder. *The impact of flooding and grazing on plant communities in the Gwydir wetlands*. 2008 Ecological Society of Australia conference, Sydney, NSW. (December)

2009

Peter Berney. *Recent research on the impacts of grazing in wetlands*. Wetland grazing field day, Moree, NSW. (February)

Peter Berney, Glenn Wilson & Darren Ryder. *A temporal comparison of the influence of flows and grazing on vegetation communities in the Gwydir Wetlands, NSW, Australia.* International Conference on Implementing Environmental Water Allocations, Port Elizabeth, South Africa. (February)

Glenn Wilson & Peter Berney. *Delivering multi-objective environmental flows into terminal floodplain wetlands, northern Murray-Darling Basin, Australia*. International Conference on Implementing Environmental Water Allocations, Port Elizabeth, South Africa. (February)

Glenn Wilson. *Recent research on responses to flow variability and environmental-flows in the Lower Gwydir wetlands, 2006 – 2009.* Murray-Darling Basin Authority – Native Fish Strategy Community Reference Panel, Glenlyon Dam, NSW. (May)

Peter Berney. *Influence of flooding and competition on the dominance of water couch and lippia in floodplain wetland communities.* Cotton CRC Science Forum, Narrabri, NSW. (August)

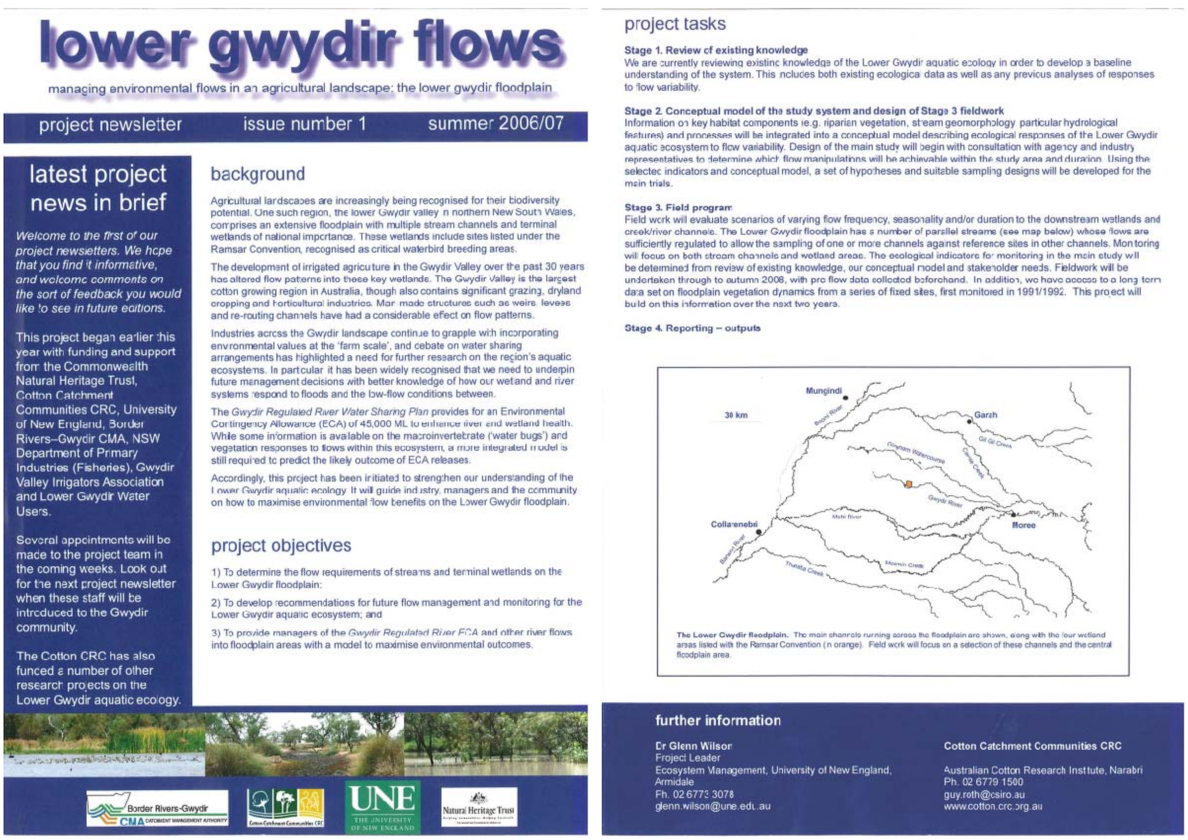
Peter Berney. *Responses of wetland plant communities to grazing. A summary of long-term grazing exclosures in the Gwydir Wetlands.* NSW DPI wetland plants/grazing field day, "Bunnor", NSW. (August)

Appendix 2

Project outputs and conference abstracts

Underlined names refer to speaker of multi-author talks. Some presentations were from other projects but that used substantial samples or information from the present study and, accordingly, included staff from the present project as co-authors. In such cases, the names of staff from the present study have been bold-font highlighted.

Project Newsletter No. 1



lower gwydir flows

managing environmental flows in an agricultural landscape: the lower gwydir floodplain

project newsletter | issue number 1 | summer 2006/07

latest project news in brief

Welcome to the first of our project newsletters. We hope that you find it informative, and welcome comments on the sort of feedback you would like to see in future editions.

This project began earlier this year with funding and support from the Commonwealth Natural Heritage Trust, Cotton Catchment Communities CRC, University of New England, Border Rivers–Gwydir CMA, NSW Department of Primary Industries (Fisheries), Gwydir Valley Irrigators Association and Lower Gwydir Water Users.

Several appointments will be made to the project team in the coming weeks. Look out for the next project newsletter when these staff will be introduced to the Gwydir community.

The Cotton CRC has also funded a number of other research projects on the Lower Gwydir aquatic ecology.

background

Agricultural landscapes are increasingly being recognised for their biodiversity potential. One such region, the lower Gwydir valley in northern New South Wales, comprises an extensive floodplain with multiple stream channels and terminal wetlands of national importance. These wetlands include sites listed under the Ramsar Convention, recognised as critical waterbird breeding areas.

The development of irrigated agriculture in the Gwydir Valley over the past 30 years has altered flow patterns into these key wetlands. The Gwydir Valley is the largest cotton growing region in Australia, though also contains significant grazing, dryland cropping and horticultural industries. Man made structures such as weirs, levees and re-routing channels have had a considerable effect on flow patterns.

Industries across the Gwydir landscape continue to grapple with incorporating environmental values at the 'farm scale', and debate on water sharing arrangements has highlighted a need for further research on the region's aquatic ecosystems. In particular it has been widely recognised that we need to underpin future management decisions with better knowledge of how our wetland and river systems respond to floods and the low-flow conditions between.

The *Gwydir Regulated River Water Sharing Plan* provides for an Environmental Contingency Allowance (ECA) of 45,000 ML to enhance river and wetland health. While some information is available on the macroinvertebrate ('water bugs') and vegetation responses to flows within this ecosystem, a more integrated model is still required to predict the likely outcome of ECA releases.

Accordingly, this project has been initiated to strengthen our understanding of the Lower Gwydir aquatic ecology. It will guide industry, managers and the community on how to maximise environmental flow benefits on the Lower Gwydir floodplain.

project objectives

1) To determine the flow requirements of streams and terminal wetlands on the Lower Gwydir floodplain;

2) To develop recommendations for future flow management and monitoring for the Lower Gwydir aquatic ecosystem; and

3) To provide managers of the *Gwydir Regulated River ECA* and other river flows into floodplain areas with a model to maximise environmental outcomes.

Border Rivers-Gwydir CMA Catchment Management Authority | Cotton Catchment Communities CRC | UNE The University of New England | Natural Heritage Trust

project tasks

Stage 1. Review of existing knowledge
We are currently reviewing existing knowledge of the Lower Gwydir aquatic ecology in order to develop a baseline understanding of the system. This includes both existing ecological data as well as any previous analyses of responses to flow variability.

Stage 2. Conceptual model of the study system and design of Stage 3 fieldwork
Information on key habitat components (e.g. riparian vegetation, stream geomorphology, particular hydrological features) and processes will be integrated into a conceptual model describing ecological responses of the Lower Gwydir aquatic ecosystem to flow variability. Design of the main study will begin with consultation with agency and industry representatives to determine which flow manipulations will be achievable within the study area and duration. Using the selected indicators and conceptual model, a set of hypotheses and suitable sampling designs will be developed for the main trials.

Stage 3. Field program
Field work will evaluate scenarios of varying flow frequency, seasonality and/or duration to the downstream wetlands and creek/river channels. The Lower Gwydir floodplain has a number of parallel streams (see map below) whose flows are sufficiently regulated to allow the sampling of one or more channels against reference sites in other channels. Monitoring will focus on both stream channels and wetland areas. The ecological indicators for monitoring in the main study will be determined from review of existing knowledge, our conceptual model and stakeholder needs. Fieldwork will be undertaken through to autumn 2008, with pre flow data collected beforehand. In addition, we have access to a long term data set on floodplain vegetation dynamics from a series of fixed sites, first monitored in 1991/1992. This project will build on this information over the next two years.

Stage 4. Reporting – outputs

The Lower Gwydir floodplain. The main channels running across the floodplain are shown, along with the four wetland areas listed with the Ramsar Convention (in orange). Field work will focus on a selection of these channels and the central floodplain area.

further information

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Project Newsletter No. 2

lower gwydir flows

managing environmental flows in an agricultural landscape: the lower gwydir floodplain

project newsletter | issue number 2 | winter/spring 2007

Latest project news in brief

It has been a productive and successful season of sampling the Lower Gwydir floodplain and channels over the past 12 months.

Since December 2006, the NSW government has sent two environmental flow releases into the lower Gwydir River and Gingham Watercourse, and 'before' and 'after' samples were collected by the project team. We were assisted by student volunteers and state agency staff, allowing the monitoring of a wide range of ecological variables, and we would like to thank everyone who has aided us so far.

We have also had a fantastic response from landowners who have allowed us access onto their properties, and we would like to also thank all of the families involved.

project staff and collaborations

Since the previous newsletter, several appointments have been made to the project. The team undertaking this project consists of Dr Glenn Wilson (Project Leader), Dr Tobias Bickel (Research Scientist) who commenced his position in July 2007, Julia Sisson (Research Assistant) who commenced her employment in September 2006, and Peter Berney (PhD student) who began his research in February 2007. These are the key personnel that will be looking at the project objectives and research questions outlined in the last newsletter.

Peter Berney has begun his research, looking at the relative influence of inundation by floods or environmental flows and grazing of domestic livestock on vegetation communities in the lower Gwydir wetlands. Among other things, Peter is building on earlier data sets compiled through UNE to gain a longer-term, historical perspective than is usually possible in projects of this nature.

In March of this year, we began a collaboration with the NSW Department of Environment and Climate Change's (DECC) Rivers and Wetlands Unit in their research on the lower Gwydir aquatic food webs. This work is aiming to provide a more thorough understanding of the processes that boost the production of waterbird prey items such as native fish or invertebrates.

Photo: Robbie van Heemert

Mehi River below Combadello Weir

Border Rivers-Gwydir CMA Catchment Management Authority | Cotton Catchment Communities CRC | UNE The University of New England | Natural Heritage Trust

so what are we monitoring?

We have selected three regulated rivers (Gwydir River, Gingham Watercourse and Mehi River) and three waterholes on the lower Gwydir floodplain to examine the effects of managed environmental flows on aquatic biodiversity and floodplain vegetation. The Gwydir River and Gingham Watercourse both currently receive environmental flows, particularly to flood their terminal and Ramsar-listed wetland areas. The Mehi River primarily receives flows intended for irrigation or 'stock and domestic' purposes, and so acts as a reference for our monitoring of environmental flows in the other channels. The three waterholes provide a further reference, although all have been dry since April 2007. Each of the rivers is sampled at three locations along its channel. At each location, samples are taken to obtain information on water chemistry, invertebrates, fish and turtles.

Methods

fish, crustaceans and turtles

We are using 'fyke nets' to sample these species. Fyke nets comprise a tubular body with funnels through which the fish swim and are trapped, and two wings which direct fish into the net tunnels. We use fyke nets of two different mesh sizes to ensure that we equally sample both small and large individuals and species. Two nets of each size are positioned parallel to the bank, each facing either upstream or downstream to further reduce any bias. The nets are left in-stream overnight and are then removed the following day. Any fish and turtles are removed from the nets, are identified and measured and, apart from exotic species such as carp, are returned to the water. Similarly, shrimps and yabbies are also removed and counted before being released. A sample of shrimps is also preserved for measuring back in the laboratory. Some of the results obtained to date for these species are discussed on the next two pages.

Fyke nets set in the Mehi River at 'Derra'. Photo: Julia Sisson.

Julia Sisson collecting a water chemistry sample. Photo: Robbie van Hemmert

zooplankton

Although microscopic, zooplankton are an important part of aquatic ecosystems such as the lower Gwydir. For example, they are a key food source for young fish, which in turn are vital for fledging waterbirds of many species. They can also feed on nuisance algae. We have been using two techniques to collect samples of these invertebrates. Firstly, we use a small boat bilge pump to collect 5-litre samples of water which are then filtered through 0.056 mm mesh. This method is designed to sample zooplankton in the water column. Secondly, we use a small PVC plastic pipe to collect samples of the stream bed sediment and overlying water to obtain an estimate of what is living in the upper layers of sediment and adjacent water. We separate these samples into sediment and water before preserving them. All zooplankton samples are processed under a microscope back in the laboratory.

water chemistry

We take several samples of water from each site to determine various aspects of the water chemistry. Some of these are frozen for further processing in the laboratory, and others are filtered first to allow the 'mudiness' and algal levels to be quantified. Samples returned to the laboratory allow us to quantify such things as levels of the nutrients nitrogen, phosphorus and carbon. In addition, we collect information at each site on water temperature, salinity, tubidity and pH using a hand-held meter.

timing of field trips

We begun our sampling of the lower Gwydir channels in October 2006. Once Environmental Contingency Allowance (ECA) releases were finalised for the 2006/2007 season, we then conducted further field trips in December 2006 and February 2007 (before and after the Gwydir ECA release), and March, April and May 2007 (before, during and following the Gingham ECA release). We sampled for all the above parameters during all but the March 2007 trip, when we only collected water chemistry samples.

What have we found so far?

fish

So far, we have collected 9 native and 3 exotic fish species from our lower Gwydir sites (see Table 1 below). These mostly comprised smaller species such as rainbowfish, gudgeons or Australian smelt. However, it is pleasing that we also got numbers of species such as Murray cod and eel-tailed catfish in our samples. The catches tended to be dominated by just three native species: spangled perch ('booloorooo'), bony bream ('forky tails') and smaller gudgeons. Only two of the three exotic species (carp, goldfish) were routinely encountered, although they sometimes dominated the native fishes. Nevertheless, exotic species only accounted for around 16% of the total numbers of fish. Although we didn't weigh fish in the field, it was clear that carp usually dominated all species by weight where they occured, due to their usual large size.

Table 1. Fish species collected between October 2006 and May 2007 from the lower Gwydir and Mehi rivers, Gingham Watercourse, and Baroona, Tillaloo and Talmoi waterholes.

Common name	Scientific name	Native (n) or exotic (e)
Australian smelt	*Retropinna semoni*	n
bony bream	*Nematalosa erebi*	n
eel-tailed catfish	*Tandanus tandanus*	n
European carp	*Cyprinus carpio*	e
golden perch (yellowbelly)	*Macquaria ambigua*	n
goldfish	*Carassius auratus*	e
mosquitofish	*Gambusia holbrooki*	e
Murray cod	*Maccullochella peelii peelii*	n
rainbowfish	*Melanotaenia fluviatilis*	n
spangled perch	*Leiopotherapon unicolor*	n
unspecked hardyhead	*Craterocephalus stercusmuscarum*	n
western carp gudgeon	*Hypseleotris spp.*	n

Relationships between flows into the study sites and changes in either fish species composition or abundances are still being investigated, and appear complex. However, several patterns appear to be emerging. Firstly, some species (carp in particular) appear to move downstream with the beginning of significant flow rises. For example, the day after a 'stock and domestic' flow commenced in December 2006, we caught a large number of big carp in our upstream-facing nets at one site on the Gingham Watercourse, and none in our nets facing downstream. Secondly, native species appear to show a mixed response to flow rises in their spawning activity. While bony bream spawn throughout the spring to autumn season, spangled perch appear to spawn under flow rises such as the Gingham ECA release in April 2007.

what have we found so far?

shrimps

Shrimps are an extremely abundant component of the lower Gwydir in-stream ecology. To date, we have routinely collected several thousand shrimps per site between our four fyke nets set overnight. The response of these populations to flows such as the recent ECA releases seems to vary between sites and channels. However, following the April ECA release along the Gingham Watercourse, shrimp abundances were generally higher upstream, although at the downstream site there was a clear increase in smaller individuals, presumably new recruits resulting from that flow event. Nevertheless, whether these smaller shrimps had been simply flushed downstream or had resulted from local spawning activity is unknown at this stage.

The highly abundant freshwater shrimp, *Macrobrachium* sp. Photo: www.mdfrc.org.au

Gingham Watercourse and adjacent wetland area, 'Westholme'. Photos: Robbie van Hemmert.

Floodplain and wetland vegetation

Since commencing in February 2007, Peter Berney has begun research in three key areas. Firstly, vegetation changes have been monitoring along the Gingham Watercourse following the release of the ECA in April 2007. This has been conducted by monitoring the species presence and percentage cover at five sites along the Gingham and at two control sites on the nearby lower Gwydir.

Another component in the study is the investigation into the effects of grazing on floodplain and wetland vegetation. This is using the four sets of full and partial grazing exclusion plots on 'Old Dromana', 'Birrah', 'Westholme' and 'Crinolyn'. This involves recording the species presence and percentage cover at each of these four sites across the wetlands, including either side of flow events. In addition, samples of soil from within these plots were recently taken back to UNE glasshouses to investigate the seedbank composition between grazed and ungrazed areas.

The third area of investigation has been to examine the floristic changes at a series of permanent transects across the wetlands to determine how the modified pattern of flooding has affected a range of wetland plant communities. This work has included continuing vegetation surveys previously undertaken on a semi-regular basis by other UNE researchers since 1992. Peter's data will be combined with this past information to explore the spatial and temporal changes in plant community composition.

further information

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University of New England School of Environmental and Rural Science 'UNTAMED 2007' Postgraduate Student conference, Coffs Harbour, NSW, July 2007

Investigating the impacts of an altered flow regime on the floodplain vegetation of the Lower Gwydir wetlands

Peter Berney, Glenn Wilson & Darren Ryder
Ecosystem Management, University of New England, Armidale NSW 2351

The Lower Gwydir Wetlands are a series of terminal wetlands on the Gwydir River in northern New South Wales. The wetlands have traditionally been renowned for their large bird breeding colonies. Since the completion of Copeton Dam in 1976, flows in the Gwydir River have been regulated. The storage of water to meet the needs of the irrigated agriculture industry that has developed has resulted in greatly reduced flows into the wetlands. An environmental contingency allowance (ECA) has now been set aside in the water sharing plan to help support and maintain key ecological processes in the wetlands. A major challenge facing pastoralists and environmental managers in the Lower Gwydir Wetlands is to understand how the altered hydrologic regime has impacted on wetland vegetation. In addition there are questions about how to effectively use the ECA water allowance to enhance wetland values.

My PhD focuses on three issues in an attempt to provide answers to questions about long-term changes in the floodplain plant communities and how flow regime and grazing influence vegetation dynamics.

To investigate temporal and spatial changes in plant community structure a series of permanent transects initially set up in 1992 will be re-monitored on a seasonal basis and current data will be analysed in conjunction with past unpublished data from these sites. Temporal grazing impacts have been similarly monitored over an extended period using a series of grazing exclosures located in plant communities experiencing differing inundation regimes. These will also be monitored to investigate how grazing intensity influences plant community assemblages.

Vegetation response to various inundation regimes will be investigated using detailed gradient analysis to determine how key native and exotic species respond to varying depth and duration of inundation along the moisture gradient between the core wetland and terrestrial plant communities on the floodplain.

2007 Cotton CRC Conference, Narrabri, NSW, August 2007

Gwydir wetlands: Environmental flows, grazing and biodiversity

Peter Berney, Glenn Wilson & Darren Ryder
Ecosystem Management, University of New England, Armidale NSW 2351

The construction of Copeton Dam has facilitated the development of irrigated agriculture on the floodplain of the Lower Gwydir River, west of Moree. While diverting water to agriculture has produced substantial economic benefits in the region, it has resulted in significant alterations to the hydrological regime in the Gwydir wetlands, an important colonial bird breeding site in the area. The reduced water flow into the wetlands has resulted in a decline in both their extent and condition. In addition there have been negative impacts on the grazing enterprises in the area that have traditionally relied on floodplain inundation to enhance feed quality. Another issue of concern is the Gwydir wetlands have four RAMSAR listed sites located on private holdings and these need to be maintained for the values for which they were listed. Part of the response to ameliorating the impacts of the altered flow regime in the wetlands has been the release of water in environmental flows in order to sustain a range of wetland ecosystem processes and thereby maintain biodiversity. This project aims to enhance our understanding of the vegetation dynamics of the Gwydir wetlands by studying how vegetation responds to environmental flows and flooding regimes and how grazing influences this response. Vegetation surveys have been conducted at a series of sites where long-term data sets are available in order to track the spatial and temporal changes in wetland communities over time in response to wetting and drying cycles. Long-term grazing trials have also been surveyed to measure how the vegetation responds to a range of grazing regimes from unrestricted access to no grazing. Over the coming summer a detailed analysis of vegetation response across the moisture gradient from core wetland to high floodplain will be undertaken to investigate how plant communities respond to depth and duration of inundation and to various grazing regimes.

2007 Ecological Society of Australia Conference, Perth, WA, November 2007

Vegetation response to an environmental flow in the Lower Gwydir wetlands, NSW

Peter Berney, Glenn Wilson & Darren Ryder
Ecosystem Management, University of New England, Armidale NSW 2351

Environmental flows are a means of ameliorating the impacts of altered flow regimes in regulated rivers by stimulating flow dependent ecological processes. The Gwydir wetlands are an inland terminal wetland system located west of Moree in northern New South Wales. Currently the impacts of environmental flows in the Gwydir wetlands are poorly understood. The aim of this study was to investigate the response of the vegetation in floodplain wetlands along the Gingham channel in the Gwydir wetlands to an environmental flow released in April

2007. The study used a multiple before-after-control-impact (MBACI) design to detect responses in the vegetation to inundation from the environmental flow. Wetlands were surveyed once before and twice after the flow. Results showed a significant increase in species richness at some of the impacted compared to control sites. While increases in percentage cover of amphibious functional groups of macrophytes were measured, they were not found to be statistically significant. Only one species, *Ranunculus undosus* was observed to flower. Two factors appear to have contributed to these results. The first factor was seasonal weather conditions. Shortly following the conclusion to the environmental flow cold winter conditions set in which limited the growth rate of many plant species, especially the dominant native species of grass (*Paspalum distichum*) which showed low tolerance to frost. The second factor was the influence of grazing by livestock. Along sampling transects there was a high incidence of pugging, indicating livestock tended to congregate in the wetted areas where they grazed on new growth but also damaged vegetation by trampling. This study indicates that a more effective vegetative response would be achieved if timing of the flow is in the warmer months of the year and if grazing pressure is reduced during and immediately after the environmental flow in order to allow germinating species sufficient time to complete their lifecycle and set seed.

The Lower Gwydir: Surface Flows and the Ecology of Streams and Wetlands. A Forum to Inform the Local Community and Guide Management. Moree, NSW, July 2008

(1) The Lower Gwydir Community Forum: Introduction and scope

Glenn Wilson
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Water management in the Murray-Darling Basin (MDB) is steadily rising in the Australian public's awareness. Media stories on the basin's water are becoming more frequent, and there is a growing expectation that water allocation and use will be managed carefully and from an appropriate knowledge base. Overarching issues of climate change and drought suggest that this public exposure will remain for some time. However, most media reports on the Murray-Darling focus almost solely on the River Murray and associated southern catchments. With few exceptions, little distinction is made between northern and southern regions of the basin, and most comments on northern catchments relate to their potential (or otherwise) to contribute to River Murray flows.

Yet, northern catchments possess intrinsic features that make them and the region of great interest in their own right. The flow seasonality of northern river systems, fed predominately by summer monsoonal rainfall, differs significantly from that of catchments such as the Murray whose peak flow periods are largely driven by snow melt. Similarly, extensive terminal wetlands are a more prominent feature of northern floodplain rivers than southern catchments, increasing the complexity of planning and delivering environmental flows along the entire system. These factors underpin the need for agencies and the region's

communities to have access to sound local scientific knowledge on which to base flow management of northern rivers.

Historically, there has been far less research undertaken on northern MDB catchments than southern areas, but this imbalance is improving. The Lower Gwydir floodplain is a particular case in point, where a significant body of recent work has built upon earlier agency monitoring programs in an attempt to understand aquatic ecological responses to flow variability. Critically, there has been a parallel recognition that such river systems must be viewed as an integrated channel-wetland complex, and that addressing the flow requirements of both floodplain and in-stream 'patches' is necessary to ensure ecosystem functioning.

The current management of environmental flows into the Lower Gwydir is through advice from the Enivonmental Contingency Allowance stakeholder advisory committee. While this body needs clear information on this ecosystem in a usable form, a broader suite of agency groups as well as the local community also need to understand the ramifications of any flow decisions. It is for this reason that the Lower Gwydir Community Forum has been established. Its primary objective is to give the Moree community, Lower Gwydir landholders and relevant managers an opportunity to learn about individual projects, how these complement each other, and ways in which the findings can contribute to management of the catchment's rivers and wetlands. Speakers have been chosen to represent as wide a coverage of recent research as possible on this ecosystem, including a sequence from upstream down into the wetlands themselves, and a mix of short and longer-term patterns.

(2) Managing environmental flows in the Lower Gwydir – invertebrates, fish and water quality

Tobias O. Bickel*, G. Glenn Wilson & Julia L. Sisson
Ecosystem Management, University of New England, Armidale NSW 2351;
Cotton Catchment Communities Cooperative Research Centre, Narrabri NSW 2390

Profound changes to the flow regime of most rivers of the Murray-Darling Basin are partly responsible for declines in water quality and aquatic invertebrates and native fish assemblages. The timing and magnitude of floods can play a crucial role in sustaining the in-stream biota and the hydraulic integrity of the rivers. To ameliorate the negative impacts of river regulation, environmental contingency allowances (ECA) are released to mimic natural flow patterns with the aim of improving riverine ecosystems.

We researched water chemistry, invertebrate and fish assemblages in the Lower Gwydir system over two years to assess the effectiveness of ECAs to improve ecological variables. We particularly hypothesised that ECA releases would improve water quality, enhance invertebrate assemblages and increase fish recruitment and diversity.

However, flow events did not always improve water quality. Other factors such as season, land use and run-off patterns seem to have a considerable affect on water quality as well. Benthic invertebrate (particularly zooplankton) assemblages appeared to be mainly shaped by seasons, and there was no consistent response to ECA flow events.

There were distinct fish communities between sites and rivers, with an upstream-downstream pattern evident in each stream. Habitat quality was thought to be a major factor explaining the structure of fish assemblages. Because of the complicated hydrographs, effects of hydrology were difficult to assess. ECAs and other high flow events had no consistent effect on fishes, although links between flow rises and spawning activity was implicated in some cases. However, abundances of the dominant fish species increased after periods of increased median flow, suggesting that flows were playing a role in the recruitment of some fishes.

These findings have direct implication to the management of the Lower Gwydir. Water quality issues have to be assessed on a catchment scale and need to include run-off, seasonal and land use variables. The dependence of native fishes on habitat quality indicates that the restoration of flows alone might not suffice to improve native fish populations.

(3) Vegetation in the Lower Gwydir Wetlands: the relative influence of flooding and grazing

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The University of New England established a long-term study into the effects of grazing on Lower Gwydir wetland plants in 1994. Plots comprising three treatments (full grazing pressure, grazing by native herbivores and feral animals only, and complete exclusion of all grazing animals) were set up at four sites across the Gwydir and Gingham wetlands. Subsequent monitoring of the plant communities at each plot over a range of inundation conditions has allowed a comparison of the relative effects of grazing and flooding on plant abundances and species diversity. The pattern of change in plant community composition over time indicated that inundation regime is the most important factor shaping the species composition and abundance of the extant vegetation. In contrast, grazing by domestic livestock and native herbivores had little long-term impact at most sites. Rather, grazing impacts tended to be more evident over shorter time scales, such as the dry period inbetween flood events. Following periods of inundation, a wide range of species are represented in the plant community. During the ensuing dry period, species tolerant to grazing tend to persist the longest.

In late 2007, soil cores were also collected from each grazing treatment site to conduct a seed-bank germination trial. Species composition and abundance were recorded for seeds germinating from the soil samples and a comparison made with the composition of the standing vegetation at the site when the samples were collected. A species-rich seed bank existed in the soil at each site. However, there were no significant differences in abundance of germinating seeds between grazing treatments. By contrast, wetter sites had significantly more germinants than drier sites. In a comparison of species richness, plots open to grazing by native herbivores and feral animals had a significantly higher species diversity of germinating seeds than either the full grazing pressure and total grazing exclusion treatments.

The response of wetland plants to grazing appears to be influenced by site productivity. At wetter sites, removal of grazing can allow more grazing-sensitive species to flourish and a

successional pattern take place resulting in a plant community dominated by tall herbaceous species. However at drier sites, removal of grazing has less impact in both the short and long term. It also indicated that an intermediate level of site disturbance promotes maximum diversity in the seed bank which is important in ensuring the wetlands retain the capacity into the future to recover from disturbances due to either hydrological pattern or grazing.

(4) Prototype decision support system for environmental flows to the Gwydir Wetlands

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A prototype decision support system (DSS) is being developed for the NSW Department of Environment, Climate Change and Water, to inform management of environmental flows for the Gwydir wetlands. A DSS is usually a computer-based tool that allows users to explore 'what-if' questions or alternate options for managing a system of interest. DSSs have three main components:

- **Data Base** – numeric and qualitative information that help users familiarise themselves with the study system and to explore the impacts of different management options.
- **Model Base** – the models used to manipulate data and generate output from user-defined actions. Data stored in the data base are input to, or created by, the model base.
- **Interface** – the DSS interface allows users to easily navigate through the tool, run the models and view outputs. The interface is kept separate from the model base to facilitate the use of the tool by users who are not familiar with programming and computer models.

The project will deliver a prototype DSS that will explore the ecological outcomes of a range of flow and climate scenarios. The Gwydir DSS will allow users to access a structured database of ecological water requirements of the wetlands, past events and outcomes. It will link a spatially distributed flood model to fish response and vegetation response (e.g. the depth and duration of flooding required to maintain the health of core wetlands). The prototype will include a relatively simple inundation model that will be replaced by a more detailed hydrological model of the wetlands in future versions of the DSS. Other important aspects of the ecology of the Gwydir wetlands will be included in the full DSS development.

(5) Using stable isotopes to construct aquatic food webs of the Lower Gwydir Wetlands

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Stable isotope techniques are being used to gain an understanding of the food web structure of the Lower Gwydir Wetlands and identify the influence of environmental flows on the trophic ecology. Benthic sediment organic matter, macrocrustaceans and fish species were sampled across the Gingham, Gwydir and Mehi watercourses. Carbon and Nitrogen isotopes were analysed as they reflect the major sources of energy driving aquatic food webs, and allow for the trophic position of each species to be assessed and compared.

Sampling across the three watercourses and the Baroona waterhole in March 2007 provided a snapshot of the trophic dynamics of the Lower Gwydir Wetlands in relatively dry conditions. Results of this survey include the identification of benthic sediment organic matter (SOM) as an important base resource for the food webs. Differences were also detected in the overall trophic structure and within-species feeding habits between locations.

Further sampling was undertaken in May 2007 following an environmental flow release in the Gingham watercourse with an aim to compare these to pre-flow trophic structure. We observed a marked shift in the isotopic values of SOM and the carnivorous fish species spangled perch (*Leiopotherapon unicolor*) after the environmental flow. These changes indicate that the environmental flow caused both the trophic resource base and overall food web structure to expand considerably. This is of particular importance to higher trophic-level species such as spangled perch – which, prior to the flow was forced to compete at a lower level with species already occupying this niche.

Long-term monitoring of the key ecosystem components is necessary to understand the influence of water management, including environmental flow releases on food web structure and follow-on effects to ecosystem processes. Without this, it is difficult to accurately assess the ecosystem conditions, to identify trends, or to develop and evaluate effective management strategies.

Australian Society for Fish Biology Conference. Bondi, NSW, September 2008

Environmental Flow Releases – Effects on the Lower Gwydir Fish Community

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The profound changes to the hydro-regimes of most rivers of the Murray-Darling Basin (MDB) are partly responsible for the decline in native fish populations. The timing and magnitude of floods can play a crucial role in native fish recruitment. To ameliorate the negative impacts of river regulation, environmental contingency allowances (ECA) are released in parts of the MDB to mimic natural flow patterns with the hope of improving riverine ecosystems and ultimately to restore native fish communities.

We researched the response of fish assemblages in the Lower Gwydir system over two years to assess the effectiveness of ECA's to improve native fish recruitment. Particularly, we hypothesized that ECA releases would increase fish recruitment and diversity in the Lower Gwydir system.

Spatial variables seemed to explain more of the variability in the fish assemblages than temporal ones. Furthermore, the diversity and structure of fish assemblages was closely associated with habitat quality. ECA's and other high flow events (bank full discharge) seemed to have only minor effects on the fish assemblages. However, there was a strong increase in fish numbers in the second year, coinciding with increased median flows. This suggests that stable base flows might be more beneficial to the recruitment of some fishes than high flow events.

These findings have direct implication to the management of native fish populations in the MDB. The limitation of native fishes by habitat quality shows that the restoration of flows alone might not achieve the desired outcome to improve native fish populations.

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(1) Responses of fish and waterbirds to flow variability in the Lower Gwydir wetlands

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Abstract

The Gwydir floodplain contains internationally significant wetlands which support threatened wetland plants, native fish and colonial waterbirds. However, development of upstream water resources for irrigated agriculture in the 1970s decreased the magnitude, frequency and duration of flooding in this lowland river ecosystem. While environmental water allocations have been used to supplement flows into the Gwydir wetlands, a greater understanding of the water requirements of native fish and colonial waterbirds is needed to predict their responses under alternative flow management scenarios. Here we review responses of fish and colonial waterbirds to flow variability in the Gwydir wetlands using a mix of historical data, contemporary field surveys and otolith-based analyses. Channels in the wetlands support a suite of fish species typical of lowland Murray-Darling river systems, with consistent compositional differences between distributary channels. Relationships between discharge and fish assemblage structure following recent environmental water releases and other flows (2006-2009) were inconsistent over time. In contrast, spatial differences in juvenile growth rate were inversely related to total discharge during the spawning/hatch and larval-juvenile periods (Australian smelt, *Retropinna semoni;* bony bream, *Nematalosa erebi*), but positively related to flow variance throughout the same period (Australian smelt). Flow regulation has also impacted the frequency of large colonial waterbird breeding events. The Gwydir wetlands were regionally-significant for at least 18 colonial waterbird species, although no significant events have been observed since 2005. Historically, the size of breeding events was positively related to cumulative discharge during summer months (October–March, 1988-2008) with discharge of at least 200,000 ML needed to trigger significant breeding in straw-necked ibis (*Threskiornis spinicollis*). During recent surveys (2007-2008), most of the Gwydir wetlands were dry and few colonial waterbirds were recorded. There is evidence that managed flows can be used successfully to augment smaller natural events to prolong the spawning/breeding season of fish and birds. However, natural flooding appears vital for maintaining long-term wetland health.

(2) Using isotopic techniques to assess trophic structure in northern Murray-Darling Basin wetlands

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Abstract

Floodplain wetlands provide habitats for diverse organisms including aquatic plant communities, nekton and waterbirds, and perform important ecosystem functions. These wetlands rely on floodwaters mobilising floodplain resources such as carbon and nutrients which are used by various organisms directly and indirectly through trophic linkages. Understanding these trophic linkages within food webs is essential for developing ecological models for sustainable management of floodplain wetlands. Stable isotope analysis has emerged as an important technique in food web research. The technique essentially involves tracing ratios of isotopes, usually carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$), through an ecosystem, or food web components. This chapter outlines the utility of stable isotope techniques in food web research in the northern Murray-Darling Basin, discusses some of the challenges, and explains some of the methods that have been developed to overcome such challenges. Studies using stable isotope approaches have contributed to our understanding of Australian freshwater food webs, particularly in identifying the sources of production sustaining floodplain food webs and the trophic status of functionally significant aquatic fauna. Three case studies of research carried out in the Gwydir Wetlands and Macquarie Marshes of the northern Murray-Darling Basin are presented. These studies highlight the spatial and temporal variability of food web structure in floodplain wetlands and the importance of environmental flow allocation to ecosystem functionality.

2008 Ecological Society of Australia Conference, Sydney, NSW, December 2008

The impact of flooding and grazing on plant communities in the Gwydir wetlands

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The practice of livestock grazing in wetlands has been reported to cause degradation, especially in parts of the southern Murray-Darling Basin (MDB), but there has been little study on grazing impacts on the wetlands in the northern region of the catchment. This study reports on the impact of 14 years of grazing exclusion in four plant communities in the Gwydir wetlands, a major wetland system in the MDB in northern New South Wales. Three treatments were implemented, namely (1) unfenced plots, (2) plots excluding cattle while allowing access for kangaroos, feral pigs and foxes, and (3) plots excluding all mammalian herbivores and feral animals. We have found that responses to grazing varied from site to site. At sites that receive regular flooding, generally annually, grazing can reduce competition from dominant species and promote increased plant diversity. However, it can also reduce abundance of grazing-sensitive species, typically with tall growth forms and soft fleshy leaves, resulting in the dominance of more grazing-tolerant species such as *Paspalum distichum* and an associated reduction in diversity. At less frequently flooded sites, one year in four, removal of grazing has less pronounced impacts on plant community composition, with changes driven by other factors such as seasonal conditions. In a soil seed-bank study, germinant species diversity was significantly higher from sites with an intermediate level of disturbance under the above treatment 2 at three of the four wetland sites. This research indicates that responses to grazing in these wetlands are complex and strongly influenced by site productivity.

Proceedings, International Conference on Implementing Environmental Water Allocations, Port Elizabeth, South Africa, February 2009

A TEMPORAL COMPARISON OF THE INFLUENCE OF FLOWS AND GRAZING ON VEGETATION COMMUNITIES IN THE GWYDIR WETLANDS, NSW, AUSTRALIA

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Abstract

Floodplain plant communities in Australia's Murray Darling Basin are dynamic in nature, showing high levels of spatial heterogeneity and temporal variability. Typical of floodplain ecosystems in many semi-arid regions, their ecology is characterized by pulses of productivity, driven by inundation patterns following river flooding. However, river regulation has significantly altered the flow regime of almost all major rivers in the Murray-Darling Basin, holding back floodwaters and consequently reducing the frequency, duration and spatial extent of floodplain inundation. While environmental flows have been introduced as a means of ameliorating the impacts of river regulation and supporting wetland ecological processes, other land use factors may potentially diminish any benefits. Grazing of domestic livestock, particularly cattle, has taken place on many of these floodplains for over 160 years. In conjunction with flooding and drought, grazing may be one of the most important agents of disturbance that shape floodplain plant communities. This study examined three wetland plant communities in the Gwydir Wetlands in New South Wales, Australia, where long-term trials have investigated whether grazing by domestic and native herbivores alter the response of vegetation to natural flooding and environmental flows. The pattern of change in plant community composition over time indicated that inundation regime is the most important factor shaping the distribution and abundance of extant vegetation. In contrast, grazing by domestic livestock and by native herbivores had a relatively minor impact. At sites where environmental water allocations resulted in wetland inundation, changes in plant community composition occurred across all grazing treatments. These changes mirrored the responses seen following major floods, dominated by pronounced increases in the cover of amphibious species and a concomitant decline in cover of terrestrial species. Significant differences between plots open and closed to grazing mostly occurred during dry periods between flood events. While grazing can influence species composition in the in the short-term, inundation from both natural flooding and environmental flows plays a far more significant role over the long-term in shaping wetland plant assemblages.

INTRODUCTION

The Gwydir Wetlands are an extensive series of lowland distributary channels, wetlands and floodplain woodlands located at the end of the Gwydir River in northern New South Wales, Australia (Fig.1). The wetlands are renowned as a site for bird breeding and a total of 823 ha across four private properties were listed as wetlands of international significance under the Ramsar Convention in 1999. The

wetlands have also supported a grazing industry for a period of 160 years. The Gwydir River has been regulated since 1976 through the construction of Copeton Dam, 120 km upstream of the wetlands. The resulting increased security in water supply allowed a large-scale irrigated agriculture industry to develop on the flat alluvial floodplains, growing crops such as cotton in summer and cereals in winter (Keyte 1994). Although initially 55 000ha of irrigation licences were to be issued, a total of 86 000 ha of irrigation licences were actually issued in the years following construction of Copeton Dam, allowing up to 530 000 ML year^{-1} to be supplied from the dam or be pumped into off-river storages from unregulated flows (Keyte 1994; Kingsford 2000). This has resulted in reduced river flows reaching the terminal wetlands and a subsequent decrease in the extent and duration of flooding. Over time, the impact of reduced wetland flooding has caused changes in floristic composition, with an increase in presence of terrestrial taxa and an increase in the presence of the invasive introduced species lippia *Phyla canescens* (McCosker 1994). Meanwhile, graziers have reported reduced pasture productivity and carrying capacity in many of their wetland paddocks (McCosker & Duggin 1993).

Strategies to address the problems of over allocation of water to irrigated agriculture focussed on achieving a more equitable balance of water use amongst the various stakeholders through State Government brokered Water Sharing Plans and recognition of the environment as a legitimate user of water. In addition to regulations limiting the amount of pumping from unregulated flows, an environmental water allocation was created to support particular ecological objectives such as water hyacinth *Eichhornia crassipes* control or maintain water levels during colonial bird breeding events (NSW Dept of Sustainable Nat. Res. 2003).

The value of this ecological use for water has been challenged by some stakeholders in the water debate on the grounds that intended ecological benefits are diminished because of the impact of cattle grazing in the wetlands. In 1994, a study was commenced by the University of New England to monitor how vegetation responds to inundation patterns and how various grazing strategies influence this response. This paper reports on changes to vegetation community composition using three different grazing treatments following a series of flow events including natural floods and environmental water allocations.

METHODS

Study sites and inundation history – Gwydir Wetlands

To assess the impacts of grazing on the Gwydir wetlands, data were collected from three sites across the wetlands with differing plant communities (Fig 1). The sites chosen were as follows:

Old Dromana - *Bolboschoenus fluviatilis* (marsh club-rush) reed bed (29° 20' 46" S, 149° 17' 38" E) near the downstream end of the Gwydir River system;

Westholme - *Paspalum distichum* (water couch) open meadow (29° 15' 45" S, 149° 23' 19" E) mid-way along the Gingham watercourse; and

Crinolyn - a degraded *Paspalum distichum* community, partially invaded by *Phyla canescens* (lippia) (29° 12' 53" S, 149° 08' 13" E) near the terminal point of the Gingham Watercourse.

Old Dromana and Westholme have experienced regular inundation, typically every 1-2 years and are considered examples of productive sites in terms of annual biomass production. By contrast, Crinolyn is at the western end of the Gingham watercourse and has traditionally experienced less frequent

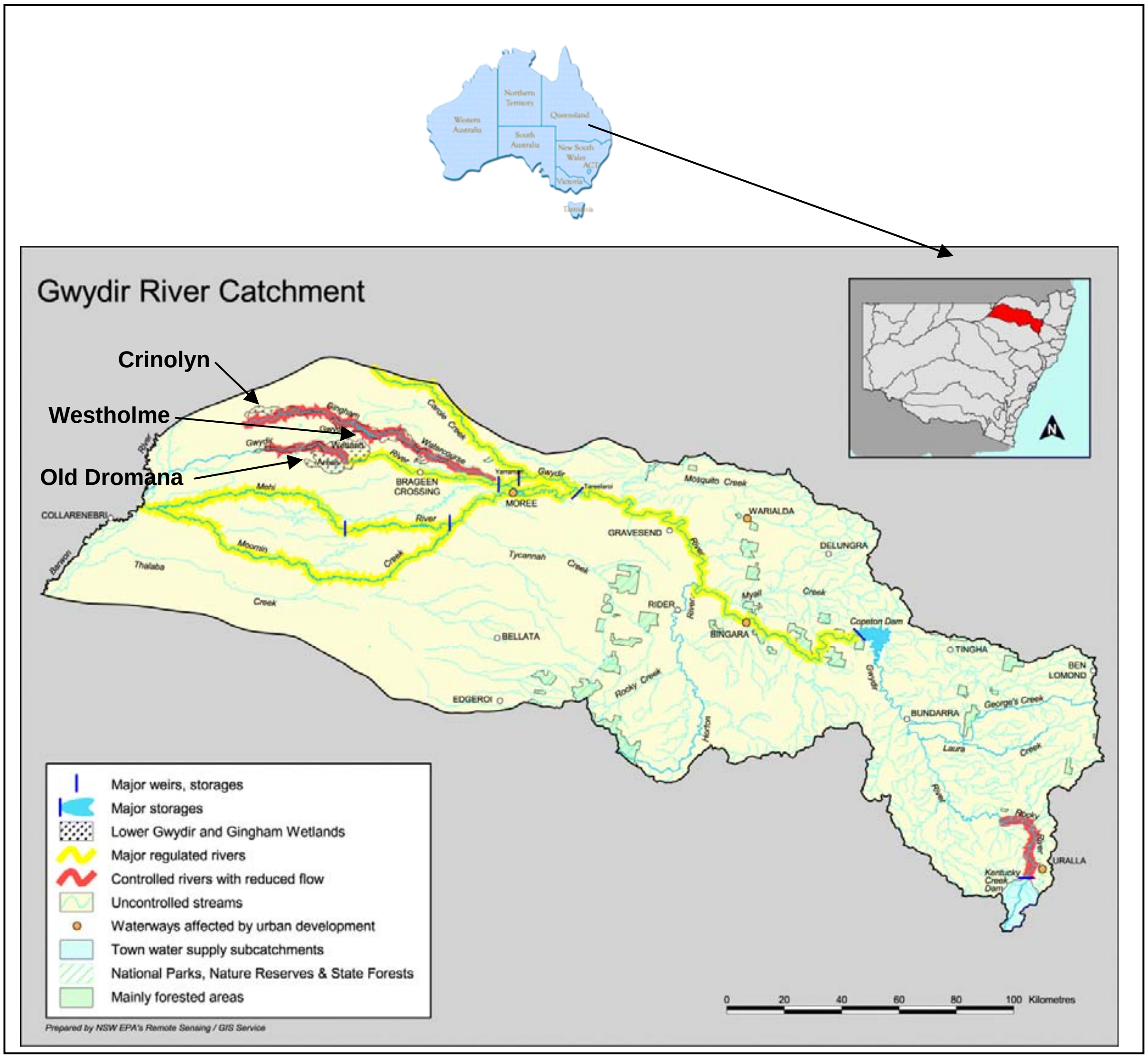


Figure 1. Gwydir River catchment in northern New South Wales, Australia with location of study sites indicated by arrows.

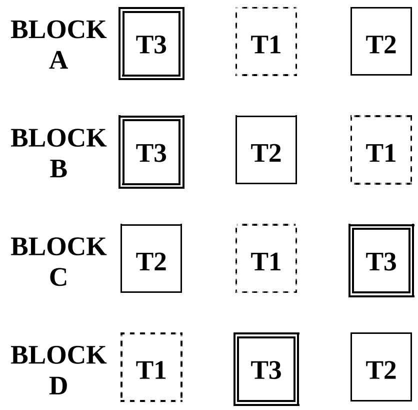
inundation. In recent decades, it has experienced a marked reduction in the frequency and duration of flooding. Productivity at this site is less than at the other two sites.

The sites were originally established by May 1994, and follow a randomised complete block design. At each site, there are four replicate blocks with each of the three treatments randomly allocated one to a plot within each block (Fig. 2). The three treatments used were:

OPEN - total grazing pressure, with plots to remain unfenced and unmarked;

PARTIAL - partial grazing pressure, surrounded by cattle-proof fences to only exclude cattle while allowing access by macropods and pigs; and

CLOSED - total exclusion of all mammal herbivores.



T1 = OPEN – unfenced;
T2 = PARTIAL – exclusion of cattle while allowing free access to kangaroos, feral pigs and foxes;
T3 = CLOSED – exclusion of cattle, kangaroos, feral pigs and foxes

Figure 2. Layout of the experimental exclosure plots at each of three sites in the Gwydir wetlands

All PARTIAL plots were fenced with 0.9 m high 6 line mesh (BHP Waratah '*hinged joint*') suspended 0.5 m above the ground. High tensile plain wire (2.5 mm) was used to support the top and bottom of the mesh. Wooden corner posts, stays and stay blocks were used in all plots, with 1.8 m BHP star pickets carrying the wire and mesh. CLOSED plots were completely fenced with 1.5 m high 14 line internal deer fence (Cyclone '*strongline*'). A high tensile plain wire was again used on the top and bottom for support. Corner assemblies and pickets were the same as for treatment 2.

Plots were monitored on a semi-regular basis over the period 1994-2008, a time period spanning four major floods and, more recently, two environmental water releases. On each monitoring occasion the presence of all species occurring in 10 replicate 1m^2 quadrats was recorded inside each of the 12 plots at each site. Projected foliage cover for each taxon was scored using a modified Braun-Blanquet cover score from 0-7 (Mueller-Dombois & Ellenberg, 1974).

Data collected in plant surveys were used to generate two data sets. The first was based on the highest taxonomic resolution, with all taxa included. The second assigned species to functional groups (Brock and Cassanova 1997) according to their position in the hydrologic gradient and their response to wetting and drying.Data for each site were analysed to test for differences between grazing treatments through time using a partly nested ANOVA model (Table 1) (Quinn and Keough 2002). Variables tested included number of species recorded, percent cover of wetland functional groups and percent cover of common macrophyte taxa such as *Bolboschoenus fluviatilis*, *Paspalum distichum* and *Phyla canescens*. The assumptions for linear models were checked with residual plots and data transformations performed (log and arc sin) if necessary.

Table 1. ANOVA model used to analyse data from Gwydir wetland grazing exclosure sites.

Source of Variation	df	F Ratio denominator
Treatment	2	Plot (Treatment)
Time	12	Plot (Treatment)
Treatment*Time	24	Time*Plot (Treatment)
Plot (Treatment)	9	Time*Plot (Treatment)
Time*Plot (Treatment)	108	Error
Error	1404	

RESULTS

Patterns in species richness and percent cover at the study sites showed a high level of variability, both spatially and temporally. Antecedent conditions for each monitoring period had a major influence on the composition of the plant community at each site and each monitoring time. Antecedent conditions for each monitoring period are summarised in Table 2. Variations in community composition were apparent when taxa were placed into amphibious and terrestrial functional groups. Cover of amphibious taxa reached a peak soon after periods of flooding (Fig. 3a, 4a), while taxa in terrestrial functional groups had higher cover at monitoring times that had not been preceded by flooding (Fig 3d).

Responses to grazing differed between sites and were influenced by plant morphological traits and the prevailing hydrological regime. At Old Dromana, the dominant species is marsh club-rush (*Bolboschoenus fluviatilis*), a 2 m tall monocotyledon taxon in the ‘amphibious tolerator’ functional group. It grows prolifically during wet periods and forms a dense canopy resulting in a lack of light for taxa growing underneath its canopy. The *B. fluviatilis* plants then persist during dry periods, initially remaining green but in time senescing and laying over to form a dense blanket of vegetative litter on the ground which gradually breaks down over time, especially through disturbances such as trampling by livestock. Figure 3a shows the variation in level of cover of this taxon over time. Peaks in percent cover coincide with periods following flooding, November 1995, October 1996, December 1998 and following an environmental water release in conjunction with a small natural flood in March 2008.

Species richness at this site tends to vary inversely with *B. fluviatilis* cover. During periods when *B. fluviatilis* cover is low, light is not limiting, and this provides an opportunity for other taxa to establish and grow (Fig 3b, 3d). Taxa in the amphibious responder functional group grow in response to inundation and tend to flourish during periods of prolonged flooding. In July and December 1996, percent cover of taxa in this functional group was higher at ungrazed sites suggesting grazing may have a negative impact on these taxa. However in the flooding during late 2007 and early 2008 taxa in the

Table 2. Prevailing hydrological conditions prior during each monitoring period at grazing sites in the Gwydir wetlands

Monitoring date	Antecedent Conditions
May 1994	Dry – all sites
May 1995	Dry – only minor summer flooding at Old Dromana and Westholme
January 1996	Wet – significant flooding all sites
July 1996	Dry - all sites
October 1996	Wet – recent flooding all sites
May 1997	Wet – recent flooding all sites
September 1997	Dry – some recent minor flooding Old Dromana and Westholme
March 1998	Wet – recent minor flooding all sites
December 1998	Wet – recent major flooding all sites
May 2007	Dry – all sites
September 2007	Dry – all sites
January 2008	Wet – recent environmental water release at Old Dromana and Westholme
March 2008	Wet – recent minor flooding Old Dromana and Westholme

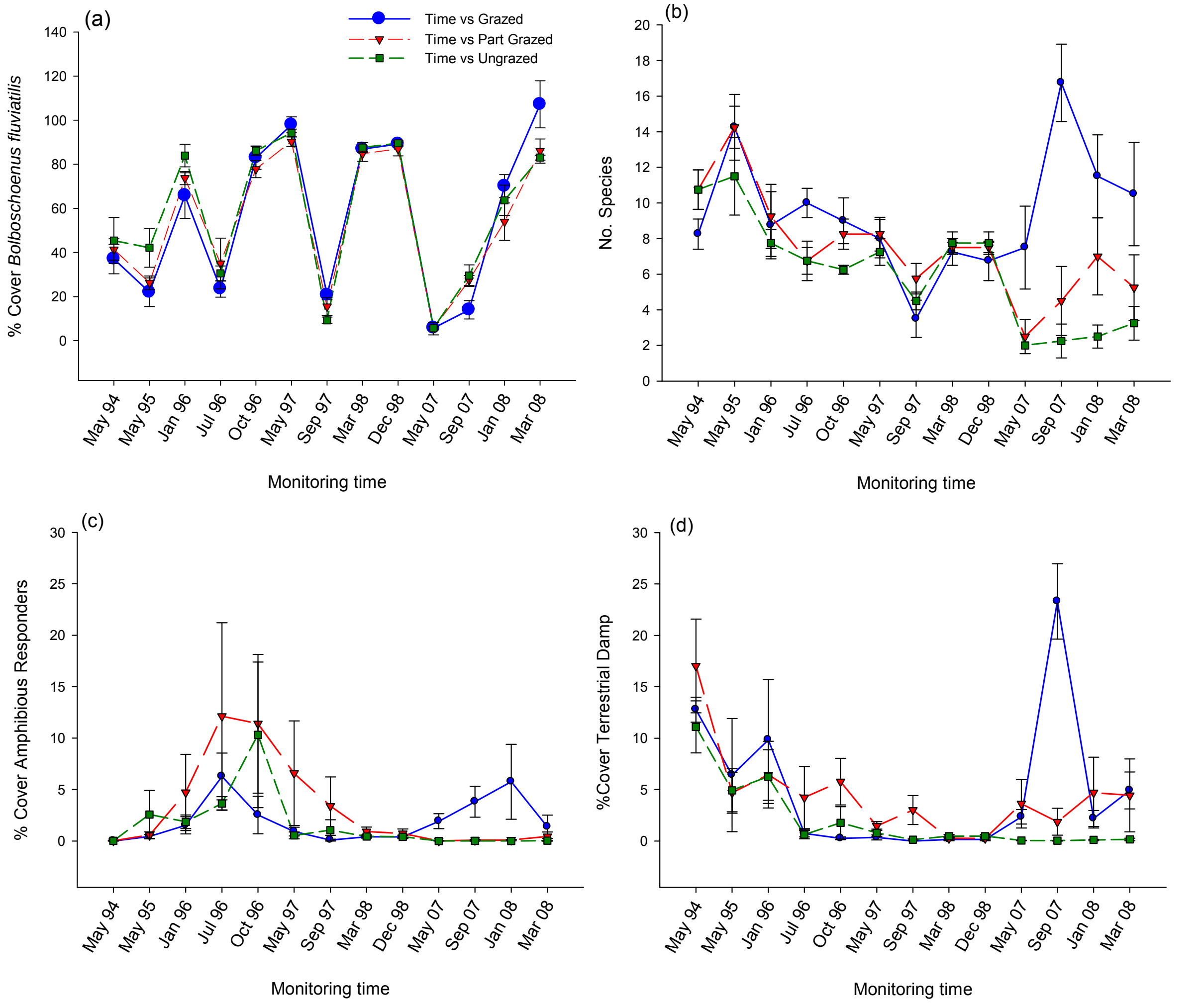


Figure 3. (a) Mean percent cover (+1SE) of *Bolboschoenus fluviatilis*, (b) number of species recorded at each monitoring time, (c) mean percent cover (+1SE) amphibious responder taxa and (d) mean percent cover (+1SE) terrestrial damp taxa at Old Dromana, recorded at monitoring times between 1994 and 2008.

amphibious responder functional group had a higher percent cover at grazed sites where conditions did not limit light compared with under the litter layer at sites where grazing was excluded (Fig. 3c).

Grazing has a major impact on the variability in community composition at Old Dromana. A significant difference in *B. fluviatilis* cover was detected in September 2007 ($F_{24,\ 108} = 1.87$; $P<0.05$), with grazed sites having a significantly lower cover but having significantly higher species richness ($F_{24,108} = 11.11$; $P<0.05$). Many of the taxa taking advantage of the reduced level of light competition were other native taxa from the regional species pool such as swamp buttercup *Ranunculus undosus* and knotweed *Persicaria decipiens*. Grazing also provided an opportunity for introduced species in the terrestrial damp functional group, such as thistles *Cirsium vulgare* and *Xanthium spinosum*, to establish. Percent cover of these taxa declined once flooding from the environmental water release occurred in December 2007 and January 2008 as they could not tolerate a period of extended inundation (Fig. 3d). The role of flooding in this plant community is that it promotes the growth of *B. fluviatilis* which then outcompetes most other taxa growing at the site until some other form of disturbance such as grazing or fire occurs and the canopy cover or litter mat of *B. fluviatilis* is broken down.

The Westholme site is a water couch *Paspalum distichum* meadow. *P. distichum* is a monocotyledon plant with a prostrate growth form. It is capable of tolerating extended periods of inundation. These meadows are considered to be both ecologically and agriculturally important as they provide feeding sites for breeding water birds from nearby nesting areas, while they are also valued by graziers for the high quality feed they provide to livestock. This site is located in the middle of the wetlands and experiences regular shallow flooding to a depth of 15-30cm which favours the growth of *P. distichum*.

Cover of *P. distichum* has declined over time at Westholme in the closed plots (Fig 4a). Where grazing occurs, *P. distichum* is the dominant species and species richness is often significantly lower ($F_{2,9}$ = 8.695; $P < 0.01$) than in closed plots (Fig 5). Removal of grazing appears to allow a range of other amphibious taxa such as *Persicaria* spp. and *Typha domingensis* to grow. These taller species end up shading *P. distichum* leading to a reduction in its percent cover. At this site, regular and prolonged flooding leads to a fall in the number of species recorded (Fig. 5) due to many of the taxa in the terrestrial damp functional group, which are favoured during drier times between floods, being extirpated following inundation.

In the Gwydir Wetlands, the introduced species lippia *Phyla canescens* has become a major weed problem. It can be spread vegetatively during floods and when it establishes in *P. distichum* pastures, it can successfully compete with *P. distichum* (McCosker 1994; Mahwinney 2003; Taylor & Ganf 2005; Crawford 2008). It is unpalatable to stock and results in declines in carrying capacity of more than 50 per cent (Crawford 2008). At Westholme, *P. canescens* cover was approximately 20% in 1994. It declined to almost zero during a period of regular flooding between 1995 and 1998. By 2007, it had increased in cover to almost 40%, but following flooding by the environmental flow in December 2007 and January 2008, *P. canescens* cover declined considerably as it struggled to survive being inundated and experienced competition from native perennial species such as *P. distichum*. Across all times grazing treatments had no significant impact on *P. canescens* cover.

The Crinolyn site is located near the western end of the wetland system and experiences a reduced frequency of natural flooding compared with the Westholme site, but in the past it had extensive *P.distichum* meadows (H.Blackburn pers. comm.). Figure 6a shows that as late as 1997 during periods of flooding, *P. distichum* developed a high percent cover. However, data from 1998 onwards show percent cover for this taxon has fallen from the peaks recorded in 1996 and 1997, and *P. canescens* has become dominant. Lippia cover has risen to between 60-80% for most experimental plots. There were no statistically significant differences in cover between any of the grazing treatments. Most water arriving at this site is now derived from rainfall. The lack of regular flooding has meant that lippia is now dominant. This taxon has been reported to have allelopathic properties (Crawford 2008), making it difficult for some native species to successfully germinate in its presence, which may further enhance the ability of lippia to maintain dominance at the site. While it is possible for environmental flows to reach Crinolyn, the depth and spatial extent of inundation is often insufficient to substantially influence plant community composition at this site.

DISCUSSION

The period of grazing on floodplains of the Gwydir Wetlands covers 160 years. To this point in time, the nature of the impact of grazing and its interaction with hydrological patterns has received only very limited research attention (Cassanova 2007). However, the present findings show that consistent effects at a range of spatial scales rarely exist. Instead, hydrological regime would appear to be the dominant factor driving changes in community composition in the Gwydir Wetlands.

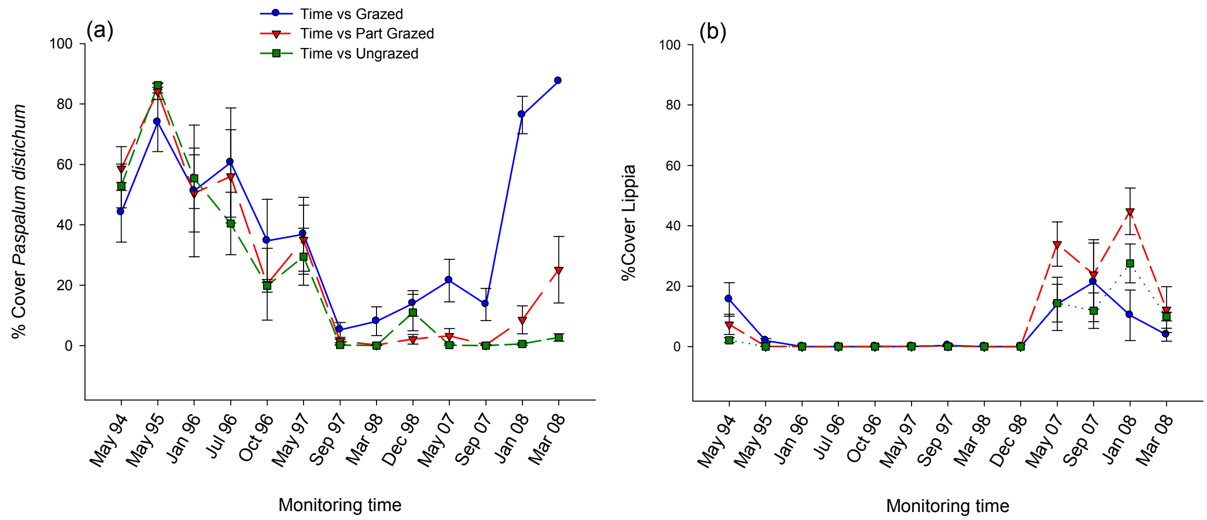


Figure 4. Percent cover for (a) water couch *Paspalum distichum* and (b) lippia *Phyla canescens* at Westholme between 1994 and 2008.

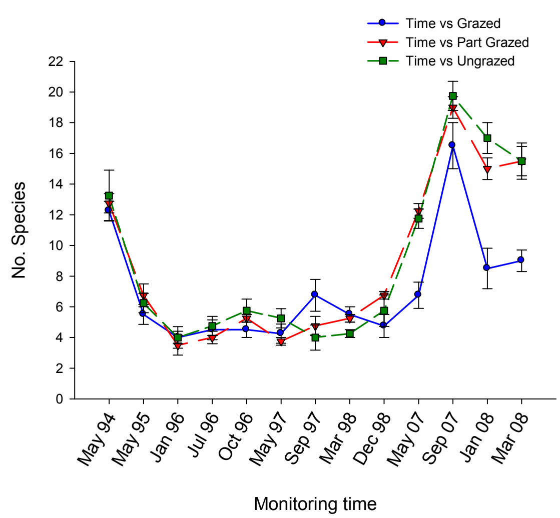


Figure 5. Number of species recorded at monitoring times between 1994-2008 in grazing study plots at Westholme.

Grazing impacts on vegetation composition differ depending on the morphological traits of the dominant taxa at a site. Tall monocotyledon taxa at frequently inundated sites tend to competitively exclude many other species. Here the disturbance by grazing animals may result in a reduction in cover of such taxa, and provide opportunities for other taxa from the regional species pool to grow. This leads to increased species richness at the local scale. In contrast, where dicotyledon taxa are dominant, such species tend to be more susceptible to grazing, due to them having their apical meristem near the stem apex. Grazing at these sites may lead to the dominance of more grazing-tolerant prostrate vegetation communities. At sites where inundation is limited, as a consequence of factors such as flow

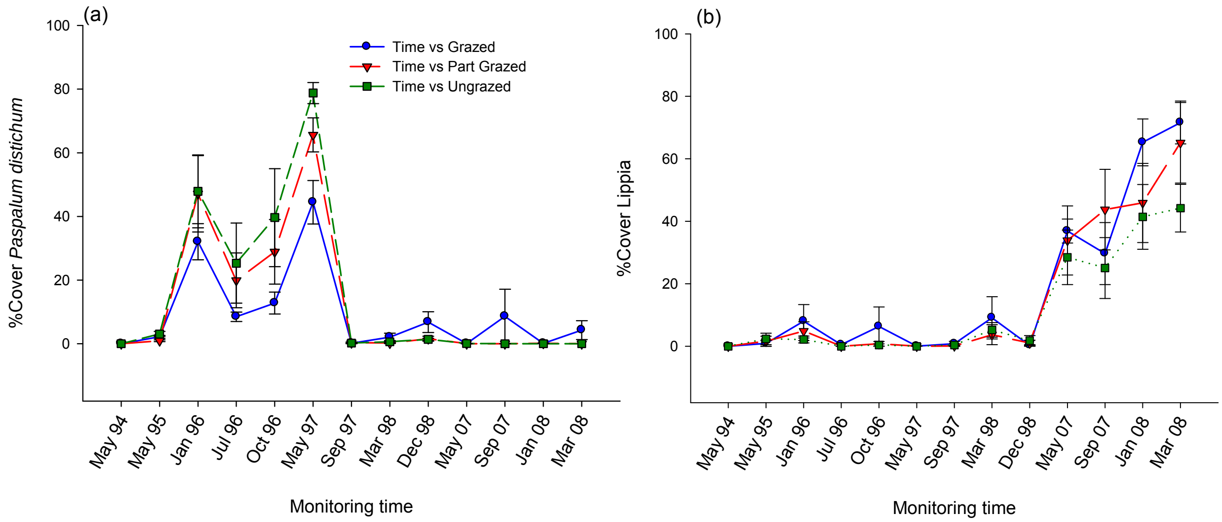


Figure 6. Percent cover for (a) water couch *Paspalum distichum* and (b) lippia *Phyla canescens* on Crinolyn between 1994 and 2008.

regulation flows, consumptive uses and extended periods of below average annual rainfall, community transition to one dominated by taxa adapted to a regime of reduced moisture levels is a likely outcome. Whether a transition back to a more traditional wetland plant assemblage is possible appears to be largely governed by the likely future water regime and the persistence of key wetland taxa in the soil seed bank (Wilson *et al*., 2008).

At all sites, flooding appeared to promote the dominance of taxa belonging to amphibious functional groups. It plays an important role in suppressing many significant weed species such as lippia and various thistles such as *Cirsium vulgare* and *Xanthium spinosum*. Environmental flows have the capacity to initiate responses in the vegetation community that mimic responses associated with natural floods. However, the spatial scale at which influence can be exerted by environmental flows in this catchment is relatively small. Backing such flows onto natural flood events appears to improve their effectiveness in achieving responses favouring the growth of taxa from amphibious functional groups through greater aerial extent and longer duration of flooding.

Under current grazing management regimes the impact of livestock grazing on plant communities appears to be most evident during dry periods between flood events. The impact of ungulate livestock in wetlands following flooding may be more evident in measures of soil attributes (Robertson 1998). Flooding plays a major role in stimulating growth of many key perennial wetland taxa, while it starts a new cycle of growth for many ephemeral wetland taxa as they emerge from the soil seed bank. It is important that grazing practices are managed to allow these natural processes to continue. Current stocking rates, which are lower than traditional rates for this region, need to be maintained. A reduction or elimination of grazing at the time of flowering and seed-set is vital for reducing impact of cattle on the vegetation by grazing and trampling, thereby helping to maintain a diverse and abundant soil seed bank. To continue grazing of wetlands on the Gwydir floodplain sustainably, grazing needs to be considered as a disturbance agent, and managed in conjunction with the natural cycles in wetland plant communities that are largely driven by the prevailing hydrological conditions.

ACKNOWLEDGEMENTS

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DELIVERING MULTI-OBJECTIVE ENVIRONMENTAL FLOWS INTO TERMINAL FLOODPLAIN WETLANDS, NORTHERN MURRAY-DARLING BASIN, AUSTRALIA

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Abstract

Terminal wetlands are a prominent ecological feature of floodplains across Australia's northern Murray-Darling Basin. They are gaining increasing recognition for their ecological role at catchment and landscape scales, and associated high conservation value, and most are recognised under national or Ramsar management agreements. However, many terminal wetlands are located in or downstream of significant agricultural landscapes, and receive a significant portion of their flows through regulated water resource development schemes. While the resulting alteration of natural flooding patterns has led to legislated environmental flow provisions for these catchments, terminal wetlands are one of the most difficult points in a catchment to which to deliver managed flow releases. Managers of these systems need clear guidelines as to how various ecosystem components respond to flow variability in order to make effective environmental flow decisions. The Lower Gwydir wetland ecosystem in north-west New South Wales comprises a large (though reduced) terminal wetland with four privately-owned Ramsar sites. Environmental flow releases from Copeton Dam have been made into the wetland area for the past 13 years. This study considered a mix of ecological data and management responses to assess the effectiveness of environmental flow (or 'Environmental Contingency Allowance', ECA) release practices in this wetland system. Although the Lower Gwydir release program is guided by nine ecological objectives, past ECA events have primarily focused only on wetland vegetation or colonial waterbird responses, with the assumption that other ecosystem components and management objectives would also receive parallel benefits. However, the spatial and (particularly) temporal scale of response will differ significantly among ecological attributes. In dry periods, ECA release volumes were limited and managers were concerned for loss of flows into floodplain areas upstream of the core and Ramsar wetland targets. However, non-target wetland areas may represent significant species-rich patches, and ECA success should be judged at the wetland or ecosystem scale rather than on an individual patch basis. Channel capacity restrictions and the need to avoid inundation of upstream cropping suggest that ECA releases may only ever achieve moderate discharge rates in this system. It should be recognised that any one flow event is unlikely to satisfy all management objectives, and that a multi-release program over an appropriate timeframe will likely be necessary to satisfy all ecosystem components.

INTRODUCTION

There is a growing recognition that lowland river ecosystems must be considered as an integration of river channels with their adjacent floodplain (Kingsford, 2000). Nevertheless, past management of such systems has often focussed on the channel and its floodplain as separate components (McPhail and Young, 1991; Kingsford, 2000; Kingsford *et al.*, 2006), with any subsequent management decisions invariably prioritising the needs of the river channel. Yet, the ecology of these river systems depends on patterns in their connectivity between channels and their floodplain (e.g. Jenkins and Boulton, 2003), either to allow for critical ontogenetic shifts or for fluxes in prey items and other materials between the two environments.

Australia's Murray-Darling Basin is dominated by floodplain river systems in dryland low-rainfall regions (Thoms and Sheldon, 2000). Catchments in its northern region feature summer-dominant rainfall and peak flow periods, although these are also recognised as being among the most hydrologically unpredictable and variable river systems globally (Puckridge *et al.*, 1999; Young and Kingsford, 2006). Despite the adaptation of their aquatic biota to extended periods of low or no flow (e.g. Boulton *et al.*, 2006), flow regulation has had a considerable impact on these ecosystems (Kingsford, 2000) through reducing the incidence of downstream flooding, and decreased flow variability and increased seasonal predictability (Thoms and Parsons, 2003; Kingsford *et al.*, 2006; Young and Kingsford, 2006). This has altered the extent of hydrological connectivity between these rivers and their floodplain, with consequences particularly for the ecological integrity of wetland areas. Environmental flow programs are beginning to address this need, yet still require a more thorough understanding of the likely ecological responses at a variety of spatial and temporal scales.

One of the key features of many northern Murray-Darling Basin rivers is their termination in large wetland systems. These 'terminal wetlands' may either comprise large lakes or networks of small distributary channels, typically with diffuse wetland patches in-between. Critically, they are difficult points in the landscape to which to deliver environmental water. They are often located downstream of irrigation schemes which harvest significant volumes of water from the river channel or off the floodplain during high-flow periods (Kingsford, 2000). Moreover, a range of downstream agricultural land uses often construct diversion channels, small weirs and floodplain levees to alter flow paths for a variety of purposes, and these structures add to the difficulty of calculating the flow volumes necessary to inundate target wetland areas. These ecosystems are also geomorphologically complex, often with poorly-defined, low-slope channels and a multitude of break-out points whose flow characteristics can shift in response to individual or sequences of flow events and associated changes in sediment transport (e.g. Rayburg *et al.*, 2004; Thoms *et al.*, 2006).

In spite of their complexity, the high conservation-value of these ecosystems and associated protection requirements under national or international agreements, as well as their prominence at the regional landscape scale, dictates that sound environmental flow management rules be devised for terminal wetlands. In the present study we examined a variety of aquatic ecological responses to environmental flow releases into a single terminal wetland system, the Lower Gwydir wetlands. These are recognised as being of national significance, and include privately-managed Ramsar sites. Management responses to these flow events and the subsequent ecological responses are considered and recommendations made as to how similar releases should be managed in this and other similar ecosystems.

THE LOWER GWYDIR CATCHMENT

Channel structure and hydrology

The Lower Gwydir wetland ecosystem in north-west New South Wales comprises a large (approximately 20,000 ha) terminal wetland system, mostly situated at the end of the Lower Gwydir River and Gingham Watercourse (Figure 1). These and two other distributary channels, Carole Creek and the Mehi River, receive regulated flows from the Gwydir River. Copeton Dam, with a total capacity of 1,360,000 ML, was completed on the Gwydir River in 1976, and regulates approximately 55% of total inflow to the river (Keyte, 1994). Smaller regulating structures at Tareelaroi, Boolooroo and Tyreel divert Gwydir River flows into the Mehi River, Carole Creek and Lower Gwydir River, respectively. All distributary channels also receive water through unregulated inflows from the Horton River and Warialda Creek into the Gwydir River below Copeton Dam. Unregulated flows peak in size over the November to February summer period. Since 1978, flows peaking at >20,000 ML per day in the downstream end of the Gwydir River have had an average return interval of 1.4 years (Figure 2A).

Environmental flow management

Environmental (or Environmental Contingency Allowance; hereafter ECA) flows into the Lower Gwydir channels and wetlands are currently administered through the New South Wales Department of Environment and Climate Change, with water for ECA releases held in an 'account' in Copeton Dam. Operating features of the account include a maximum allocation of 45 GL in any one water year, carry-over provisions if the balance is unused in the current water year, an account limit of 90 GL, and no limits on usage in any single release event (NSW Department of Environment and Climate Change, 2008). Water is accrued in the account as a percentage of inflows into Copeton Dam. Additional 'loss account' water is also held in Copeton Dam, and used to offset evaporative losses from the ECA account during storage and transmission losses during the delivery of an ECA release from Copeton Dam to the upstream end of the wetlands. ECA flows are tracked for compliance purposes by the dam and river operators to a point immediately upstream of the Lower Gwydir wetlands.

A stakeholder operations advisory committee, with agency, scientific and agricultural industry representation, makes recommendations to senior river managers for any use of ECA water. ECA recommendations are based on one or more ecological objectives, including:

1. To support a colonially-nesting native waterbird breeding event triggered by natural flooding;
2. To inundate core wetland areas during periods of extended dry climatic conditions;
3. To inundate higher-level in-channel benches downstream of Copeton Dam;
4. To provide short-term inundation to promote germination of exotic hyacinth as part of a wetting and drying weed management strategy;
5. To provide flows in distributary channels for environmental purposes;
6. To support native fish populations and habitat;
7. To support invertebrates and other aquatic species;
8. To support threatened species; and
9. To maintain aquatic ecosystem health.

Eight environmental flow releases have been made from Copeton Dam into the Lower Gwydir wetlands during the past 13 years (NSW Department of Environment and Climate Change, 2008; Table 1). Although the Lower Gwydir ECA release program is guided by the above nine ecological objectives, past ECA events have primarily focused only on stimulating core areas of wetland vegetation or to support colonially-nesting waterbird events, with the assumption that other ecosystem components and management objectives would receive parallel benefits.

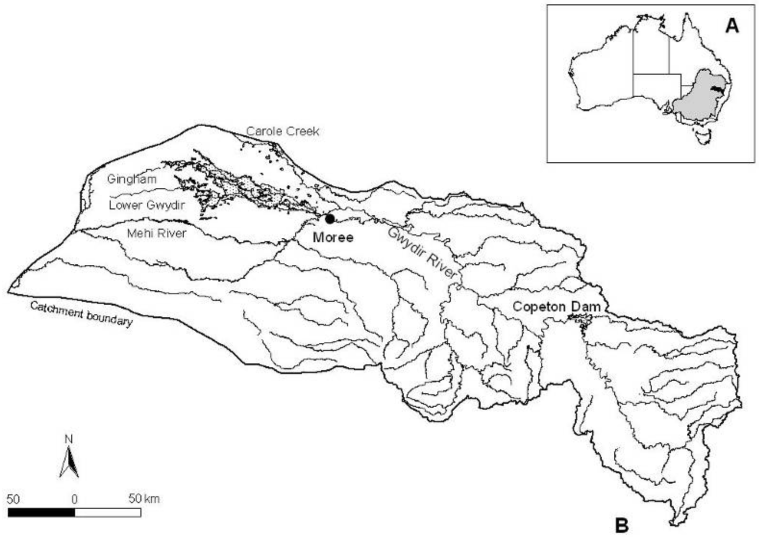

Figure 1. Location of the Lower Gwydir catchment, northern region of the Murray-Darling Basin, Australia, (A), and downstream terminal wetland complex (B). Reproduced from Wilson *et al*., in press.

Monitoring of hydrological and ecological outcomes is achieved in four ways. First, an ECA Manager tracks progress of water from the upstream delivery point through the Lower Gwydir channels to the target wetland areas. Aerial photography and satellite imagery is used to map the aerial extent of wetland inundation, backed up by ground-truthing. Second, researchers and government agency ecologists have undertaken monitoring, before and following recent ECA releases, of wetland vegetation and in-channel parameters such as water chemistry, fish assemblages and phyto- and zooplankton. Last, landholder observations are particularly useful in detecting the commencement of any waterbird breeding events.

CASE STUDY – 2006-2007 ENVIRONMENTAL FLOW RELEASES

Two separate ECA releases were made into the Lower Gwydir wetlands in late 2006 and early 2007 (Table 1; Figure 2 B,C). For operational reasons, these flows were sent into the Lower Gwydir River and Gingham Watercourse wetlands as two separate releases rather than as a single release split between the two channels, although most other ECA releases in this system have been executed as a single flow. The primary ecological objective in each case was to provide critical inundation of the core wetland areas, particularly to stimulate aquatic/wetland plant growth. Prior to this release, significant flooding of these wetlands had not occurred for 2–3 years.

We monitored the response of wetland vegetation and in-channel parameters (fish, water chemistry, phyto- and zooplankton) to the two ECA events. Vegetation monitoring sites were positioned in the core wetlands area at the end of both the Lower Gwydir River and Gingham Watercourse, and control sites were located in nearby areas of comparable elevation and plant assemblage structure but away from likely inundation. In-stream monitoring included three sites along each the two channels receiving ECA water (Lower Gwydir River, Gingham Watercourse) and the nearby Mehi River (Figure 1).

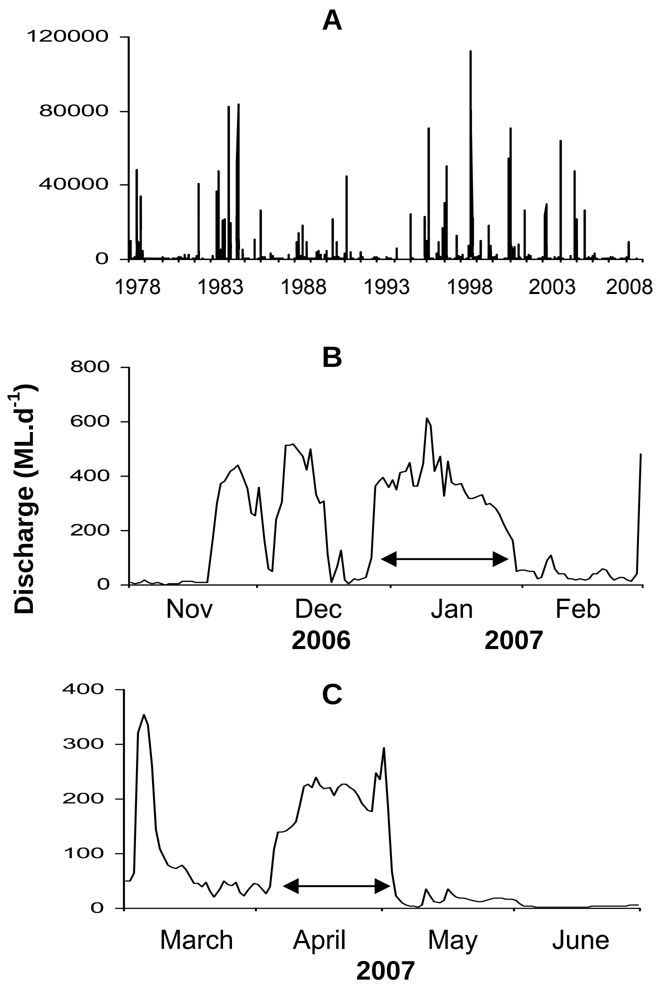

Figure 2. Flow variability in the Lower Gwydir River system, 1978–2008 (A), and hydrograph of ECA releases (arrows) in December 2006–January 2007 (B) and April 2007 (C). Flow data in (A) to (C) are from telemetered flow gauges at "Yarraman" in the Gwydir River, "Tyreel" in the Gwydir River, and "Teralba" in the Gingham Watercourse, respectively. All flow data are courtesy of the New South Wales Department of Water and Energy.

Table 1. Ecological objectives of environmental flow releases into the Lower Gwydir wetlands, 1996 to 2007. * release terminated after approximately 9,000 ML total discharge due to onset of natural flooding.

Timing	Primary ecological objectives	Release volume (ML)
February 1996	Support waterbird breeding	40,000 in total
February 1997	Support waterbird breeding	
December 1998	Support waterbird breeding	11,500
November 2002	Inundation of core wetland vegetation areas	20,000*
January 2005	Support waterbird breeding	13,395
December 2006	Inundation of core wetland vegetation areas	6,934
April 2007	Inundation of core wetland vegetation areas	6,633
November 2007	Inundation of core wetland vegetation areas	10,000

Hydrology and timing

The 2006/2007 ECA releases into the Lower Gwydir wetlands were constrained in two ways. First, the total volume of water available for releases at the beginning of the water year was only approximately 34 GL. Accordingly, the final release volumes were a compromise between (a) what was considered necessary to inundate each core wetland area to a sufficient aerial extent and duration to generate a vegetation response and (b) the need to retain a significant volume in the account for contingencies later in the 2006/2007 water year and/or beginning of the 2007/2008 water year. Second, as the key objective in each release was to deliver water to the core wetland areas within the Ramsar sites, discharge rates were calculated to minimise losses onto the floodplain upstream of the targets.

The ECA release into the Lower Gwydir River began on the 27^{th} December and lasted for approximately 26 days (Figure 2 B). It flowed at a peak discharge rate of approximately 750 ML per day upstream of the wetlands and 385 ML per day at the end of the river channel. The release was preceded by two flow pulses for consumptives uses (to 443 and 519 ML per day peaks) in November and December, and followed by two brief natural flows (479 and 628 ML per day peaks) in late February and early March. The ECA release into the Gingham Watercourse (Figure 2 C) began on the 3^{rd} April and lasted for approximately 28 days. Its peak rate of discharge at the upstream end of the wetlands was 239 ML per day, apart from a brief rise to 294 ML per day towards the end of the flow. No significant flow events followed this release, although it was preceded by a brief flow pulse to 355 ML per day in early March.

Vegetation responses

A ‘Before–After–Control–Impact’ sampling design was used to assess the efficacy of the April 2007 ECA release for stimulating wetland vegetation assemblages along the Gingham Watercourse. Data were obtained from five sites along the Gingham Watercourse (“Joanville”, “Westholme”, “Munwonga”, “Goddard’s Lease”, “Crinolyn”) and two control sites (“Allambie”, “Currigundi”) along the nearby Lower Gwydir River. Monitoring was undertaken in March (two weeks prior to the release) and in May and August (two and 14 weeks following the release, respectively). At each site, five fixed transects were set up, and the species present and their percentage cover was monitored using visual estimates on the three occasions. Data were analysed in terms of the overall number of species, as well as the presence of species in different functional groups. Species were arranged into four functional groups based on where they grow in a wetland and their life cycle traits in following inundation. Four functional groups were recognized in the Lower Gwydir wetlands:

- Amphibious responders (AmR) – plants which change their growth form in response to flooding and drying cycles;
- Amphibious tolerators (AmT) – plants which tolerate flooding patterns without changing their growth form;
- Terrestrial damp plants (TDa) – plants which are terrestrial species but tend to grow close to the
  water margin on damp soils; and
- Terrestrial dry plants (TDr) - those which are terrestrial species which don’t normally grow in wetlands but may be encroaching into the area due to prolonged drying.

The level of inundation varied among sites throughout the study period (Figure 3). “Joanville” was already wet prior to the start of the flow, due to water having spilt from the channel during prior stock and domestic releases. All other monitoring sites were dry in March. Water had also spilt into the wetland on “Munwonga” but no surface flow had reached the position of the monitoring transects. During the August monitoring, water was still covering some transects on both “Joanville” and “Crinolyn”.

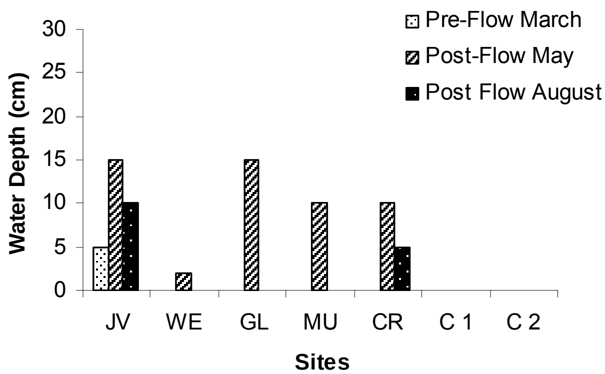

Figure 3. Water depth at vegetation monitoring sites along the Gingham Watercourse and Lower Gwydir River, March to August 2007.

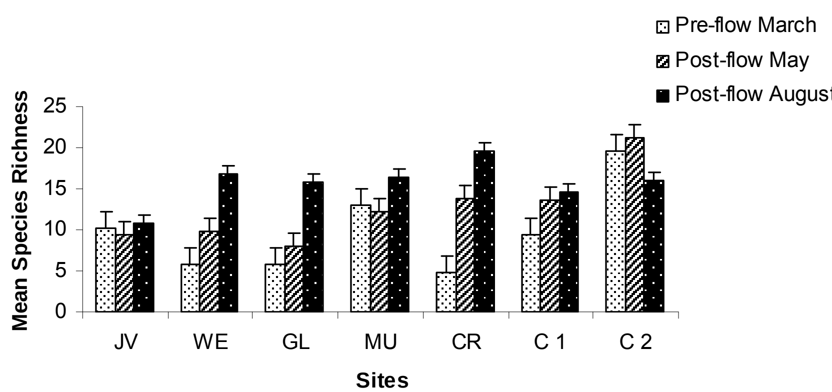

Figure 4. Mean number of wetland plant species along the Gingham Watercourse and Lower Gwydir River, March to August 2007. Significant temporal differences ($p < 0.025$) were detected at "Westholme", "Goddard's Lease" and "Crinolyn".

Three of the five Gingham watercourse sites experienced a significant increase in the number of species present following the release of the ECA flow (Figure 4). The two sites which didn't respond in this way ("Joanville, "Munwonga") were those that had already some moisture at or near the transects prior to the ECA release. Throughout the same period, neither of the two control sites displayed any consistent temporal pattern in species richness. Species from the amphibious responder and amphibious tolerator functional groups comprised approximately one-third of the species that emerged after the flow (Table 2), and the post-release appearance of new species in these categories was restricted to the Gingham Watercourse sites. No amphibious species were recorded at the control sites. Overall, the majority of species that emerged were from the Terrestrial Damp and Terrestrial Dry functional groups. Many of these species germinated on the damp ground after the water from the ECA release had receded.

Water couch (*Paspalum distichum*) is one of the key native plants of conservation concern in the Lower Gwydir wetlands. At most sites, live water couch cover decreased during the survey period

Table 2. Number of new species detected at study sites following the April 2007 ECA release, Gingham Watercourse and Lower Gwydir River wetlands.

Functional group	**Gingham Watercourse sites**					**Gwydir River control sites**	
	"Joanville"	"Westholme"	"Goddard's Lease"	"Munwonga"	"Crinolyn"	"Allambie"	"Currigundi"
AmR	0	1	2	0	1	0	0
AmT	1	2	2	0	3	0	0
TDa	2	2	2	0	4	3	1
TDr	3	5	5	8	8	9	6
Number of amphibious species	1	3	4	0	4	0	0
Number of terrestrial species	5	7	7	8	12	12	7
Total number of species	6	10	11	8	16	12	7

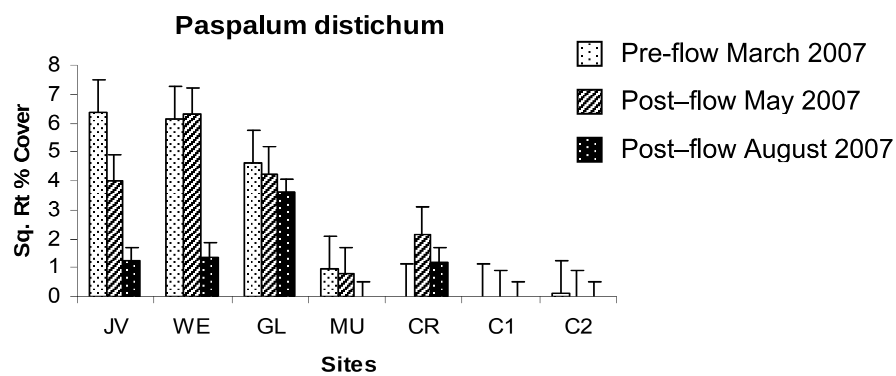

Figure 5. Mean percentage cover (square-root transformed) of water couch (*Paspalum distichum*) along the Gingham Watercourse and Lower Gwydir River, March to August 2007.

(Figure 5). This may have been due in part to antecedent weather patterns during the monitoring period. Rainfall and warm daytime temperatures throughout late autumn and early winter probably provided good conditions for germinating seedlings to grow and for existing species to take advantage of the high soil moisture following the ECA release. However, in late June and throughout July, a series of cold nights with heavy frosts appeared to arrest the growth of water couch. This species is frost sensitive and all above-ground vegetation was killed off by the frost. This response to the weather conditions, in combination with grazing by livestock, meant that the cover of live water couch was greatly reduced. Only a few green leaves were visible around plant meristems and plants would need to re-shoot once warmer conditions arrived in spring. During the study period, water couch was not observed to flower or set seed.

In-stream responses

A 'Before–After–Control–Impact' sampling design was also used to examine in-stream responses to

the two ECA flow events. Three sites were sampled along each of the Lower Gwydir River, the Gingham Watercourse and the Mehi River. The latter does not receive ECA flows and so was used as a control to any responses observed along the two other channels. A further set of control data was obtained from three floodplain waterholes near the Gingham Watercourse which did not receive any flows into them during the study period. In-stream sites were located from 8.4 to 54 km apart, while the floodplain waterholes were 2.7 to 5.2 km apart. Sampling for the Gwydir ECA release was undertaken in December 2006 prior to the flow and then in February and March 2007, while sampling for the Gingham ECA release was undertaken in March and May 2007.

We sampled fish assemblages using two sizes of fyke net: large nets of 12 mm (stretched) mesh, 1.1 m diameter body, 7 m long wings; and smaller nets of 0.3 m diameter body and 1.5 m wings. At each site, nets were set in the late afternoon and retrieved the next morning, with a large and small fyke set facing upstream and a second pair facing downstream. These have previously been found to be a useful method for sampling fishes in similar river systems (Balcombe *et al*., 2006). All fish and large crustacea were identified and counted, and fish lengths recorded to the nearest mm. A range of water chemistry data was also collected, including the nutrients total nitrogen, total phosphorous and soluble reactable phosphorous, chlorophyll a, dissolved organic carbon, suspended solid load, turbidity and electro-conductivity. Values were obtained from laboratory analyses.

Fish sampling from October 2006 to February 2008 indicated significant differences in species dominance among the three study channels (G. Wilson, T. Bickel and J. Sisson, unpublished data): Mehi River 58% western carp gudgeon (*Hypseleotris* spp., Gobiidae), Lower Gwydir River 62% bony bream (*Nematolosa erebi*, Clupeidae), Gingham Watecourse 42% spangled perch (*Leiopotherapon unicolor,* Tetrapontidae). This made it difficult to compare the response of individual species to ECA events across channels as abundances were generally too low at sites where a species wasn't dominant.

A number of dryland river fishes in the Murray-Darling Basin are thought to spawn in response to flow pulses although low-flow periods also appear important to their subsequent recruitment (Koehn and O'Connor, 1990; Humphries *et al.*, 1999, 2006; Wilson and Wright, 2005). While age data provide the best means of linking spawning activity to specific flow events in dryland river fishes (Wilson and Smith, 2002), size-structure data may also provide some indication of recent spawning and recruitment activity (e.g. Balcombe *et al*., 2006). In the present study, we examined temporal patterns in the size structure of two native fishes, bony bream and spangled perch. Due to the dominance of these species in the Lower Gwydir River and Gingham Watercourse, respectively, we used them to examine whether either of the ECA events was successful in triggering fish recruitment.

Bony bream size-structure in both the Lower Gwydir River and the floodplain waterholes before the Gwydir ECA release was dominated by two modes at around 40–60 mm and 90–110 mm in length (Figure 6). Following the ECA event, fish in the floodplain waterholes still largely reflected the pre-release size-structure, while the appearance of new individuals became progressively clearer in the Gwydir River following the release. Fish in this latter cohort were around 20–39 and 40–79 mm in February and March, respectively. Preliminary knowledge of size-at-age relationships in this species (Heagney, 2008), suggests that these fish were largely derived from spawning during the ECA flow. Spangled perch in the Gingham Watercourse prior to the April 2007 ECA event were dominated by a broad cohort, with a peak size of 40–49 mm, and minor peaks at 100–109 and 130–139 mm (Figure 7). Following the ECA release, the previous 40–49 mm peak appeared to have shifted to the 70–79 mm size-class, while a small cohort of 20–39 mm fish was evident. Again, prior knowledge of size-at-age in this species (Wilson and Smith, 2002) suggested that these smaller fish had been derived from spawning activity during the ECA release, although their relatively low abundances suggested a weak response. Unfortunately, spangled perch were not abundant enough in either the two other rivers or the floodplain waterholes to allow similar comparisons in the absence of ECA flows.

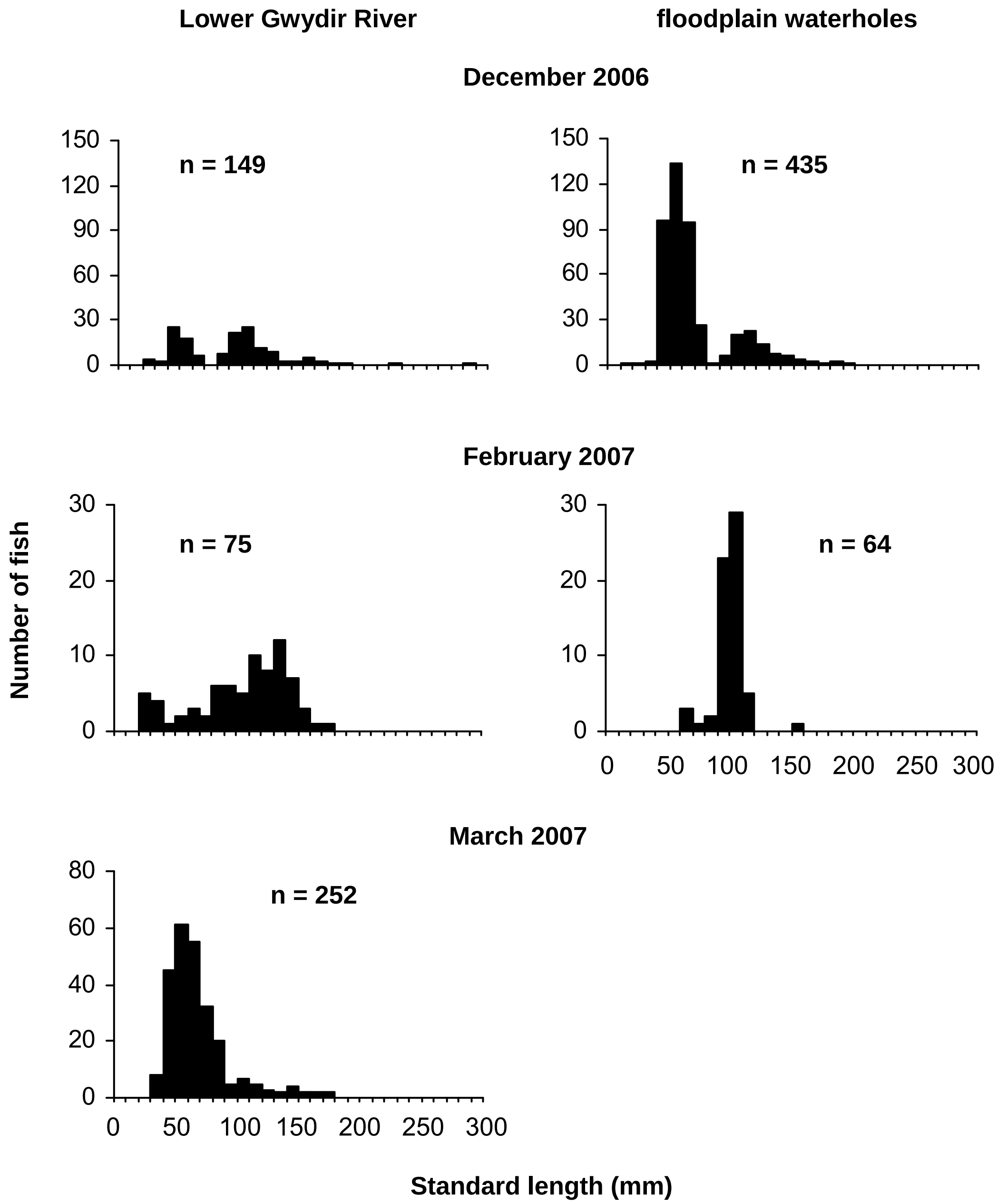

Figure 6. Bony bream, *Nematolosa erebi* (Clupeidae). Changes in size-structure before and after an ECA release into the Lower Gwydir River, December 2006 and January 2007. Floodplain waterholes nearby were not subject to the same flow-pulse. No bony bream were detected in the floodplain waterholes in March.

Due to flow conditions among the three river channels at the time of the two ECA releases, the most valid examination of their influence on in-channel water chemistry was to compare the Gingham Watercourse and Lower Gwydir River before, during and after the April 2007 event. Changes in water chemistry following this event appeared largely restricted to the three nutrient measures (Figure 8). Gingham Watercourse levels of total nitrogen, total phosphorous and soluble reactable phosphorous were similar to those in the Gwydir River prior to the release, though were still elevated relative to

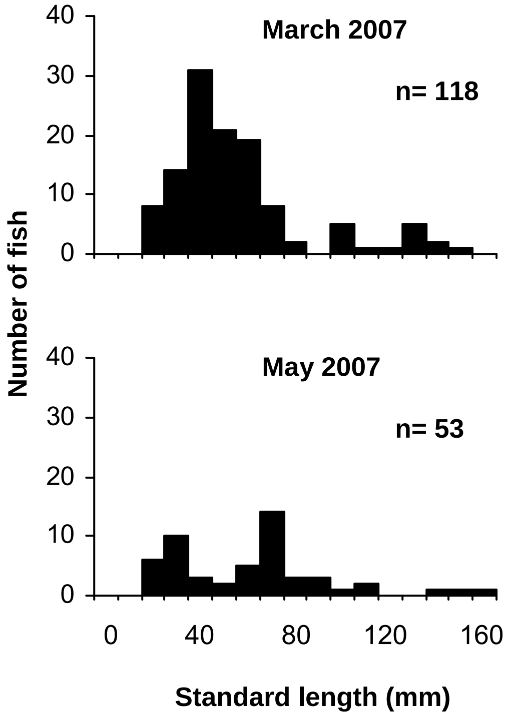

Figure 7. Spangled perch, *Leiopotherapon unicolor* (Terapontidae). Changes in size-structure before and after an April 2007 ECA release into the Gingham Watercourse.

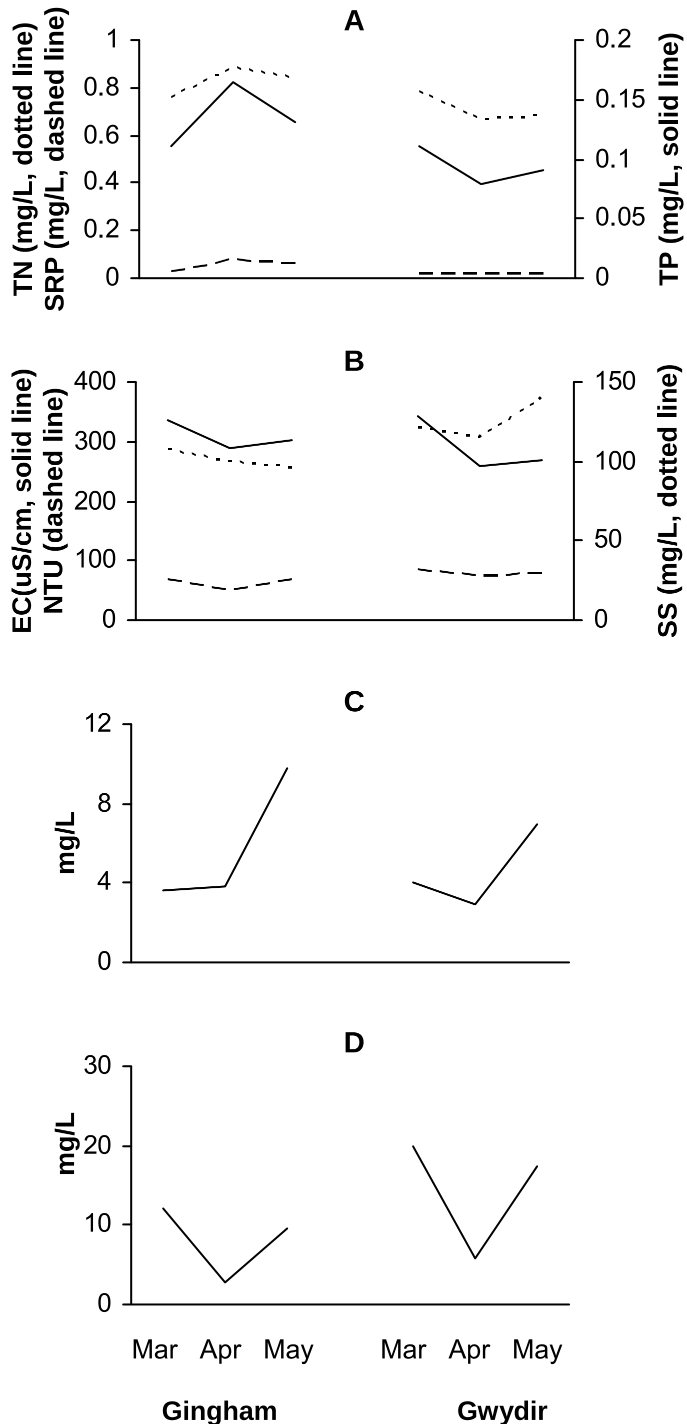

Figure 8. Shifts in water chemistry in the Gingham Watercourse and Lower Gwydir River, March to May 2007. A – total nitrogen (TN), total phosphorous (TP) and soluble reactable phosphorous (SRP); B – electro-conductivity (EC), turbidity (NTU) and suspended solid load (SS); C – dissolved organic carbon; D – chlorophyll a.

those in the Gwydir River a week after the release had finished. All measures peaked in concentration during the release. By contrast, neither of the other water chemistry variables showed a clear response to this ECA event.

DISCUSSION AND RECOMMENDATIONS

Dryland river systems are both geomorphologically and hydrologically complex (Thoms *et al*., 2006; Young and Kingsford, 2006), and determining their environmental flow requirements under highly flow-regulated conditions is a challenging task (Kingsford, 2000; Kingsford *et al.*, 2006). This complexity is further amplified in situations where restorative flows are required for both in-stream and floodplain wetland environments. This is especially the case where the wetlands are fringed by substantial areas of agricultural activity. Despite the extent of agricultural development on floodplains such as the Lower Gwydir, they should still be viewed as a mosaic of patches with significant biodiversity value (Morton *et al.*, 2002), and 'accidental' spills away from the flow target during transmission of an environmental flow should not be considered a loss unless onto areas of cultivation or vegetation clearing.

There are four broad recommendations to come from this work. First, expectations of what ecological responses might be achieved need to be realistic — not every release is likely to satisfy the hydrological requirements of all aquatic biota, particularly in cases like the 2006–2007 releases in the Lower Gwydir where the overriding objective was to retain as much water as possible in the channel upstream of the core wetland target.

Second, carefully designed monitoring programs are essential for determining the ecological outcomes from an ECA event and to demonstrate the benefits of environmental flows to the community and relevant stakeholder groups (Downes *et al*., 2002). Long-term reference data sets are necessary to understand the extent to which aquatic populations fluctuate in response to seasonal and hydrological cycles and habitat factors, while shorter-term monitoring programs are necessary to delineate responses to specific releases or other flows. However, the difficulties in tracking responses to specific flow events in should not be underestimated in flow-managed rivers like the Lower Gwydir where releases are being made for a variety of consumptive purposes as well as environmental ones. Clearly, ECA managers need to prioritise which ecological parameters they should focus on, particularly in circumstances where releases are recommended for a narrow set of ecological criteria.

Furthermore, such monitoring programs need to account for likely differences in temporal scale of response among biota, as not all responses will be adequately detected by a single monitoring program. For instance, while responses of wetland vegetation and some fish species were still evident 1–2 months after an ECA event in the Lower Gwydir, elevated nutrient levels were already diminishing a week after cessation of the April 2007 release. Other water chemistry variables did not show as clear a shift during and following the same release, either because their temporal scale of response differed from that of the nutrients or because the hydrology of the release was insufficient to generate a detectable response. While a multi-indicator monitoring program such as ours can provide an integrated picture of ecosystem responses to an environmental flow event, it will invariably be advisable to monitor different variables at varying temporal scales, from days to weeks or months following the onset of a flow event.

Given this temporal variability in response time, it may also be necessary to design multi-release programs to satisfy as many ecological objectives as possible. For example, while we detected changes in nutrient availability within the Gingham Channel following the largely in-channel April 2007 ECA,

dissolved organic carbon and fish assemblages may have responded more to a flow that had been allowed to inundate the floodplain upstream, irrespective of flow duration.

Third, the ‘boom-bust’ dynamics of biota in dryland floodplain rivers must be acknowledged in any monitoring program of ecological responses to flow variability. Again, long-term monitoring programs will be essential to ‘capture’ reference levels of population fluctuation. This will allow an appropriate understanding of the trade-offs or ecological costs of water resource developments that dampen the natural flow variability, as well as providing a reference against which to measure any gains from environmental flow programs. Similarly, it is vital to have a thorough understanding of the lifehistory of key species within the ecosystem. For instance, prior knowledge of age at size in bony bream and spangled perch allowed a preliminary match between the appearance of small fish and the timing of recent ECA flows.

Last, the seasonal timing of ECA events should be matched as closely as possible to the unregulated hydrological record. While the December–January ECA along the Lower Gwydir River occurred in the natural period of peak flows, the April release was at the end of this period and was followed by cold winter conditions. In the wetland plant assemblages, this meant that most species failed to set significant quantities of seed for the season as cold conditions from June onwards appeared to kill off much of their above-ground reproductive biomass. Similarly, the relatively low abundance of spangled perch may have also reflected this aseasonality, particularly given observations of their spawning response to summer flows elsewhere in the region (Wilson and Wright, 2005).

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Trophic structure of benthic resources and consumers varies across a regulated floodplain wetland

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Abstract. Riverine food webs are often laterally disconnected (i.e. between watercourses) in regulated floodplain wetlands for prolonged periods. This study reports the spatial variation observed in the trophic structure between watercourses in a regulated floodplain wetland that shared the same source water but were laterally disconnected. Specifically we investigated the trophic structure of benthic resources and consumers (species of crustaceans, and native and exotic fish) of three watercourses in the Gwydir Wetlands in eastern Australia. Results showed that the crustaceans *Cherax destructor* (yabby), *Macrobrachium australiense* (freshwater prawn), the exotic fish *Cyprinus carpio* (European carp) and *Carassius auratus* (goldfish) showed significantly different $\delta 13C$ values between watercourses, suggesting spatial differences in primary carbon sources. Trophic positions were estimated using $\delta 15N$ values of benthic organic matter as the base of the food web in each watercourse. The estimated trophic positions and gut contents showed differences in trophic positions and feeding behaviours of consumers between watercourses, in particular for *Melanotaenia fluviatilis* (Murray-Darling rainbowfish) and *M. australiense*. Our findings suggest that the observed spatial variation in trophic structure appear to be largely related to the spatial differences in the extent and type of riparian vegetation (i.e. allochthonous carbon source) across the floodplain that most likely constituted part of the benthic resources.