Wetland Hydrology in an Agricultural Landscape, Implications for Biodiversity.

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Abstract

Intensification of agricultural practices, such as groundwater extraction, stream flow regulation and vegetation clearing often leads to a reduction in both the number and hydrological diversity of wetlands in a landscape, reducing the amount of habitat available for many species. Remaining wetlands are often hydrologically homogenized and far less variable than under natural conditions and as consequence many species are no longer able to persist in the landscape over the long term. However, many studies only observe wetland hydrology at relatively small spatial and temporal scales. Consequently, there is little knowledge about wetland hydrology at the broader landscape scale and how it may change under changing climatic conditions. To help address this knowledge gap we analyzed hydrological data from 251 wetlands across 3 regions over a 17 year period from 1987 to 2005 to examine temporal changes in wetland hydrology in an agricultural landscape. This research investigated changes in the hydrological nature of wetlands in an agricultural landscape between two time periods from 1987-2005 and 2000-2005 (dry climatic period) to examine how wetlands may change through time, particularly under changing climatic conditions. In the recent time period, there was a significant change in the number of wetland hydrology groups represented in some of the landscapes. In the recent dryer period there was an increase in the number of frequently dry and wet wetlands and a reduction in the number of wetland representing the intermediate hydrological range. Changes in the number of wetland groups represented could have implications for biodiversity across the landscape if climate change intensifies the patterns observed.

Keywords: wetlands; agriculture; landscape ecology; climate change

Introduction

Globally, wetlands in agricultural landscapes are undergoing substantial hydrological changes as a result of anthropogenic activities, such as river regulation, groundwater extraction and climate change (Zedler, 2003). However, there is little data on the scope and magnitude of hydrological changes in wetlands across the landscape as a whole. Consequently, little is known of how wetland hydrology changes through time, whether all wetlands are being affected to the same extent or whether certain wetland hydrology types are becoming more or less prevalent throughout the landscape.

Maintaining a range of wetland hydrology types spanning both hydrologically variable and permanent wetlands is important for maintaining a range of habitat for water dependent biodiversity throughout the landscape (Roshier et al., 2002; Amona et al., 2008). In the Sahel wetlands of Africa, a spatially and temporally heterogeneous landscape of wetlands supports a wide array of biodiversity by providing a diverse range of vegetation and habitat types (Finlayson et al., 2005). For example, the biodiversity of floodplain seed banks is maintained across the landscape by temporal hydrological heterogeneity (Liu et al., 2006). Similarly, Barrett et al., (2009) argue that across a landscape a diverse range of wetland types influenced by a variety of water regimes maximizes wetland plant diversity. In an agricultural landscape in Japan, Amano et al, (2008) also observed that a diversity of wetland types, represented by rice fields and sources of open water, is important for meeting the habitat requirements of different bird species.

Consequently, floodplains and their wetlands 'naturally' exhibit high habitat heterogeneity, which supports a wide range of biodiversity adapted to a temporal and spatially dynamic landscape (Tockner and Standford, 2002). However, changes to wetland hydrology, as a result of human activities in agricultural landscapes or as a result of climate change, that reduce temporal and spatial diversity may have serious implications for biota dependent on wetlands across a landscape.

Drought conditions have been present over most of eastern Australia, including the study area, since 2001 (Rakich et al., 2008). In the future, rainfall reductions of 2-6% are also anticipated for the region (Cottrill, 2009). This research investigates changes in the hydrological nature of wetlands in an agricultural landscape between two time periods 1987-2005 and 2000-2005 (dryer climatic period) to examine how wetlands in this landscape may change through time, particularly under changing climatic conditions. The implication of these changes for the persistence of biodiversity and wetlands in agricultural landscapes is discussed.

Methodology applied

Wetland hydrological classification

Hydrological metrics relevant to wetland eco-hydrological functioning were derived for 251 wetlands; 105 wetlands in the Chinchilla region, 75 in the Dalby region and 71 in the Warwick region (Figure 1). Metrics relating to, percentage of time inundated, the number of wet dry cycles and the longest consecutive number of dry and wet years were determined (Table 1). These metrics were calculated for each time period; 1987-2005 and 2000-2005.

Wetlands were grouped into three separate ordinal categories for each variable (Table 1). Rarely inundated wetlands were those that were inundated less than 33% of the time, intermittently inundated were those inundated between 34 and 67% of the time and frequently inundated wetlands were those inundated more than 68% of the time. To examine changes in the hydrology metrics for wetlands in the Chinchilla sub-region the classification rare, moderate and frequent were used. Rarely variable wetlands were those that changed from wet to dry less than 33% of the time. Moderately variable wetlands were those that went from wet to dry between 34 and 50% of the time, and frequently variable wetlands those that changed from wet to dry greater than 50% of the time. The <33; 34-49 and >50% thresholds were also used to define rare, intermittent and frequently long wet and dry periods in wetlands (Table 1). The division for each group was selected arbitrarily and is only meant as a broad classification to reflect the general nature of the wetlands in each group. In reality, the hydrology of wetlands represents a continuum across each of these groups.

Table 1
Response variables for wetland hydrology used for analysis. Metrics derived from QWBD (2005) metadata for wetlands in the Condamine catchment.

Wetland hydrology metric	Ordinal categories		Time periods
Inundation (Time inundated (%))	Rarely inundated	< 33%	Inundation$_{1987-2005}$
	Intermittently inundated	< 34 – 67 %	Inundation$_{1994-2005}$
	Frequently inundated	> 68 %	Inundation$_{2000-2005}$
Variability (Frequency of wet dry cycles)	Low variability	< 33 %	*Variability$_{1987-2005}$
	Moderate variability	34 – 50%	*Variability$_{1994-2005}$
	High variability	> 50 %	Variability$_{2000-2005}$
Long wet (Proportion of time wetland stayed wet; without an intervening dry period)	Rarely wet	< 33 %	*Long wet$_{1987-2005}$
	Intermittently wet	34 – 50%	*Long wet$_{1994-2005}$
	Frequently wet	> 50 %	Long wet$_{2000-2005}$
Long dry (Proportion of time wetland stayed dry; without an intervening wet period)	Rarely dry	< 33 %	*Long dry$_{1987-2005}$
	Intermittently dry	34 – 50%	*Long dry$_{1994-2005}$
	Frequently dry	> 50 %	Long dry$_{2000-2005}$

*only calculated for the Chinchilla sub-region

Analysis - Confidence Intervals, dependent t-tests & Chi-square tests

Chi-squared tests were used to test for differences in the frequency of wetlands in each category within each hydrological variable during the 1987-2005 and 2000-2005 time periods. Additional to this, hydrological variables were also treated as continuous data and analyzed using confidence intervals and dependent t-tests to provide an overall indication of hydrological changes.

Confidence intervals and dependent sample t-tests were also carried out across three time periods 1987-2005, 1994-2005 and 2000-2005, to help clarify the impact of the dryer climatic conditions during the 2000-2005 period. All confidence intervals, chi-square and t-tests were performed in the SPSS version 17.0 (SPSS Inc., 2005).

Unfortunately, the Dalby and Warwick region scenes were missing six and five years of data respectively, and as a consequence, only metrics related to percentage of time inundated were calculated for wetlands in these regions. In the Chinchilla sub-region where the full dataset was available, confidence intervals were completed for the frequency of wet dry cycles, longest consecutive number of wet years and longest consecutive number of dry years, for each time period. Between each time period dependent sample t-tests were also performed. For each region confidence intervals between each year were also constructed for the average percentage of time wetlands were inundated for within each sub-region. Again, dependent sample t-tests were carried out to test for difference between each year. As there were differences in the times of scene capture for wetland inundation for wetlands in each region, no cross regional analysis were performed.

Case study description

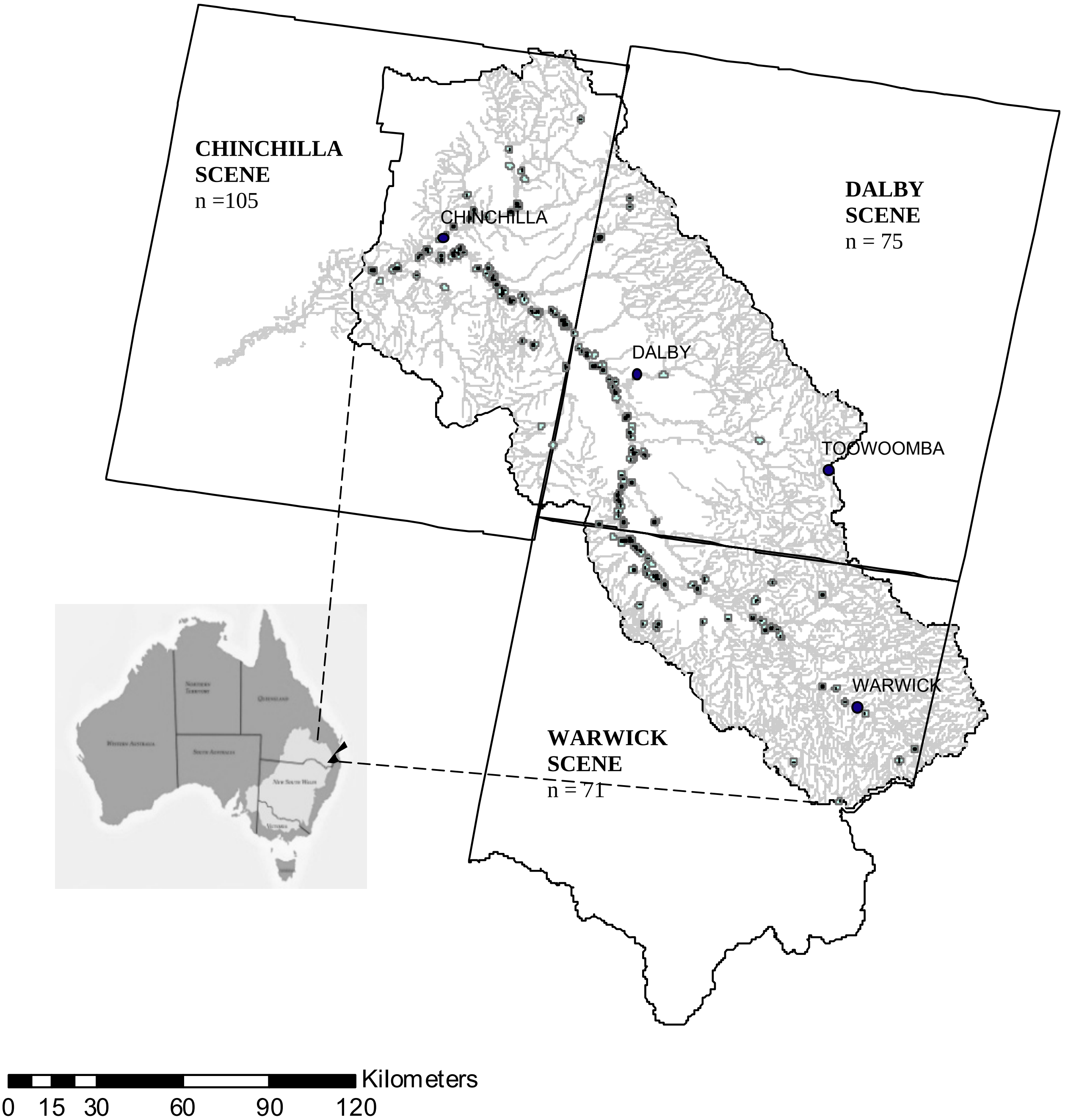

Figure 1
The Condamine catchment; showing the location of the 251 wetlands across the three regions; Chinchilla, Dalby and Warwick. Each wetland has been buffered to 1 km to highlight their location. The riverine network of the catchment is shown in light grey. The main River is the Condamine River.

The Upper Condamine catchment is located at the headwaters of the MDB in south east Queensland and covers approximately 2, 750, 000 (ha) (Department of Environment and Heritage, 2009) (Figure 2). The floodplains catchment is home to most of the 2000 plus wetlands that the catchment supports, which collectively cover 32,000 to 35, 400 ha (Clayton et al., 2006; Environmental Protection Agency, 2008). The majority of wetlands throughout the area are likely to have had ecological and hydrological processes significantly impacted as a result of agricultural practices in the catchment. Although, the proportion of wetlands lost has not been quantified, it is likely that a significant proportion have already been drained, in filled or transformed in some other way for agricultural purposes.

The Condamine catchment is characterised by a variable climate varying from sub-tropical to semi-arid (Searle et al., 2007). Minimum and maximum mean temperatures range from, -1.3 °C (July) to 32.3°C (December) in the south near Warwick, to 3.6 °C (July) to 33.2 °C (December) in the west near Chinchilla (Bureau of Meteorology, 2009). Average annual precipitation for the area varies from 549 mm in the west to 689mm in the east (Bureau of Meteorology, 2009). Precipitation can vary significantly between years (Figure 2). However, drought conditions have been present over most over eastern Australia, including the study area, since 2001 (Figure 3; Rakich et al., 2008). In the future reductions of 2-6% in rainfall are also anticipated for the region (Cottrill, 2009).

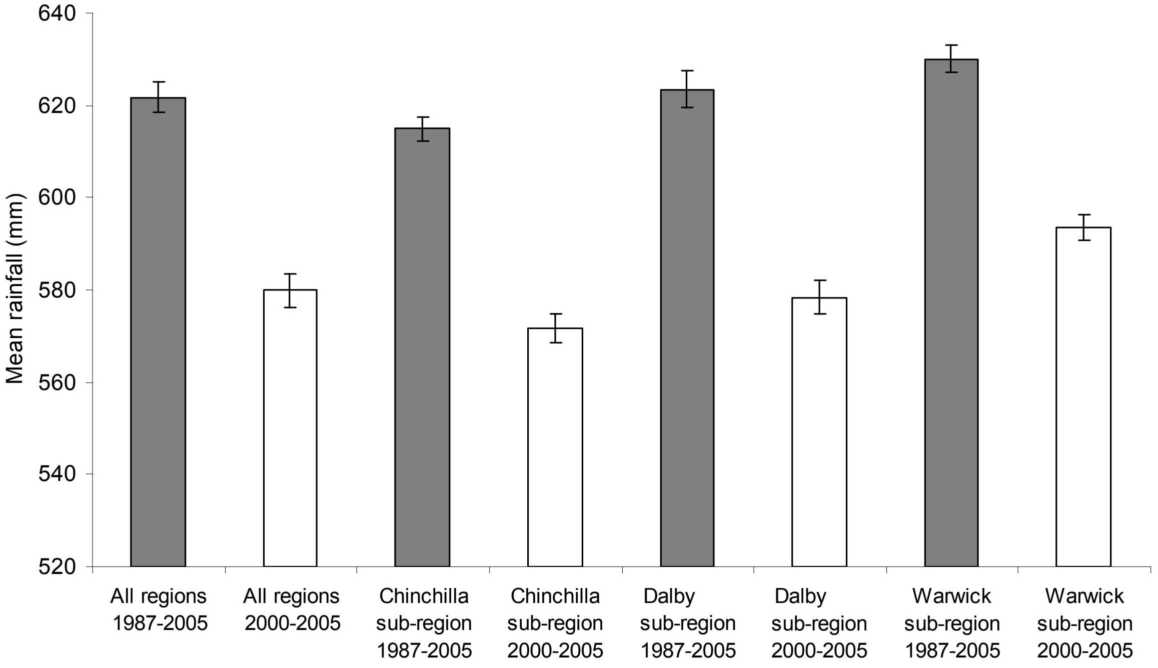

Figure 2
Mean rainfall (mm)l for 1987-2005 and from 2000-2005 across all wetlands for All regions (n=251) and each sub-region; Chinchilla (n=105), Dalby (n=75) and Warwick (n=71). Error bars represent standard errors.

Results obtained

Chi square tests

In the Chinchilla sub-region there was a significantly lower frequency of intermittently inundated wetlands in the 2000-2005 (chi-square <0.01; Table 2). There were no differences in the frequency of wetland types between the 1987-2005 and 2000-2005 time periods in the Dalby and Warwick sub-regions (Table 2; Figure 3). In the Chinchilla sub-region moderately variable wetlands were significantly more frequent (chi-square <0.01;) in the 2000-2005 time period (Table 3). Also in the Chinchilla sub-region rarely and moderately dry wetlands both decreased in frequency, while relative to the 1987-2005 time period frequently dry wetlands increased in frequency by 15 in the 2000-2005 period. In contrast rarely wet wetlands decreased in frequency while moderately wet ones increased (Figure 4). There was only a slight increase in the frequency of frequently wet wetlands (Table 3).

Table 2
Summary of results of chi-square tests for frequency of time inundated for sub-regions and across the entire region between the 1987-2000 and 2000-2005 time periods

Region	Wetland type	Residual	Chi-Sqaure	Asymp. Sig.
Chinchilla	Rarely inundated	7.5	1.8	0.18
	Intermittently inundated	-7.5	3.571	0.059*
	Frequently inundated	0	0	1
Dalby	Rarely inundated	5	1.471	0.225
	Intermittently inundated	-5	2.273	0.132
	Frequently inundated	0	0	1
Warwick	Rarely inundated	1.5	0.153	0.696
	Intermittently inundated	0	0	1
	Frequently inundated	-1.5	0.176	0.674
Combined	Rarely inundated	14	3.111	0.078*
	Intermittently inundated	-12.5	4.496	0.034**
	Frequently inundated	-1.5	0.081	0.776

sig p <0.01*; <0.05**, <0.0001***

df=1

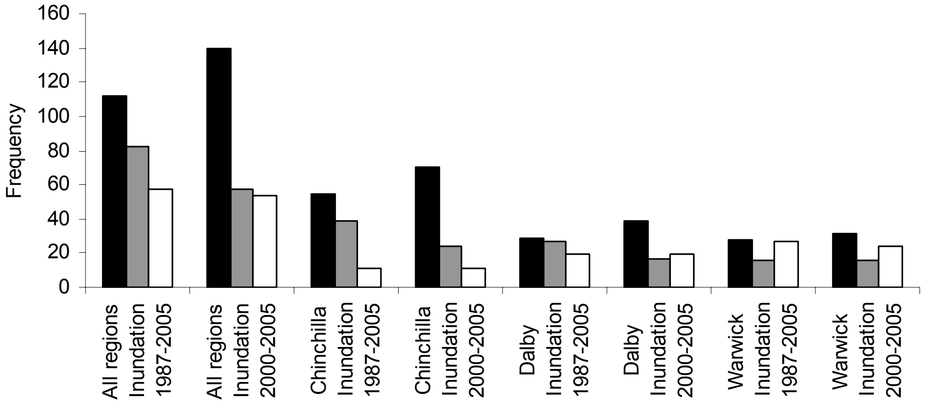

Figure 3
Number of wetlands in each ordinal category for $TI_{1987-2005}$ and $TI_{2000-2005}$ for the entire region and for each sub-region. Inundation frequency: (■) – rarely inundated; (▨) – intermittently inundated; (□) – frequently inundated.

Table 3
Chi-square test results for changes in the frequency of wetland types in the Chinchilla sub-region between 1987-2005 and 2000-2005.

Wetland type	Residual	Chi-Sqaure	Asymp. Sig.
rarely variable	-8	2.667	0.102
moderate variability	9.5	4.349	0.037**
frequently variability	-1.5	0.29	0.59
rarely dry	-24.5	29.642	0.0001***
moderately dry	-9.5	3.8	0.051*
frequently dry	15	26.471	0.0001***
rarely wet	-14	5.091	0.024**
moderately wet	12.5	14.535	0.0001***
frequently wet	1.5	0.692	0.405

sig <0.01*; <0.05**,<0.001*** df=1

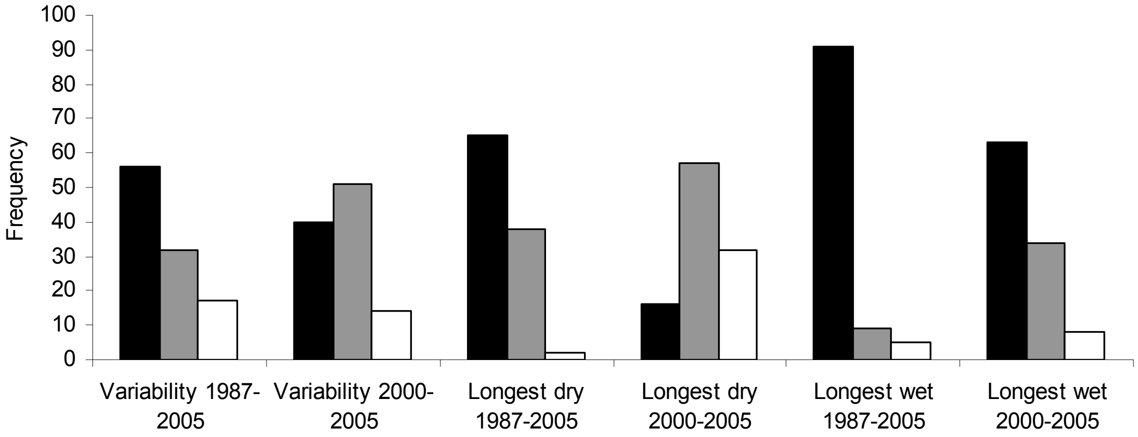

Figure 4
Number of wetlands in each of the wetland groups for variability in the Chinchilla sub-region.
(■) – low variability wetlands; (■) – moderate variability wetlands; (□) – high variability wetlands.

Confidence intervals and dependent t-tests

In the Chinchilla sub-region there was a significant difference between Variability$_{1994-2005}$ and Varaibility$_{2000-2005}$ (p<0.000, df =104, t=7.969) and Varaibility$_{2000-2005}$ and Varaibility$_{1987-2005}$ (p<0.000, df =104, t=6.849) with the frequency of wet dry cycles decreasing significantly in the recent time period from 2000 to 2005 (Figure 5a). The frequency of longest consecutive wet years increased significantly between Longest wet$_{1987-2005}$ and Longest wet$_{1994-2005}$ (p<0.000, df =104, t=-6.260) and between Longest wet$_{1987-2005}$ and Long wet$_{2000-2005}$ (p = 0.005, df =104, t=-2.840) (Figure 5b). While for the longest dry period in Chinchilla, between Longest dry$_{1987-2005}$ and Longest dry$_{1994-2005}$ (p<0.000, df =104, t= -6.260); Longest dry$_{1987-2005}$ and Longest dry$_{2000-2005}$ (p<0.000, df =104, t= -10.215) and Longest dry$_{1994-2005}$ and Longest dry$_{2000-2005}$ (p<0.000, df =104, t= - 10.573) there was a significant increase in the relative frequency of the longest consecutive number of dry years between each time period (Figure 5c).

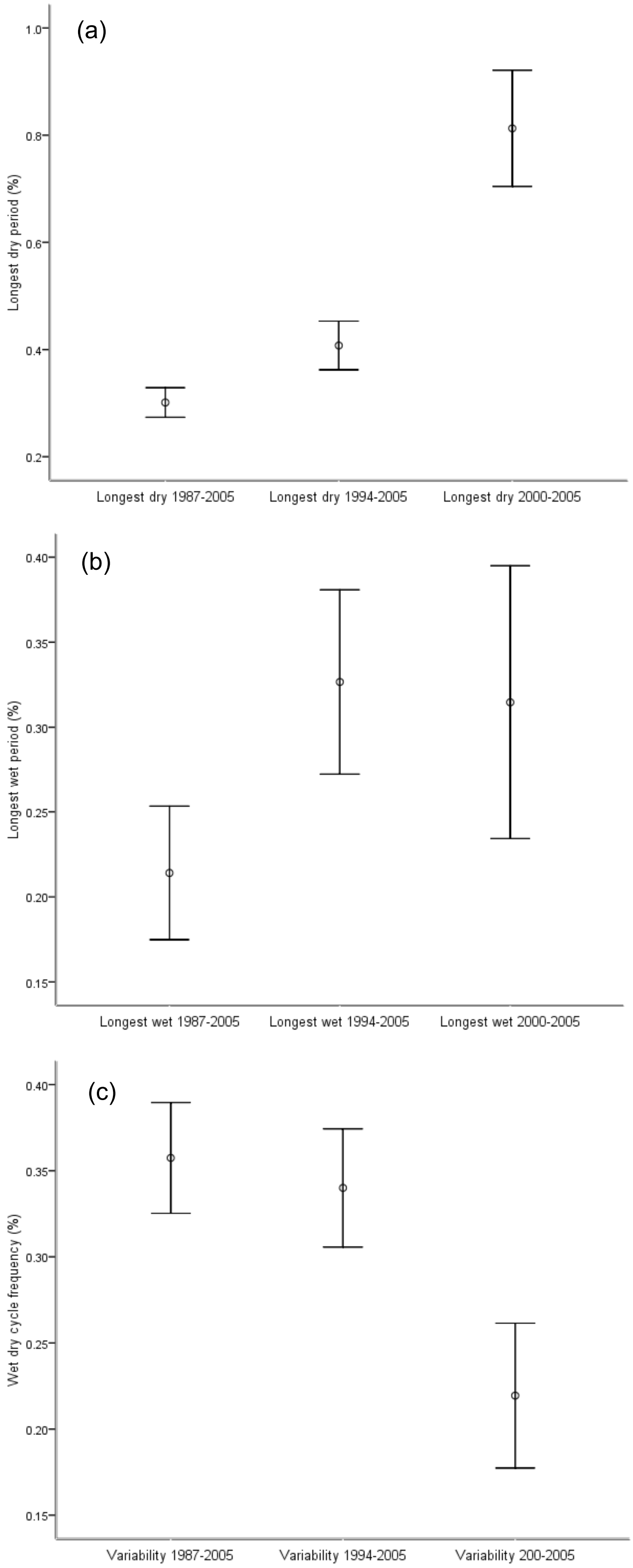

Figure 5
For the Chinchilla region confidence intervals comparing (a) Longest dry, (b) Longest wet and (c) Variability across three different time periods.

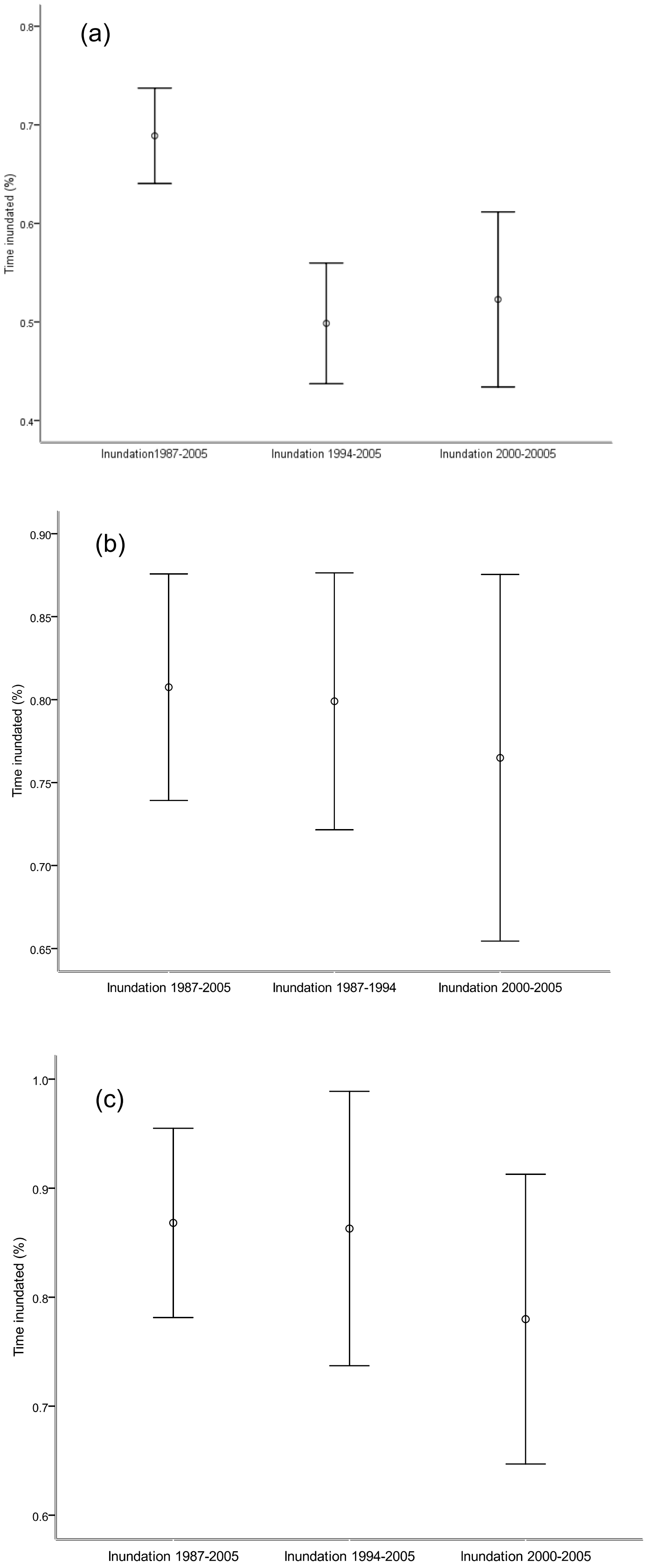

Figure 6
Comparisons of percentage of time inundated for each wetland across three different time periods for each sub-region (a) Chinchilla, (b) Dalby and (c) Warwick.

In the Chinchilla sub-region, there was a significant reduction in the percentage of time inundated when comparing $\text{Inundation}_{2000\text{-}2005}$ to $\text{Inundation}_{1987\text{-}2005}$ ($p<0.000$, df =104, t=5.474). There was also significant reduction between $\text{Inundation}_{1994\text{-}2005}$ and $\text{Inundation}_{2000\text{-}2005}$ ($p<0.000$, df =104, t=8.367). There was a small but significant difference between $\text{Inundation}_{1987\text{-}2005}$ and $\text{Inundation}_{1994\text{-}2005}$ ($p<0.006$, df =104, t=2.832) (Figure 6a). For the Dalby and Warwick sub-regions there were also decreases, but not of the same magnitude (Figure 6b and c). In contrast to wetlands in the Chinchilla and Warwick sub-regions, wetlands in the Dalby sub-region did not show significant reduction in the percent of time inundated across the three time periods ($p>0.180$, df = 74, $t<1.354$) (Figure 6b).

There was no significant difference between $\text{Inundation}_{1987\text{-}2005}$ and $\text{Inundation}_{1994\text{-}2005}$ ($p = 0.068$, df = 70, t= 1.853) in the Warwick sub-region. However, there was a slightly significant reduction in percent time inundated when comparing $\text{Inundation}_{2000\text{-}2005}$ and $\text{Inundation}_{1994\text{-}2005}$ ($p = 0.000$, df = 70, t = 3.989); and between $\text{Inundation}_{1987\text{-}2005}$ and $\text{Inundation}_{2000\text{-}2005}$ ($p =0.013$, df = 70, t= 2.555) (Figure 6c).

Discussion

Hydrological changes to wetlands; implications for biodiversity

Wetlands throughout the Upper Condamine catchment have undergone substantial hydrological changes in the recent 2000-2005 time period. On average wetlands in all sub-regions, showed changes in the wetland hydrology metrics examined. Wetlands in all regions did showed a decrease in the time inundated, when comparing the recent and long term. However, these changes were not significant for wetlands in the Dalby and Warwick sub-regions (Figure 6). The results of the Chi-square tests similarly show that there were no significant changes in the Dalby and Warwick regions. In the Chinchilla region there were significant changes in the frequency of wetlands in each of the classified hydrology groups (Table 2 & 3). In the Chinchilla sub-region, wetlands become less variable, while at the same time also became wetter or dryer (Table 3). In the Chinchilla sub-region also the Chi-square tests showed that there was an increase in the frequency of moderately variable wetlands, a dramatic increase in the frequency of frequently dry wetlands and a subsequent decrease in the frequency of rarely wet wetlands (Table 3).

The lack of change in the Dalby sub-region and relatively moderate changes in the Warwick sub-region may reflect the more intense agricultural utilization of these areas, relative to the more westerly and drier Chinchilla sub-region. Throughout the three sub-regions examined, the Dalby and Warwick sub-regions were historically, and are currently, far more heavily utilised for agriculture. In the Dalby and Warwick sub-regions irrigated land covers approximately 9-10% of the land surface, while around Chinchilla it only comprises 2% (Queensland Environment and Resource Management, 1999;). Vegetation clearing has also been much higher in the Dalby and Warwick sub-regions: only 16 and 21% of native remnant vegetation remains in these areas compared to 46% in the Chinchilla region (Queensland Environmental Protection Agency, 2003). Consequently, within the Dalby and Warwick sub-regions, more wetlands are likely to be utilised for agricultural purposes for longer periods of time. As such, many wetlands may have already had their water regimes stabilized or altered.

In most parts of the world, recent information on landscape scale changes to wetland hydrology is sparse. However, Beeri and Phillips (2007) found a reduction in wetland density from 7.6 basins per km^{-2} with water in 1997 to 3.5 in 2005. Beeri and Phillips (2007) postulated that these reductions could be the result of decreases in snowfall, anthropogenic factors or other factors. In most cases the substantial changes to wetland hydrology observed in many parts of the world, whether at the individual wetlands scale or across entire landscapes, are often attributed to anthropogenic facilitated changes to one of a wetland's key hydrological inputs: groundwater, run-off or stream flows. Jenkins et al., (2005) postulate that within Australia it is agreed that the most significant change to wetlands has been facilitated by river regulation through weirs and dams, irrigation and domestic supply, and groundwater pumping.

In other parts of Australia changes to wetland hydrology have been noted by various authors. Along the Murrumbidgee River in south-eastern Australia, regulation has halved the frequency and duration of flows that connect the river to the floodplain, resulting in an approximately 40% reduction in the duration and frequency of floodplain wetland inundation (Page et al., 2005; Frazier and Page, 2006). For a large wetland (2581 ha) on the floodplain of the Murray and Goulbourn Rivers, Victoria, oral history was used to determine that wetland flood inundation events have decreased over the last 60 years (Robertson and McGee, 2003). Similarly, since the regulation of the Macquarie River, the Macquire Marshes, flood frequencies have reduced by 25-30% (Jenkins et al., 2005). Kingsford (2000) argues that on developed rivers, more than 50% of floodplain wetlands may no longer flood.

In this study, the significant changes are likely the result of an amalgamation of anthropogenic and climatic changes. The climate of the region is naturally dynamic with floods and droughts possible at any time of the year (Thoms and Parsons, 2003). The more recent 2000-2005 period was, on average, dryer than the long term 1987-2005 period. Consequently, the changes in time inundated may be simply reflecting the dryer climate in 2000-2005. Although it is also likely that the dryer climatic conditions have increased the utilisation of ground and surface water resources, which would have further exacerbated the hydrological changes in the wetlands as a result of dryer climatic conditions.

In the Chinchilla sub-region during the 2000-2005 time period wetlands were inundated less frequently and become less variable. Additional to this they also moved to either end of the hydrological continuum, becoming dryer for longer periods of time or wetter for longer periods of time (Figure 5).

The increase in the number of wetlands staying wet, in combination with a reduction in their variability , suggests an increase in anthropogenic influences. Quinn et al., (2000) state that river regulation and extraction of water to support irrigated agriculture has likely increased the temporary nature of some wetlands by reducing the frequency of flood events that lead to overbank flows, causing them to remain dry for longer. Brock et al., (1999) argue that many wetlands remaining in agricultural landscapes have had the water regimes altered in such a way that their ‘stability’ is increased, so that they are more continuously either dry or wet. It is possible that in the recent time period the changes in the Chinchilla wetlands are not only resulting from dryer climatic conditions, but also as a result of increased on site modification to wetland hydrology, that increases their stability.

In this study, there was no quantification of anthropogenic wetland modification. Consequently, it can not be concluded that the reduction in wetland variability for wetlands in the Chinchilla sub-region reflect recent anthropogenic activities. Nonetheless, regardless of whether the patterns of wetland change in the Chinchilla sub-region are resulting from anthropogenic or climatic factors if the patterns continue or intensify, there are various ecological implications.

Climate change projections for the broader region predict that precipitation will reduce by 2-6% (Cottrill, 2009). If reductions in precipitation observed during the 2000-2005 period continue into the future, then the changes in the frequency of different wetland hydrology types observed may intensify and have substantial implications for biodiversity remaining in the landscape.

The implications of a reduction in wetland variability and a reduction in the hydrological variability in the landscape so that more of the wetlands are at the extremes of the continuum as predominantly dry or wet has key ecological implications. Many water dependent biota require a diversity of wetland types and a spatial and temporally diverse hydrological landscape. The maintenance of different wetland hydrological types ensures that there is spatial and temporal heterogeneity of wetlands, which is critical for the persistence and future resilience of biota in landscapes (Brock, 2003).

If the variability and frequency of inundation of many wetlands in the landscape is significantly altered, then wetland diversity at the landscape and local scales may decline. At a broad spatial scale, a decrease in the variability of hydrological inundation frequency has been illustrated to lead to a reduction in landscape scale diversity. In the Copper Creek floodplain of central Australia, Capon (2005) found that more frequently flooded sites were more homogenous than rarely inundated sites, which were more divergent from each other. While, at smaller spatial scales, regulation of flows leading to permanent inundation has lead to the homogenization of site level biodiversity, where one or more species being better adapted to a permanent water regime comes to dominate (Brock, 2000;Francis and Sheldon, 2002; Warwick and Brock, 2003).

Conclusions

If the patterns in wetland hydrology change observed in this study continue, namely an increase in the number of frequently dry and wet wetlands and a reduction in the number of wetland representing the intermediate hydrological range, then there could be substantial implications for biodiversity. Over time, changes to climatic conditions, coupled with anthropogenic activities, may further reduce the frequency of wetland hydrology types represented and as such further reduce the diversity of wetlands in the landscape. Knowledge is currently limited regarding how wetland hydrological diversity interacts with biodiversity over broad spatial and temporal scales. To help understand how biota may change under changing climatic conditions future research should examine both how hydrological diversity will change in the landscape and quantitatively link this to local and landscape scale assessments of biodiversity and other values ecological values.

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