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Application of thresholds of potential concern and limits of acceptable change in the condition assessment of a significant wetland

Kerrylee Rogers
University of Wollongong, kerrylee@uow.edu.au

Neil Saintilan
Office of Environment and Heritage (OEH), Neil.Saintilan@environment.nsw.gov.au

Matthew J. Colloff
CSIRO - Ecosystem Sciences

Li Wen
Office of Environment and Heritage (OEH)

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Keywords

change, condition, assessment, significant, wetland, potential, concern, application, limits, thresholds, acceptable

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

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Application of Thresholds of Potential Concern and Limits of Acceptable Change in the condition assessment of a significant wetland

Rogers Kerrylee[2], Saintilan Neil[1*], Colloff Matthew J.[3], and Wen Li[1]

[1] Rivers and Wetlands Unit, Office of Environment and Heritage

[2] School of Earth and Environmental Science, University of Wollongong

[3] CSIRO Ecosystem Sciences, GPO Box 1700, Canberra, ACT 2601

[*] Corresponding author

PO Box A290, Sydney South NSW 1232

Neil.Saintilan@environment.nsw.gov.au

Tel: 612 9995 5631

KEYWORDS: Monitoring, inundation, management, indicators, Murrumbidgee

Abstract

We propose a framework in which Thresholds of Potential Concern (TPCs) and Limits of Acceptable Change (LACs) are used in concert in the assessment of wetland condition and vulnerability, and apply the framework in a case study. The lower Murrumbidgee River floodplain (the 'Lowbidgee') is one of the most ecologically important wetlands in Australia and the focus of intense management intervention by State and Federal government agencies. We used a targeted management stakeholder workshop to identify key values that contribute to the ecological significance of the Lowbidgee floodplain, and identified LACs that, if crossed, would signify the loss of significance. We then used conceptual models linking the condition of these values (wetland vegetation communities, waterbirds, fish species and the endangered southern bell frog) to measurable threat indicators, for which we defined a management goal and a TPC. We applied this framework to data collected across 70 wetland "storages", or eco-hydrological units, at the peak of a prolonged drought (2008) and following extensive re-flooding (2010). At the suggestion of water and wetland mangers, indicators were neither aggregated nor integrated, but reported separately in a series of chloropleth maps. The resulting assessment clearly identified the effect of rewetting in restoring indicators within TPC in most cases, for most storages. The scale of assessment was useful in informing the targeted and timely management intervention, and provided a context for retaining and utilising monitoring information in an adaptive management context.

Introduction

The extent and condition of significant wetlands is intimately linked to the presence of water in the landscape, and therefore to the many ‘drivers’ of hydrological variability and change. This is nowhere more true than the large wetlands of semi-arid Australia, where variability of flow is high (Puckridge et al. 1998), and biota have adapted through millennia to boom-bust cycles in resource availability (Roshier et al. 2002; Bunn et al. 2006). The monitoring of wetland extent and condition is therefore a complex task easily confounded by high natural variability, and a lack of clarity over management and monitoring objectives (Saintilan and Imgraben 2012).

Thresholds are a fundamental concept in ecological resilience thinking. A critical threshold exists below which an ecosystem retains its capacity to absorb disturbance, recover and maintain its character and functions. If the threshold is crossed, the ecosystem may function in a different way, often with undesirable consequences, and the transition to a new ecosystem state may be permanent (Scheffer et al. 2001; Walker and Myers 2004). The parties to the Convention on Wetlands (Ramsar, Iran, 1971) have sought to incorporate natural variability in wetland extent and condition assessment through the concept of a “limit of acceptable change” (LAC); more recently referred to as “limits for defining change in ecological character” to differentiate it from a different concept of the same name in US recreational management usage (Ramsar Convention Secretariat 2011). Beyond the LAC notification should be made under Article 3.2 of the Convention that the ecological character of the wetland has changed as a result of modification (Ramsar Convention Secretariat 2010; Pittock et al. 2010).

However, a range of other management triggers, such as Thresholds of Potential Concern (TPC) may also be used, as has been applied to the adaptive management of Kruger National Park. The TPC has been defined by Biggs and Rogers (2003) as a multi-dimensional envelope within which the variation of the ecosystem is acceptable to both scientists and managers. Rates of movement towards or away from thresholds give an indication of how the ecosystem is tracking in relation to its resilience characteristics and undesirable change. The TPC has become a unifying concept in the adaptive management of Kruger National Park, set in the context of a hierarchy of objectives relating clearly to goals set for its management (Biggs and Rogers 2003; K. H. Rogers and Biggs 1999; Kingsford et al. 2011).

In this paper we outline how LACs and TPCs might be used in concert as an aid to effective management of a large wetland complex, and we apply this framework to the monitoring of extent and condition in the Lowbidgee wetland, one of the most significant wetlands in Australia. We illustrate how LACs and TPCs can be used for different but complimentary roles in triggering management intervention for the preservation of wetland values.

Within the proposed framework, the LAC establishes that the ecological character of the wetland has changed in relation to one or more key wetland values. The purpose of the LAC is to trigger the notification of this changing ecological character to a high management level (e.g. State, National or International) so that additional higher-level management intervention may occur. The LAC is essentially a social construct, and is best defined by local asset managers with delegated authority for the management of the wetland values. These managers are in the best position to identify the values identified for the wetland by the community and their agency, and the points at which change to these values has become unacceptable to the community charging them with responsibility for asset management. In some cases the LAC might relate to a biological threshold, but may not in all cases. For example, identification of the exceedance of a biologically defined critical threshold cannot be identified for a stand of river red gum (*Eucalyptus camaldulensis*) that is undergoing incremental decline; however a LAC still needs to be established.

The purpose of the TPC is to trigger management intervention at a more local scale than the entire wetland, within existing management regimes and using locally available management options or actions (levers). For example, a TPC might flag the need to water a particular asset within the wetland using available water, while crossing an LAC would indicate that the water planning regime is failing the wetland. The TPC implies movement beyond a threshold or a change from one condition or risk state to another. For example, the TPC for maximum inter-flood dry-period may be crossed for a vegetation class, or vegetation may transition from one class to another on a part of the floodplain. Such changes will occur incrementally across the floodplain. This contrasts with the LAC, which might define the proportion of the asset for which such a change might be acceptable (e.g. 30% of the total extent of the asset transitioning from one state to another).

TPCs may not always be a measure of the status of the key asset or value being managed. Often the TPC will be a measure of a threat variable relating to the asset or value goal identified through a conceptual model developed for the wetland. For example, the value of a viable southern bell frog (*Litoria raniformis*) population will be influenced by a range of threat variables, such as carp numbers within floodplain waterholes, the health of aquatic vegetation within the wetland, connectivity between southern bell frog habitats across the floodplain, duration of flooding, inter-flood period, and the timing of flooding. While vegetation health, carp populations and habitat connectivity represent threat variables for the southern bell frog, it is important to note that each also represents a response variable to altered flow and constitutes a potential TPC in its own right. The TPC provides a basis for reporting on trends in these indicators and whether they have crossed thresholds of concern, but does not draw any direct or predictive relationship with the LAC, which might in this case be the loss of bell frog from the Lowbidgee or a reduction in numbers and their confinement to a key refuge. However, TPCs should prompt management intervention, such as the construction of carp exclusion structures, the watering of specific waterholes and refugia, or the exclusion of grazing to protect or restore wetland aquatic vegetation.

It is envisaged, therefore that there would be many more TPCs than LACs covering a greater range of indicators and that these would be quantitatively defined where possible, and biologically or geomorphologically meaningful (in the sense that thresholds are, where possible, not arbitrary but defined by physical thresholds of ecosystem resilience).

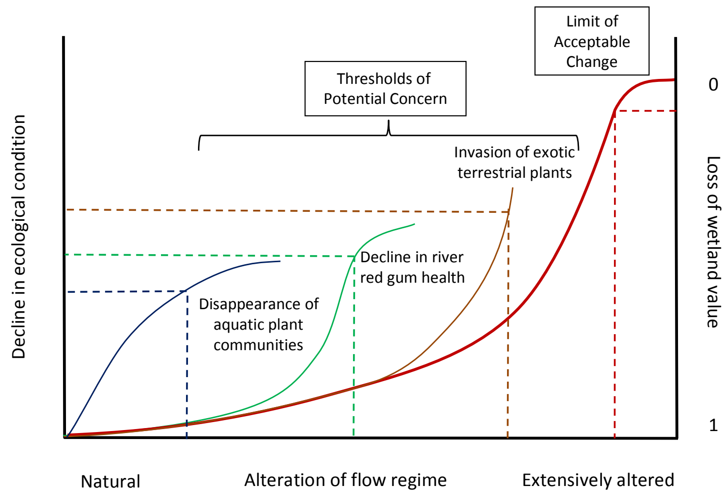


Figure 1. Relationship between a limit of acceptable change (right hand *y* axis) for a wetland value (where 1 = a healthy wetland and 0 = loss of a wetland value) and thresholds of potential concern in relation to ecological condition (left hand *y* axis) with respect to specific management targets, driven by changes in flow (*x* axis). Note each threshold has a different trajectory of change.

The “Lowbidgee”, a large wetland complex near the confluence of the Murrumbidgee and Murray Rivers in New South Wales, is a data-rich environment within which to test the utility of LAC and TPC application to wetland and water management. The Lowbidgee was the focus of a concerted science and management investment under the Rivers Environmental Restoration Program (Alexander et al. 2009) between 2008 and 2010 and the Commonwealth Environmental Research Facilities (Baldwin 2011). As a result, the wetland values and management goals within the Lowbidgee have been clearly articulated, conceptual models of the relationship between wetland values, threats and management actions have been developed (Li Wen et al. 2009; Spencer et al. 2010; L. Wen et al. 2011), and extensive surveys made of inundation history, vegetation extent and condition, and faunal and ecosystem function responses to environmental flows (Spencer and Wassens 2010; Li Wen et al. 2011a; Li Wen et al. 2011b; L. Wen et al. 2011; Baldwin et al. in press).

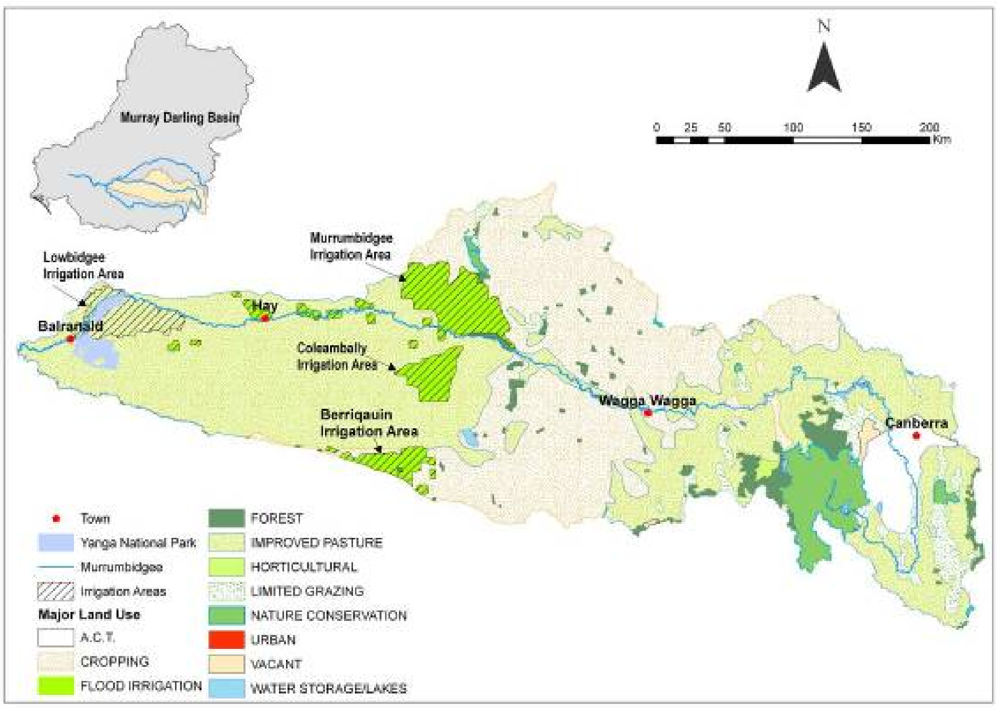
In this paper we test this proposed monitoring framework for the Lowbidgee wetland, for assets and thresholds identified in collaboration with water and wetland managers, and using data derived from the Rivers Environmental Restoration Program. The selection of the Lowbidgee wetland complex for the case-study is intended to highlight key datasets that might be usefully applied to values-based assessments.

Methods

Study Site

The Murrumbidgee catchment is the fourth largest in Australia's largest river basin, the Murray-Darling Basin, and drains an area exceeding 84 000 km^2 (Figure 2). The catchment consists of 6749 km of streams including about 1500 km of the Murrumbidgee River, which is regarded as the main channel.

Figure 2: Murrumbidgee catchment and Lowbidgee floodplain



The Lowbidgee floodplain is the largest area of floodplain wetland remaining in the Murrumbidgee Valley, and includes one of the largest contiguous river red gum forests in Australia, as well as significant black box (*Eucalyptus largiflorens*), lignum (*Muehlenbeckia florulenta*) and reed-bed communities (Eastburn 2003, cited in Sinclair Knight Mertz 2011). The wetlands also include 15 000 ha of common reed *Phragmites australis*, cumbungi *Typha* spp., rushes *Eleocharis* spp. and *Juncus* spp.

(Macgrath 1992). The Lowbidgee has been identified as a nationally important wetland (Environment Australia 2001), in part because it covers a large area (217 000 ha) and is strategically placed for the provision of ecosystem services to the Murray-Darling Basin, but also because it is regionally significant for waterbirds, both as a drought refuge and as breeding habitat.

Under natural conditions the Lowbidgee wetlands experienced regular inundation by floodwaters from the Murrumbidgee River, driven by reliable winter and spring rainfall and snow melt (Kingsford and Thomas 2004). Channel capacity within the Lowbidgee floodplain was low and comprised a complex system of interconnected creeks flowing east to west including Fiddlers, Uara, Caira, Nimmie, Pollen, Waugorah, Talpee, Monkem, Kietta, Yanga, and Paika Creeks (Kingsford and Thomas 2004). Flooding occurred on average every two to three years, although there were years where the river achieved bankfull conditions without overflowing onto the floodplain (Eastburn 2003, cited in Sinclair Knight Mertz 2011; L. Wen 2009). Flood events were also known to ‘cluster’, whereby the system would experience two or three floods in quick succession followed by a drier period.

The Lowbidgee, in particular the Nimmie-Caira system, is one of the most significant wetland habitats for waterbirds in eastern Australia. Sixty species of waterbirds have been recorded on the Lowbidgee floodplain and 41 of these are known to breed in the Lowbidgee wetland (Kingsford and Thomas 2001). The area contains nationally important breeding colonies of Australian white ibis (*Threskiornis molucca*), glossy ibis (*Threskiornis falcinellus*), straw-necked ibis (*Threskiornis spinicollis*), royal spoonbill (*Platalea regia*), great egret (*Ardea alba*), and intermediate egret (*Ardea intermedia*). Annual bird surveys conducted by the New South Wales National Parks and Wildlife Service (NPWS) monitor the 13 rookeries in the Lowbidgee system. The most significant of these occur at Avalon Swamp, Telephone Bank, Eulimbah and Suicide Bank, although all may be utilised during optimum conditions in the September to November breeding season. A total of 58 000 ML of water is required in the Nimmie-Caira system to provide stable water in rookeries during the bird breeding season (Kneebone et al. 2000). The minimum required duration of flooding to support successful breeding for many waterbirds is approximately 4-7 months (K. Rogers

2011). The wetlands also provide important habitat for fish, frogs (including the endangered southern bell frog) and macroinvertebrates.

Studies have shown that inland wetlands are most productive when flooding follows a period of complete drying. Under natural conditions the entire Lowbidgee system was ephemeral, with the channel, riparian zone and floodplain each linked in a wetting and drying regime that supported a diverse ‘boom and bust’ ecology typical of inland river systems in Australia (Bunn et al. 2006; Kingsford et al. 1999). Accordingly, under natural conditions water levels in the Lowbidgee would have been highly variable.

The extent of the Lowbidgee wetlands has significantly decreased in recent decades due to flow regime changes in the regulated Murrumbidgee River (Frazier and Page 2006; Li Wen et al. 2011a) and conversion of wetland floodplain into irrigated cropland. The flow regime of the Lowbidgee floodplain was ranked 6th most altered of 40 floodplains in the Murray-Darling Basin (Sims et al. 2012). Conversion of wetland into cropland within the former Yanga Station and in the wider Lowbidgee floodplain has involved the construction of extensive channels and embankments throughout the wetlands and large supplementary licence water storages. These threaten the health of the remaining wetlands, such as the Yanga Nature Reserve, which are adversely affected by the change in the distribution of flows and reduced flood volumes (Kingsford and Thomas 2004). The current extended drought has exacerbated the effects of river regulation placing greater environmental stress on water dependent ecosystems. River red gum communities in particular, were subject to significant water stress during the ‘Millennium Drought’ of 2000-2009 (Li Wen et al. 2009).

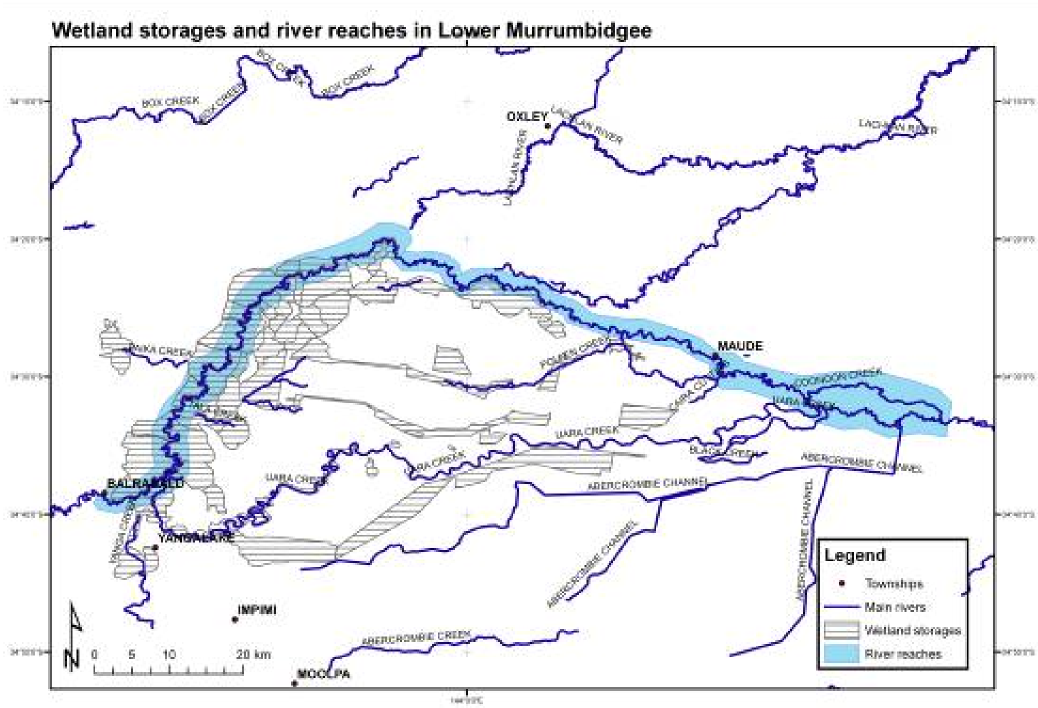


Figure 3: Aquatic ecosystems of the Lowbidgee; these include the 60 reporting locations identified in the LYNC DSS, 10 additional wetlands located in the southern and western regions of the Lowbidgee and three river reaches.

Identification of Assets and Indicators

Several management agencies have an interest in the management of the Lowbidgee wetland. The lead nature conservation agency in NSW is the Office of Environment and Heritage (OEH), and relevant divisions include the National Parks and Wildlife Service, the Environmental Regulation and Protection Group (leading environmental water management in the lower Murrumbidgee) and the Programs and Policy Group (formulating water and wetland policy within OEH). In addition to OEH, the NSW Office of Water manages water planning within the state and monitors the environmental outcomes of water delivered to the environment under these plans. The Federal government also has a role in the management of water and the protection of wetlands within the Murrumbidgee catchment, through the Murray-Darling Basin Authority, the Commonwealth Environmental Water Office.

Key representatives of all relevant State and Federal agencies assembled for a workshop in which key environmental values of the Lowbidgee wetland were identified, LACs defined, and TPCs discussed with the aid of conceptual models linking threats to values. The values identified for the Lowbidgee floodplain were related back to nationally agreed values for High Conservation Aquatic Ecosystems (HCVAE) developed under the auspices of the national inter-jurisdictional Aquatic Ecosystem Task Group (Sinclair Knight Mertz 2007). The criteria are similar to those developed for Ramsar assessment, and the four value criteria relevant to the Lowbidgee floodplain were: Vital Habitat; Representativeness; Distinctiveness; and Diversity, as documented in Table 1.

Table 1: Ecological values identified for the Lowbidgee floodplain as relevant to HEVAE Criteria

HCVAE Criterion/Value	**Services**
Vital Habitat	Supports 50 000+ breeding pairs of waterbirds in favourable hydrological conditions
Representativeness	Supports third largest contiguous RRG forest/woodland in Australia at 45 000 ha
Distinctiveness	Supports the threatened species, such as southern bell frog, and is especially important as critical drought refuge
Diversity	Supports extensive area and diversity of wetland habitat including spike-rush, river red gum forest and woodland, black box woodland, lignum shrubland Supports diversity of wetland fauna including waterbirds, fish, amphibians and invertebrates

Of the vegetation communities, the steering group agreed that river red gum forest, river red gum woodland, black box woodland, lignum and tall spike rush (*Eleocharis sphacelata*) are integral components of the vegetation that relate to the values of the HCVAE of the Lowbidgee. Vegetation communities contribute to the distinctiveness of the Lowbidgee floodplain and provide outstanding representation of semi-arid floodplain wetland vegetation. The river red gum forest is the third-largest contiguous forest in the Murray-Darling Basin, and each of the vegetation communities provides important habitat for biota occupying the floodplain.

Several threatened and endangered species are found within the Lowbidgee floodplain, and the southern bell frog was chosen as a target species for conservation actions and monitoring. The southern bell frog was once widespread and abundant throughout southeastern Australia (Wassens et al. 2008). Over the last three decades, its population and distribution has reduced to a critical level (Lunney et al. 2000) and for this reason it is listed as endangered on the schedule of the NSW *Threatened Species Conservation Act* (1995).

In the past the Lowbidgee has regularly supported more than 50 000 waterbirds and sometimes more than 100 000 waterbirds, including some of the largest breeding colonies of straw-necked ibis in Australia (Kingsford and Thomas 2001; Department of Water Resources 1994; Wetlandcare Australia 2008). Of these, egrets, including the great egret, eastern great egret (*Ardea modesta*), intermediate egret and the little egret (*Egretta garzetta*); and ibis, including the glossy ibis, Australian white ibis and straw-necked ibis, were selected as indicator species representing different guilds of waterbirds important to the Lowbidgee floodplain.

Two fish species were selected as indicator species for fish management goals; unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*) and the Murray cod (*Maccullochella peelii peelii*). Unspecked hardyhead is regarded as a wetland specialist, tending to spawn and recruit in anabranches, billabongs and floodplain wetlands, although the species may also spawn in riverine settings (Ralph et al. 2011). The Murray cod is a large, long-lived fish that is regarded as a main channel specialist as it tends to spawn and recruit during high or low flows in the main channel. While they do not require floods to stimulate spawning, large floods may enhance recruitment due to an increase in food availability (King et al. 2003).

Identification of TPCs and LACs

TPCs in our framework are based on the status of both the asset being managed and known threats to the condition of the asset. To develop these, conceptual models were required which linked the condition of indicator biota to known threats in the Lowbidgee landscape. The example of the waterbird conceptual models is shown in Figure 4. Once relevant threats had been identified, the working group was able to determine management goals for each, and levels of threat or thresholds of condition that would precipitate a local management response. These are represented in Table 2.

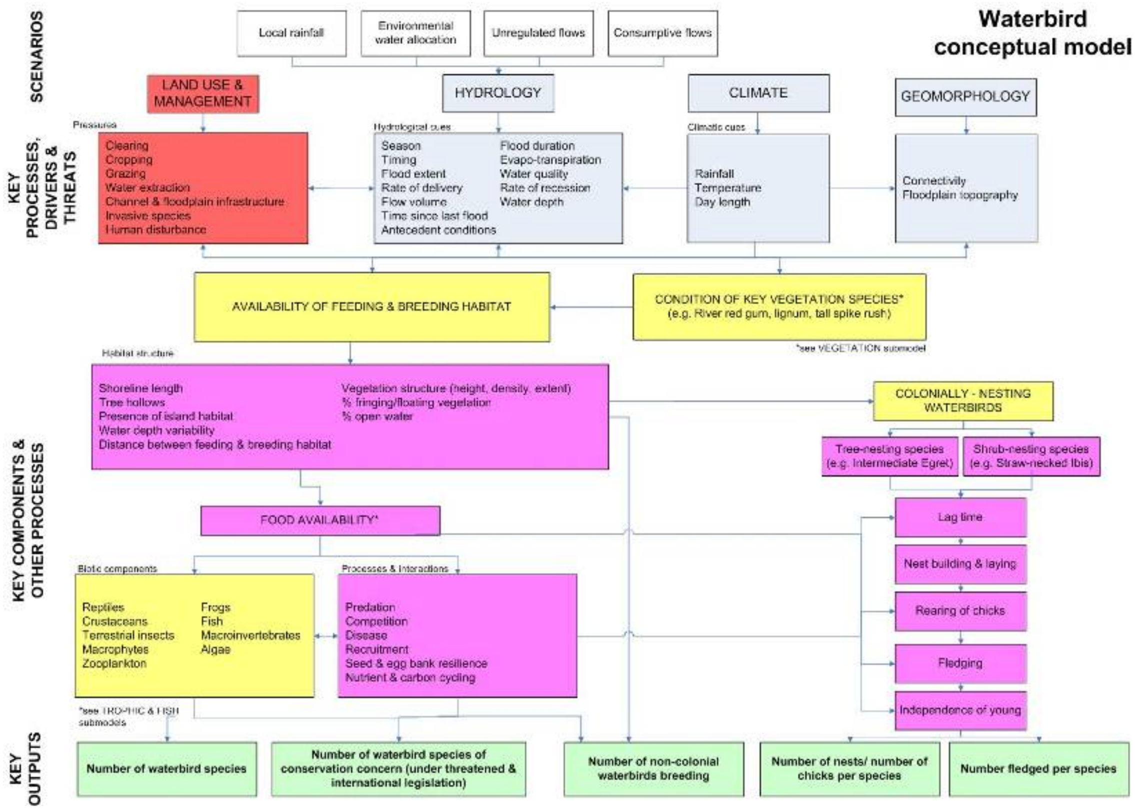


Figure 4: A conceptual model linking threats to the condition of waterbirds within the Lowbidgee floodplain. Similar conceptual models were developed for vegetation, frog and fish condition as a guide to the development of thresholds of potential concern.

Table 2: Thresholds of potential concern for critical components and indicators that relate to ecological values of the Lowbidgee.

Selected value/ component	Threat/condition indicator	Threshold of Potential Concern	Goal
Diversity/ Threatened species - Southern bell frog (SBR)	Sites with Frogs/tadpoles	Found in less than10 sites across the Lowbidgee	Found in 40 sites across the Lowbidgee
	Carp numbers	Carp in most sampled SBF sites	Carp in less than 10% of sampled sites
	Loss of Aquatic vegetation	Notable thinning of submerged vegetation at SBF locations	All sites containing submerged aquatic veg
	Lack of Flooding	Increase in inter-flood period of key bell frog habitat to greater than 2 years	Annual watering of key bell frog habitat
Uniqueness/River Red Gum (RRG) forest-woodland	Loss of Flooding Frequency	Maximum recommended inter-flood period exceeded in RRG forest or woodland storage	Optimal inter-flood period in all RRG storages
	Decline in crown condition	Change in crown condition category across storage	Good or moderate crown condition in all storages

	Too frequent flooding	Exceeding maximum recommended flooding duration/frequency in forest or woodland storage	Optimal inter-flood period and duration in all RRG storages
	Clearance	Loss of RRG forest or woodland to land clearance	No loss of RRG forest or woodland to land clearance
Diversity/ Waterbirds - Ibis egrets	Loss of rookery sites	Clearing of lignum shrubland anywhere on the floodplain	Restoration of lignum shrubland
		Decline in condition class of RRG or Lignum in more than 20% of rookery storages	All RRG and Lignum in known rookeries in good condition class
	Alteration to hydrology	Rookery sites not flooded for sufficient depth/duration during suitable climatic conditions	All rookery sites flooded to suitable depth/duration in moderate and wet years
	Numbers of waterbirds	Less than 30 000 pairs in conditions suitable for major event	More than 50 000 breeding pairs in conditions suitable for a major event
		Less than 30 000 breeding pairs in 5 consecutive years	More than 30 000 breeding pairs one year in 3

For each of the values identified LACs were developed by the working group that, if triggered, would threaten the values for which the Lowbidgee floodplain is recognised as significant, and require management intervention beyond the authority of local officers and catchment management groups. These are presented in Table 3.

Table 3. Limits of Acceptable Change as they relate to key values of the Lowbidgee floodplain

HCVAE Criterion/Value	**Component or Process**	**Limit of Acceptable Change**
Vital Habitat	50 000+ breeding pairs of waterbirds in favourable hydrological conditions	Less than 30 000 breeding pairs in three consecutive events of suitable climatic conditions, co-incident with loss of suitable hydrological and/or vegetated habitat
Representativeness	Second largest stand of River Red Gum (RRG) forest and woodland in Australia at 45 000 ha	Loss of 7000 ha of RRG, ie loss of status as second largest stand.
Distinctiveness	Stronghold of the Southern Bell Frog, especially critical drought refuge	Reduction in distribution of mature frogs and tadpoles to 5 waterholes, threatening population viability
Diversity	Supports extensive area and diversity of wetland habitat including spike-rush, river red gum forest and woodland, blackbox woodland, lignum shrubland	Reduction in extent of spike-rush by 20% (measured post-flood against previous post-flood benchmarks). Reduction in RRG as above. Reduction in blackbox woodland and lignum shrubland by 20% each.

Identification of Relevant Datasets

The Lowbidgee floodplain was impacted by an extensive drought (2000-2009) which, in association with reduced river-flow resulting from water diversion (L. Wen et al. 2011) led to deterioration in the condition of many components of the floodplain (Li Wen et al. 2009; Spencer et al. 2010). The year 2008 represented the height of the drought and was chosen as an assessment year on that basis. The drought broke following good rains in summer 2010, resulting in extensive, natural overbank flooding of broad areas of the floodplain for the first time since 1993. The assessment was repeated for 2010 using post-flooding data. Data populating the 2008 and 2010 assessments were drawn from monitoring reports conducted under the Rivers Environmental Restoration Program (Alexander et al. 2009), and observations of regionally based water and wetland managers. Data-sources (Table 4) correspond to TPC indicators (Table 3) and included a combination of remotely sensed data on inundation and vegetation extent, and targeted field sampling.

Table 4: Sources of data used in the assessment of TPC and LAC

Component	Indicator	Source	
Southern bell frog	Southern bell frog presence/absence	2008	Spencer and Wassens (2009)
		2010	Spencer *et al.* (2010)
	Carp presence/absence	2008	Spencer and Wassens (2009)
		2010	Spencer *et al.* (2010)
	Aquatic vegetation cover	2008	Spencer and Wassens (2009)
		2010	Spencer *et al.* (2010)
	Feral animal population density	2008	No data
		2010	No data
	Area flooded	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011), Spencer *et al.* (2010)
River red gum	Change in river red gum area	2008	Bowen and Simpson (2010)
		2010	No data
	Maximum inter-flood period for river red gum forest	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011)
	Maximum inter-flood period for river red gum woodland	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011)
	River red gum crown condition	2008	Bowen and Simpson (2010)
		2010	No data
	Change in river red gum condition	2008	McCosker (2008), Bowen and Simpson (2010)
		2010	No data
	Maximum flood duration for river red gum	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011)
	Unmanaged clearance of river red gum	2008	James Maguire, *pers. comm.*
		2010	James Maguire, *pers. comm.*
Waterbirds	Loss of river red gum area	2008	McCosker (2008), Bowen and Simpson (2010)
		2010	No data
	Loss of lignum area	2008	McCosker (2008), Bowen and Simpson (2010)
		2010	No data

	Change in river red gum condition	2008	McCosker (2008), Bowen and Simpson (2010)
		2010	No data
	Flood conditions to support egret breeding	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011)
	Flood conditions to support ibis breeding	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011)
	Degree of waterbird breeding under suitable hydrological conditions	2008	Not suitable breeding conditions
		2010	James Maguire, *pers. comm.*
	Degree of waterbird breeding in previous 5 years	2008	Kingsford *et al.* (2008)
		2010	James Maguire, *pers. comm.*
	Area flooded	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011), Spencer *et al.* (2010)
Vegetation	Maximum inter-flood period for lignum	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011)
	Ideal flood frequency for tall spike rush	2008	Sinclair Knight Mertz (2011)
		2010	Sinclair Knight Mertz (2011)
	Change in black box woodland area	2008	McCosker (2008), Bowen and Simpson (2010)
		2010	No data
	Change in lignum area	2008	McCosker (2008), Bowen and Simpson (2010)
		2010	No data
	Change in tall spike rush area	2008	McCosker (2008), Bowen and Simpson (2010)
		2010	No data
Fish	Fish kill associated with black water	2008	No data
		2010	Observations
	Golden perch presence/absence	2008	Spencer and Wassens (2009)
		2010	Spencer *et al.* (2010)
	Carp presence/absence	2008	Spencer and Wassens (2009)
		2010	Spencer *et al.* (2010)

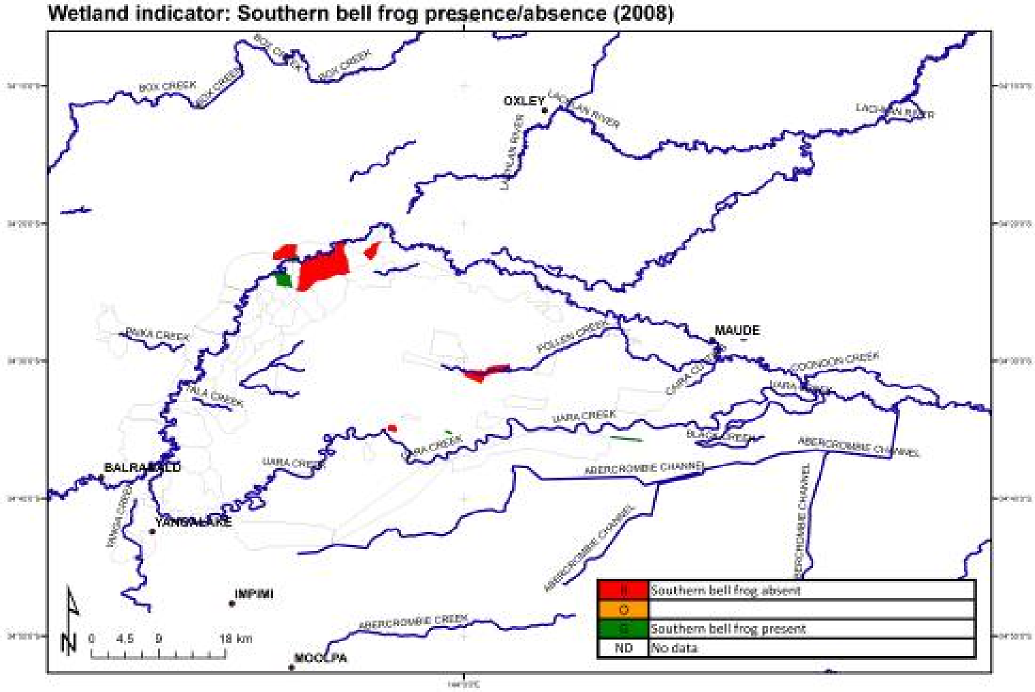
For each TPC and LAC, a chloropleth “traffic light” map was produced and scored the status of the indicator in each relevant storage represented in Figure 2. On advice from local water and wetland managers, no attempt was made to integrate indices or TPCs. Water and wetland managers felt that the disaggregated information provided them with a clearer context within which to make management decisions.

Results

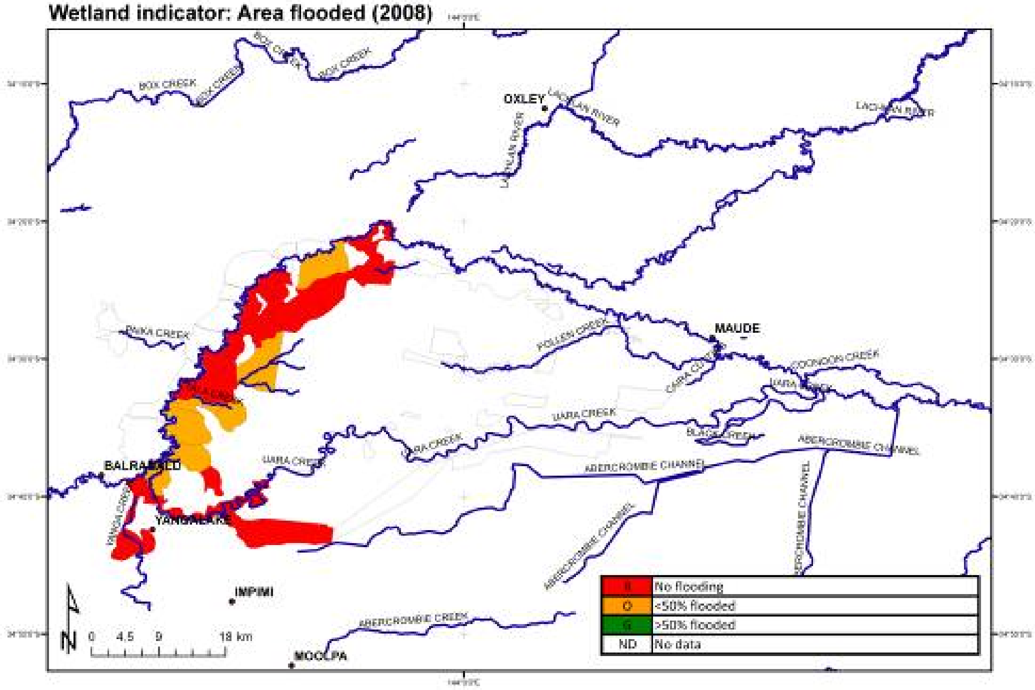
A total of 50 TPC maps were produced for the wetland and riverine components of the Lowbidgee floodplain for each year (2008 and 2010). Figure 5 a-h provides the example of TPC indicators for the southern bell frog across the two years. The southern bell frog is an interesting example in that the species was the only asset chosen that triggered the LAC in 2008, by decreasing to less than 5 sites across the floodplain. All TPCs were triggered at most southern bell frog sites, including carp infestation, the absence or thinning of aquatic weeds and low inundation extent and frequency. Widespread rainfall and flooding in 2010 alleviated TPCs in most sites, and expanded the population beyond the LAC trigger value. However, flooding also led to the breeding of the introduced European carp on the floodplain, which remained a concern and important management consideration.

Figure 5: Status of Thresholds of Potential Concern for the southern bell frog across the Lowbidgee floodplain in 2008 (a-d) and 2010 (e-h)

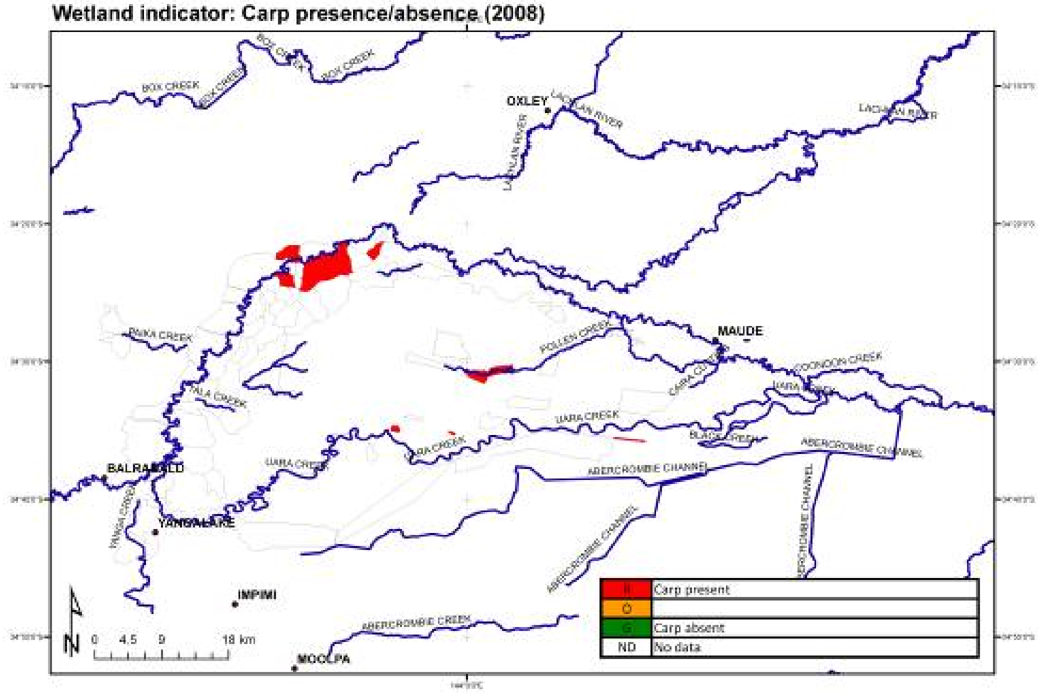
Wetland indicator: Southern bell frog presence/absence (2008)



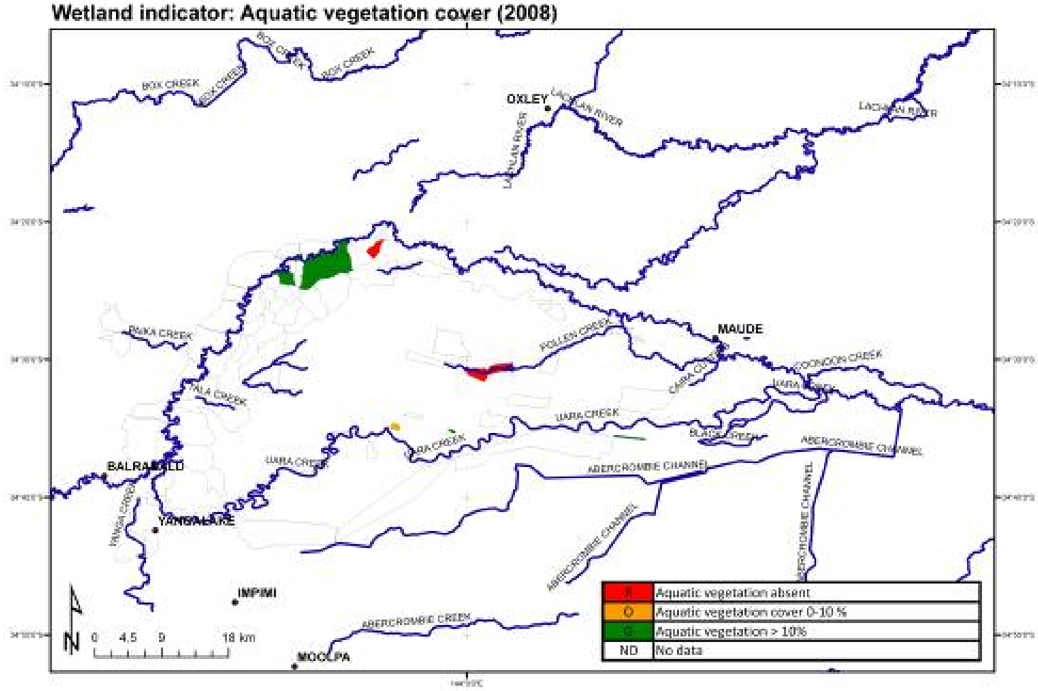
Wetland indicator: Area flooded (2008)



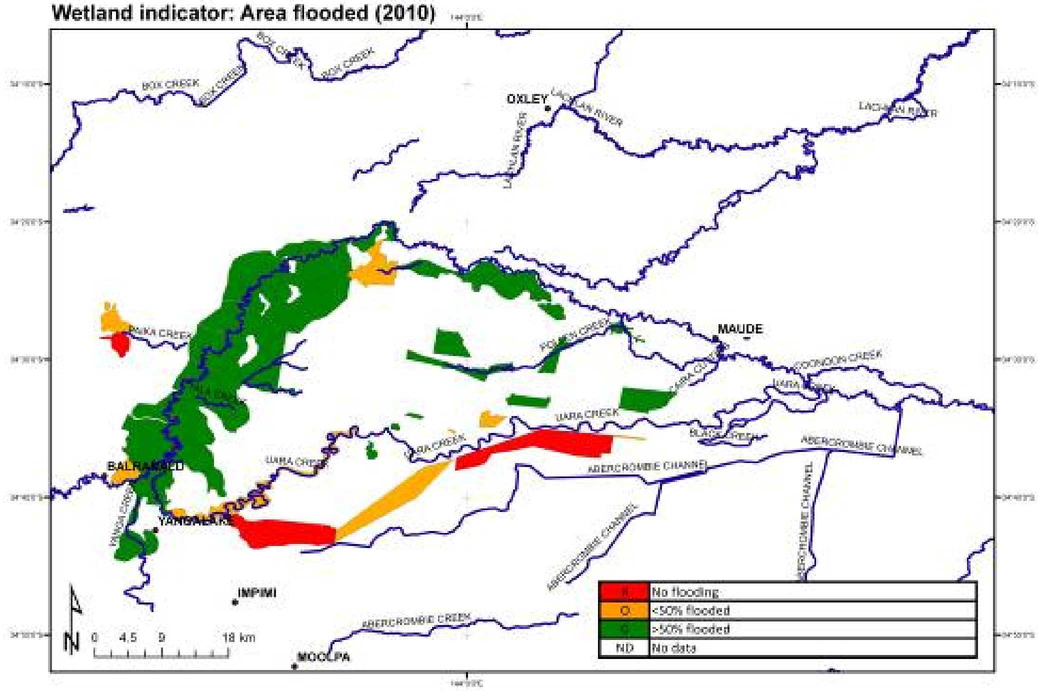
Wetland indicator: Carp presence/absence (2008)



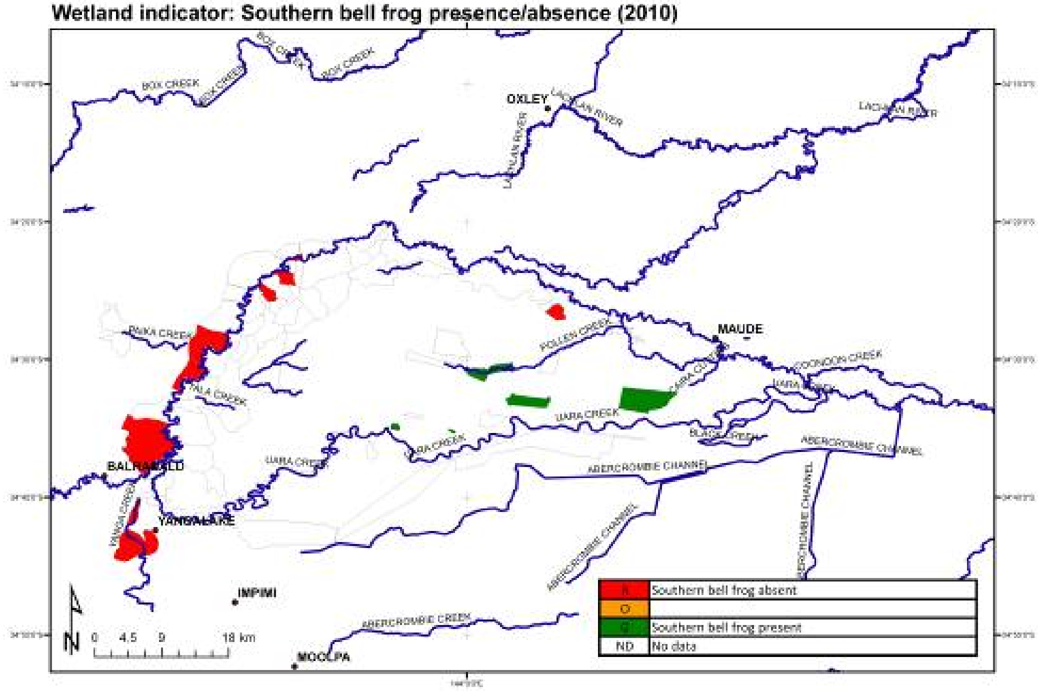
Wetland indicator: Aquatic vegetation cover (2008)



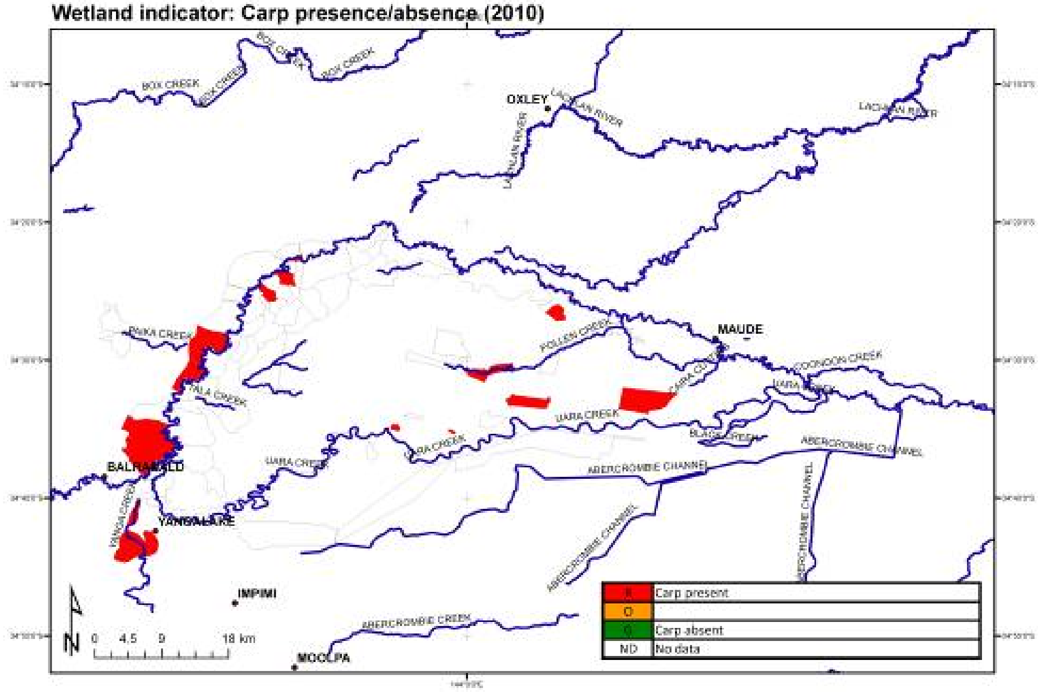
Wetland indicator: Area flooded (2010)



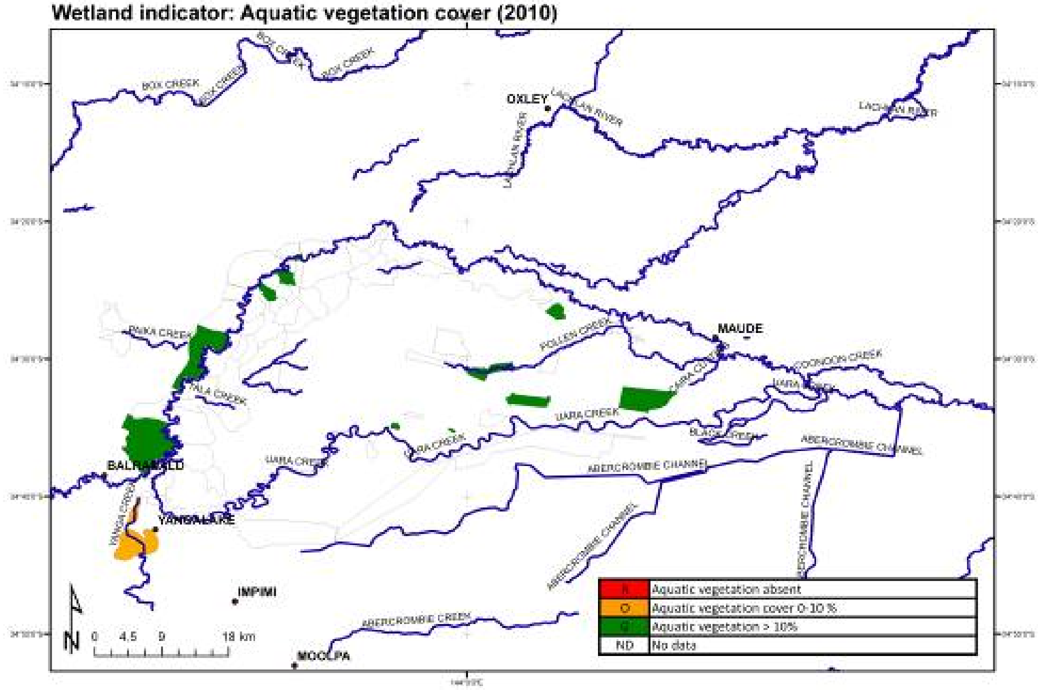
Wetland indicator: Southern bell frog presence/absence (2010)



Wetland indicator: Carp presence/absence (2010)



Wetland indicator: Aquatic vegetation cover (2010)



Flooding in 2010 inundated 62 of the 70 wetland “storages” to more than 50%, and only three storages received no flooding. This large-scale watering event restored condition within TPCs for all vegetation communities with the exception of tall spike rush, which, though flooded, needed follow-up flooding to bring inundation frequency within the TPC in the 5-year minimum requirement. More than 30 000 breeding pairs of waterbirds were observed in the spring-summer season, demonstrating the capacity for recovery in waterbird breeding following prolonged drought and confirming that the waterbird LAC had not been crossed in spite of several consecutive years with no major breeding event. However, waterbird TPCs were still triggered, with flooding duration insufficient to support ibis breeding in all but two storages.

Native fish fared less well as a result of flooding. Inundation of floodplains in the lower Murrumbidgee in 2010 had the unintended consequence of return flows depleted in oxygen (blackwater events) which led to extensive fish kills in the lower Murrumbidgee and Murray Rivers, triggering a TPC for Murray cod. European carp numbers exploded across most floodplain storages, though this did not prevent the native species also expanding their range across the floodplain.

Discussion

The approach we have taken to wetland condition assessment is linked directly to values identified by water and wetland managers in the Lowbidgee as contributing to the high ecological value of the site. We identified links between values and threats for each of these values using conceptual models representing best available science, a process supported by detailed ecological investigations into the Lowbidgee wetland conducted under the Rivers Environmental Restoration Program (2007-2010). Using these values and associated indicators, we developed LACs and TPCs in collaboration with the relevant water and wetland managers from State and Federal government agencies, and produced report cards documenting where TPCs had been exceeded for each of the indicators identified for the wetland values.

Our approach was useful in providing a geographic representation that highlights the variability in condition between storages. We did not seek to create summary indices of trends or aggregate scores across storages. This was in response to feedback from managers who believed that combining scores would be too coarse-scaled, obscuring the links between indicators and threats. Our approach focusses on targeted management intervention and requires an appropriate level of granularity, represented by the indicators and components of TPCs at the scale of individual storages within the wetland and an event-based reporting timeframe. In this regard it is similar to that described for river adaptive management in Kruger National Park (McLoughlin et al.

2011) but differs from assessments designed primarily to report on condition and trend (but that do not trigger specific management intervention) that integrate scores across several habitats, ecosystems, and spatial and temporal scales (e.g. Davies et al. 2010; State of the Environment Committee 2011).

One of the major challenges facing wetland managers is to reconcile human values-based assessments of what constitutes healthy riverine and floodplain ecosystems with the biophysical reality that underpins ecosystem function, integrity and resilience. Choices of indicators may be subject to personal bias, and technical and knowledge constraints (Boulton 1999). It may be hard to define whether and where real thresholds exist. In the setting of TPCs there is a perception of an underlying tension between accommodating social preferences and constructs alongside what are perceived as objective biophysical variables (Biggs et al. 2011). We would argue that an overlap between social preferences and what is biophysically desirable and sustainable is integral to the adaptive management of a wetland that is dependent for its health upon releases of environmental water from a regulated river system. Not only does this approach reflect the interconnectedness of social and biophysical factors in such a system but it also provides a holistic, inclusive and flexible framework for community engagement and empowerment of water managers (Kingsford et al. 2011).

The work reported here demonstrated the response of the Lowbidgee wetland to inflows during the 2010/11 watering season. The comparatively large December 2010 inflows led to an improvement in indices associated with flooding, though there were some negative outcomes, most notably the spread of carp through storages supporting southern bell-frog, and the fish kills along the main channel associated with a blackwater event. Some consideration will need to be given in further re-flooding events to the exclusion of carp from the floodplain, and methods for minimising or preventing the negative ecological effects of blackwater, especially during periods of high risk, such as following build-up of plant residues on the floodplain during prolonged drought (Whitworth et al. 2012).

We have demonstrated the importance of regular, detailed inundation mapping (conducted in 2008 and 2010), for the management of a major wetland. When combined with vegetation extent and condition mapping, the maps provide a broad coverage of indicators relevant to both LACs (for the vegetation communities) and TPCs for biota occupying the floodplain. The extent of inundation and time since previous inundation were critically important indicators for a range of biota and were the basis for many condition estimates. One significant information gap was the absence of 2010 vegetation condition mapping. A rolling program of image collection and mapping for the major wetland systems in the Murray-Darling Basin would be a key component of any wetland condition assessment program reporting on the values identified in this report. Incorporation into conceptual models and management plans of representative species as surrogates for the water requirements of a broader suite of wetland species is likely to lead to more inclusive adaptive management of environmental water (K. Rogers et al. 2012).

In conclusion, we propose that the LAC/TPC approach, when informed by site-specific conceptual models linking condition to threats, and applied across wetland mosaics and the landscape scale, provides a robust assessment framework easily interpretable by on-ground managers. This approach targets appropriate intervention at the appropriate time, and facilitates adaptive management as wetland responses to interventions are documented and used to refine our understanding of system resilience and appropriate thresholds of potential concern.

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