Technical report: Vegetation extent and condition mapping of the Gwydir Wetlands and floodplains 2008 - 2015

June 2019

NSW GOVERNMENT | Office of Environment & Heritage

Table of Contents
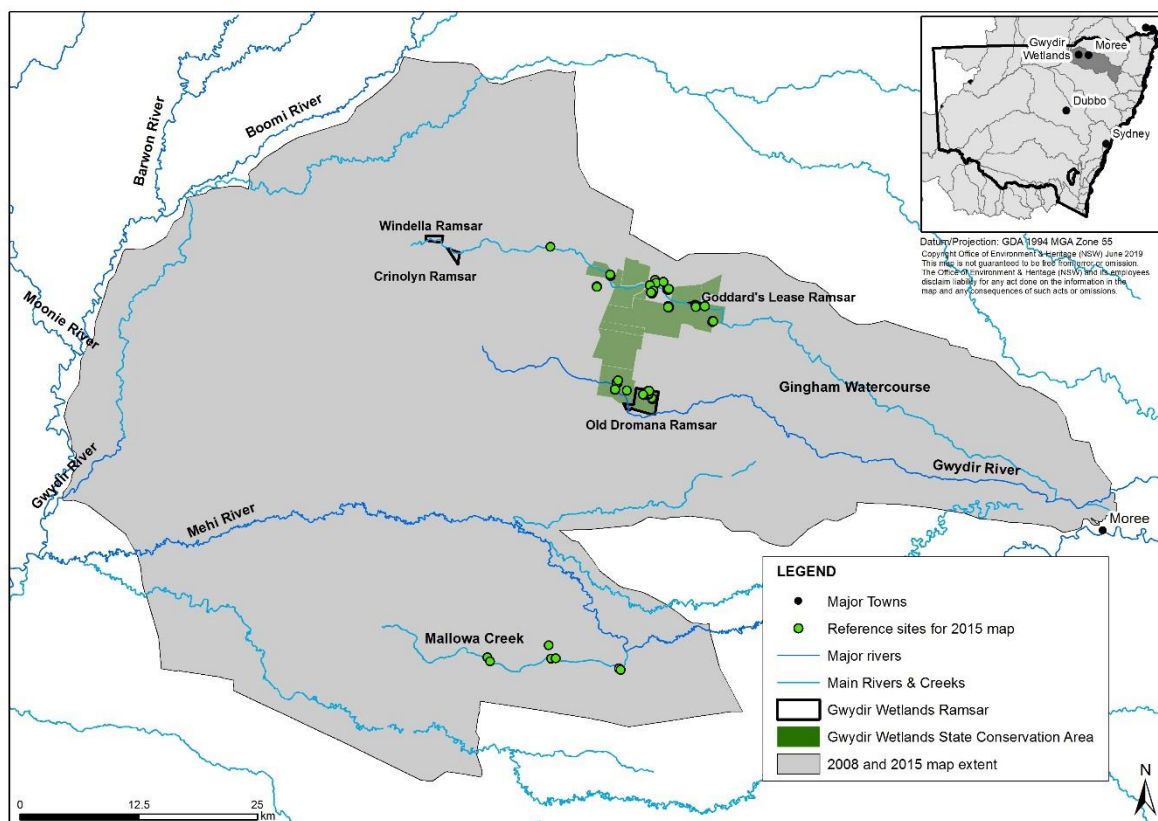
List of Tables

List of Figures

1. Background

1.1 Report purpose

This report is intended to accompany the Vegetation communities of the Gwydir Wetlands 2008 and 2015 mapping product (SEED Dataset VIS_ID 4686; https://datasets.seed.nsw.gov.au/dataset/vegetation-extent-and-condition-map-of-the-gwydir-wetlands-and-floodplain-2008-and-2015-vis_id-4686). The mapping product in the SEED Portal provides a map of the distribution and condition of vegetation communities in the Gwydir Wetlands from 2008 and 2015. This report details the mapping methodology and provides some examples of vegetation change during the mapped period. This report does not evaluate the effect of water delivery to the vegetation communities.

1.2 The Gwydir Wetlands

The Gwydir Wetlands are a complex floodplain wetland system located in the Gwydir River catchment approximately 60 km northwest of Moree in Northern NSW. The Gwydir Wetlands are serviced by major watercourses that make up the Gwydir River delta: the Gingham Watercourse, Lower Gwydir Watercourse and the Mehi River- Mallowa Creek–Moomin Creek System (Figure 1)). The Gwydir Wetlands have been recognised internationally as habitat for migratory waterbirds listed under international migratory bird treaties, and for their unique assemblages of wetland and floodplain plant communities. These plant communities include the endangered marsh-club rush (*Bolboschoenus fluviatilis*) sedgeland community and coolibah (*Eucalyptus coolabah*) – black box (*Eucalyptus largiflorens*) woodland communities. Parts of the Gwydir Wetlands are managed by NSW OEH as National Park estate (Gwydir Wetlands State Conservation Area, 7 400 hectares). The Gwydir Wetlands also include four privately owned areas listed as wetlands of international importance under the Ramsar Convention in 1999 (OEH 2018). The Ramsar site totals 823 hectares (ha) and is comprised of two areas within the Gwydir Wetlands State Conservation Area, namely "Old Dromana" on the Lower Gwydir, and "Goddard's Lease" on the Gingham Watercourse, and two further areas on the Gingham Watercourse, namely "Crinolyn" and "Windella" (**Figure 1**).

The Gwydir Wetlands are under ecological stress due to prolonged drought and changes in land and water management practices. Water resource development, including construction of Copeton Dam in the 1970s and the implementation of policies that encouraged production of irrigated crops on the floodplains, led to changes in the inundation regimes of these wetlands. The wetlands experienced rapid and widespread degradation over the next two decades (McCosker and Duggin 1993, Keyte 1994). Historic and contemporary agricultural land uses (grazing for cattle and sheep along with cereal and cotton cropping) of the Gwydir Wetlands (Anon 1999) have also affected their ecological integrity.

Figure 1 Gwydir Wetlands 2008 and 2015 map extent

1.3   Wetland and floodplain vegetation as indicators of wetland condition

Flood-dependent vegetation communities are plant communities that occur on floodplains, where the dominant species depend on moist conditions to complete their life cycle (DECCW 2010). Periodic mapping of the extent and condition of wetland and floodplain vegetation communities allows land and water managers to monitor vegetation response to conservation actions. The Basin-wide environmental watering strategy (MDBA 2014) advocates for an evidence-based prioritisation of the ecological condition of biological assets through monitoring. The mapping product described here provides one of several mechanisms to achieve this monitoring objective.

Hydrologic regime is a key variable influencing the structure and function of flood-dependent plant communities (Mitsch and Gosselink 2000). Water plants respond to patterns of water presence over time and their continued survival can provide an indication of the historical water regime, or the flow and availability of water in the site during the lifetime of the plants (Casanova 2011). Research has been conducted on the links between hydrology and plant community dynamics (Brander 1987, Bren 1988, Driver and Knight 2007, Thomas et al. 2010, Bino et al. 2015) and vegetation is a sensitive measure of anthropogenic impacts on wetland ecosystems (Rogers and Ralph 2011). Many human-related alterations to the environment that act to degrade wetland ecosystems cause shifts in plant community composition that can be quantified (Chesterfield 1986, Rogers and Ralph 2011).

Flood-dependent vegetation changes in response to hydrology: increased hydrological connectivity (increased inundation frequency and duration) drives structure and composition towards more flood-dependent species, while increased drying promotes establishment of

2

more terrestrial species (Thomas et al. 2010, Bino et al. 2015, Wassens et al. 2017). Changes are expected to be slow for communities dominated by long-lived woody species (e.g. River Red Gum, Black Box), compared to communities dominated by herbaceous species (e.g. Common Reed, Marsh Club Rush, Water Couch), where changes can occur relatively quickly (Bino et al. 2015). There are likely to be considerable ecological consequences when the natural flow regime is significantly disrupted by upstream river regulation and diversion of water resources for human uses (Kingsford 2000).

The current report acknowledges that wetland vegetation boundaries are in flux because they are dependent on seasonal and flood conditions (DLWC 2000). Mapped boundaries cannot be considered static over time.

2. Mapping methodology

2.1 Mapping vegetation community extent

Previous studies have examined the vegetation of the Gwydir Wetlands and floodplain (Keyte 1994, Torrible et al. 2009). McCosker and Duggin (1993) mapped vegetation communities using a sequence of historic aerial photographs. More recent vegetation mapping used colour air photo interpretation (API) (McCosker 1997, 2007). In 2008 the Gwydir Wetlands and floodplains were mapped under the NSW Wetland Recovery Program (Bowen and Simpson 2010a, b, DECCW 2011). The spatial extent of vegetation communities in 2008 was delineated by manual aerial photo interpretation (API) of high-resolution (30 cm) digital colour aerial photographs captured in June and July 2008. Field surveys were conducted to provide a reference for the interpretation of mapping units, verify their extent and to quantitatively assess condition. The spatial extent of the map product matched the area of the revised (McCosker 2007) vegetation community map (Bowen and Simpson 2010a).

In 2015, the same area was re-mapped using manual API of high-resolution (50 cm) ADS40 digital colour aerial photographs captured in September 2015 and on ground survey data collected in October 2015 (**Figure 1**), using the same methods as 2008 (Bowen and Simpson 2010a, Bowen 2016). Co-incident georeferenced on-ground survey data, stored in the NSW OEH Vegetation Information System (VIS) Flora Module, were analysed for vegetation type and condition.

Vegetation community mapping units in the two most recent maps (2008 and 2015) were converted to NSW OEH Plant Community Types (PCTs) identified in the NSW OEH (VIS) Classification Module (OEH 2017) . Within the NSW VIS, a PCT is based on structural-growth form (physiognomic) systems (Specht 1970, Walker and Hopkins 1990) and the floristic composition following the vegetation classifications of Benson (2006) and Keith (2004). Descriptions of these PCTs are contained in the NSW OEH VIS Classification (OEH 2017).

Bowen and Simpson (2010b) defined several Hydro-ecological Functional Groups (HFGs) as a floodplain-specific classification system for the PCTs mapped in the Macquarie Marshes. HFGs are based on the structure, watering and life history requirements of the dominant species in the vegetation community and may be similarly classified in the Gwydir Wetlands (Roberts and Marston 2011). All mapped PCTS were assigned to HFGs listed in **Table 1** to provide a higher order grouping for comparing changes in extent and condition. Land use types that were not vegetation communities and PCTs with a cultivated understorey were allocated to

a "cleared" map unit. HFGs were allocated for illustrative purposes in this report and are not a designated field in the map product.

For this study we compared the total areas of the mapped HFGs and PCTs in the Gwydir Wetlands at two points in time (2008 and 2015) to address differences in the extent and condition of flood-dependent and floodplain vegetation communities.

Table 1 Hydro-ecological Functional Groups (HFG) and their corresponding Plant Community Types (PCT) (Bowen and Simpson 2010a)

Hydro-ecological Functional Group / Map Unit	Plant Community Type ID no.	Plant Community Type name
Non-woody wetland (Formerly semi-permanent wetland)	181	Common Reed – Bushy groundsel aquatic tall grassland of inland river systems
	181 & 205	Marsh Club-Rush very tall sedgeland/Common Reed–Bushy groundsel aquatic tall grassland
	182	Cumbungi rushland of shallow semi-permanent water bodies of the inland river systems
	182 & 205	Cumbungi rushland of shallow semi-permanent water bodies/Marsh Club-Rush very tall sedgeland
	182 & 53	Shallow freshwater wetland sedgeland/Cumbungi rushland
	204	Water Couch marsh grassland of frequently flooded inland watercourses
	205	Marsh Club-Rush very tall sedgeland of inland river systems
	238	Permanent and semi-permanent freshwater lakes of inland slopes and plains
	53	Shallow freshwater wetland sedgeland in depressions on inland alluvial plains and floodplains
	Channel	Channel
	Flowpath	Cultivated land
River Red Gum	36	River Red Gum open forest of the Darling Riverine Plains (DRP) Bioregion
	36a	River Red Gum woodland of the DRP
Flood-dependent shrubland wetland	241	River Cooba swamp/Lignum shrubland on regularly flooded alluvial clay depressions in BBS (Brigalow Belt South) and DRP
	247	Lignum shrubland on regularly flooded alluvial clay depressions in BBS and DRP
Flood-dependent woodland	37	Black Box woodlands on floodplains of the NSW central and northern wheatbelt including the DRP
	40	Coolibah open woodland with chenopod grassy ground cover on grey and brown clay floodplains
	39	Coolibah - River Coobah - Lignum woodland wetland of frequently flooded floodplains mainly in the DRP
Non flood-dependent floodplain vegetation	27	Weeping Myall open woodland of the DRP and Brigalow Belt South (BBS) Bioregion
	35	Brigalow - Belah open forest / woodland BBS
	49	Windmill Grass – copperburr alluvial plains shrubby partly derived grassland of the DRP and BBS
	55	Belah woodland on alluvial plains in the central wheatbelt of NSW
	71	Carbeen - White Cypress Pine - River Red Gum - bloodwood tall woodland on sandy loam alluvial and eolian soils in the northern BBS and DRP
	98	Poplar Box/White Cypress/Budda/Wilga shrubby woodland on sandy loam soils mainly of the NW plains

Hydro-ecological Functional Group / Map Unit	Plant Community Type ID no.	Plant Community Type name
	144	Leopardwood low woodland mainly on clayey soils in the semi-arid zone
	206	Dirty Gum,White Cypress Pine tall woodland of alluvial sandy lenses (sand monkeys) mainly of the DRP
	214	Native Millet – Cup Grass grassland of the DRP
	378	Belah - Wilga +/- White Box dry viney scrub woodland the NSW Brigalow Belt South Bioregion
Cleared	Cleared	Cleared land
	Cultivated land	Cultivated land
	Cultivated – Irrigation	Cultivated - land developed for irrigation
	Water storage	Irrigation water storage reservoir
	Dam	Water storage
	Rural infrastructure	Rural infrastructure
	Flowpath	Cultivated land
	27 – cultivated	Cultivated land - Weeping Myall open woodland
	37 - cultivated	Cultivated land - Black Box woodland wetland
	39 - cultivated	Cultivated land- Coolabah - River Coobah - Lignum woodland wetland of frequently flooded floodplains mainly in the Darling Riverine Plains Bioregion
	40 – cultivated	Cultivated land - Coolibah open woodland wetland
	55 – cultivated	Cultivated land - Belah Woodland
	98 - cultivated	Cultivated land- Poplar Box - White Cypress Pine - Wilga woodland
	206 – cultivated	Cultivated land- Dirty Gum-White Cypress Pine tall woodland
	241 - cultivated	Cultivated land - River Coobah - lignum swamp wetland

2.2 Mapping vegetation community condition

Aerial photography can effectively identify changes in riparian and wetland vegetation (Knapp et al. 1990, Tickle et al. 2006, Yang 2007). API has been effective in determining tree canopy health measures (e.g. canopy cover, foliage cover, canopy density) and mapping the spatial distribution of condition classes (Armstrong et al. 2009, Blackwood 2009, McCosker 2009, Bowen et al. 2011, Bowen and Simpson 2012) . We used API to map the condition of River Red Gum forest and woodland and other flood-dependent woodland HFGs at two points in time (2008 and 2015). In the absence of clearing, the long-lived species that dominate these communities are more likely to respond to environmental drivers firstly via altered condition. Vegetation extent may require longer time spans to respond to novel environmental conditions. Under the NSW Environmental Water Management Program, the condition of flood-dependent vegetation communities in the Gwydir Wetlands is determined annually from plot-based surveys, using measures of tree canopy health, structural diversity and species composition (Bowen 2016). These measures include estimates of canopy cover, canopy extent and dead canopy in 20 x 50m plots. The survey data from October 2015 were analysed for condition class and the survey sites were georeferenced on screen for use as reference sites to standardise signature recognition during manual API.

We viewed high resolution aerial photography in false colour infrared to allow for textural signatures of foliage reflectance to be separated from reflectance from boughs, limbs and other tree surfaces. Shadows cast on the ground by canopies were also useful in assessing the delineation of crowns in mid dense stands. The percentage of dead or extremely stressed trees (trees with denuded boughs and limbs) was assessed within randomly generated 100 x 100 m (1 ha) squares for all polygons and compared to survey reference sites. An average of two x 1 ha squares per 20 ha were sampled. Polygons were split where necessary to delineate differences in tree canopy condition. One in 20 squares was re-sampled to check for consistency of attribution. Polygons were assigned to one of the condition classes in **Table 2**.

Table 2 Descriptions of condition classes for River Red Gum forest and woodland and other flood-dependent woodland Hydro-ecological Functional Groups (Bowen and Simpson 2010b).

Condition class	Description
Good	0 - 10 % dead canopy
Intermediate	11-40 % dead canopy
Intermediate/poor	41-80 % dead canopy
Poor	>80 % dead canopy

2.3   Accuracy assessment of vegetation community extent and condition

Map accuracy reflects how well the mapped features match the on-ground distribution of features. Accuracy assessments may follow quantitative or qualitative approaches (Keith and Simpson 2008). Quantitative methods rely on a large number of random and stratified field observations to estimate accuracy. These field requirements exceeded available resources for the current mapping exercise. The mapping therefore uses a qualitative approach to infer accuracy.

Map creation depended on expert knowledge of the system along with field survey of representative vegetation communities and conditions prior to manual interpretation. The authors have extensive on-ground knowledge of the Gwydir Wetlands: members of the team have conducted bi-annual field surveys within the study area since 2010. In addition, the high spatial resolution of mapped features improved interpretation. The 50 cm resolution 3D aerial photography facilitated detailed understanding of vegetation components such as texture and landscape context. The median polygon size for the 2015 map was 10 ha.

2.4   Calculating extent and condition of vegetation communities

We calculated the extent in hectares for each HFG and PCT at each time interval (2008 and 2015). We also determined the extents of condition classes (**Table 2**), but condition was only applied to the woodland HFGs. Changes in condition for treeless communities are more likely to reflect changes in their species composition and thus a change in their community extent.

3. Trends in vegetation extent and condition in the Gwydir Wetlands across the mapped years (2008 - 2015).

The report highlights overall trends in vegetation change across the mapped years (2008 and 2015). Refer to the mapping product for specific spatial and temporal patterns.

The extents for both Plant Community Types (**Figure 2**,**Table 3**) and Hydro-ecological Functional Group map units (**Figure 3, Table 3**) are presented across the two mapped years.

It was difficult to discern vegetation trends across the two time periods. The extent of cleared areas appeared to increase from 2008 to 2015. However, it was difficult to assign a trend direction for the extent of PCTs and HFGs because changes appeared minor and map accuracy was undetermined.

The distribution of condition classes for woodland communities appeared to change between 2008 and 2015 (**Figure 4, Table 4).** Woodland condition appeared to decrease in some areas from 2008 to 2015.
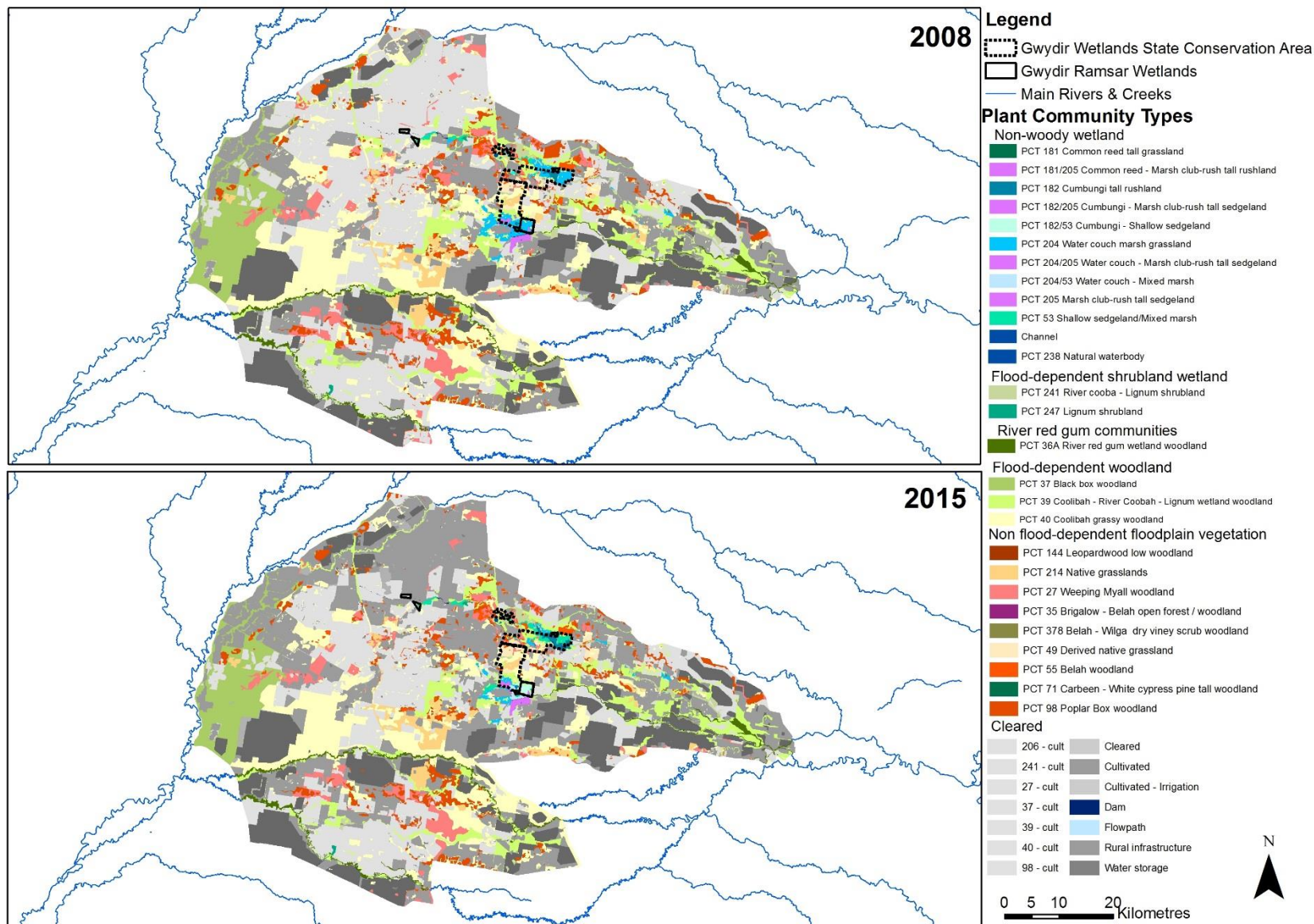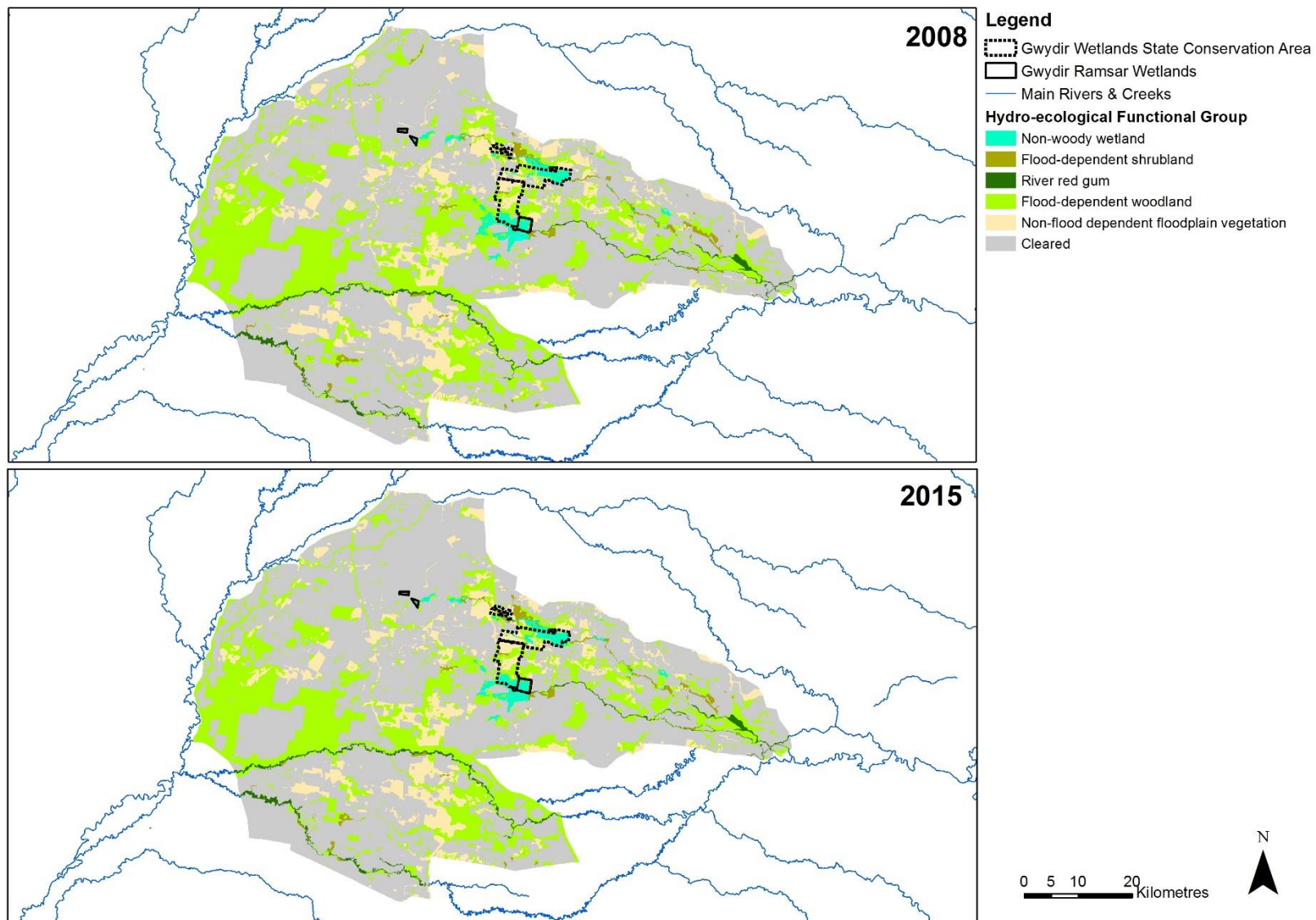
Figure 2 Spatial extent of Plant Community Types mapped in the Gwydir Wetlands in 2008 and 2015.
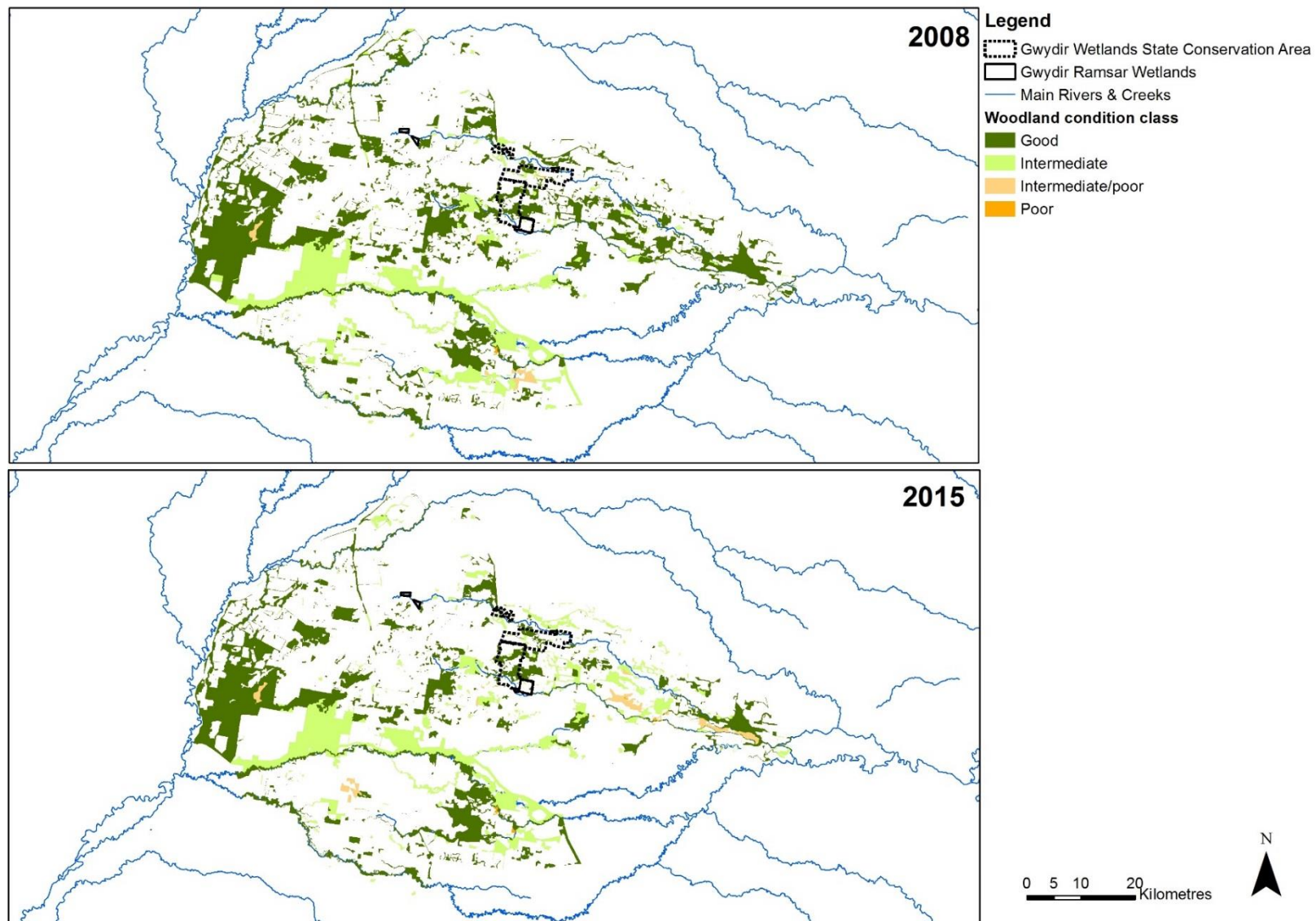
2008

2015

Error! Reference source not found.

Table 3 Extent, in hectares (ha), of Hydro-ecological Functional Groups and Plant Community Types for the mapped area of the Gwydir Wetlands in 2008 and 2015.

Hydro-ecological Functional groups/ Map Unit	Plant Community Type ID No.	Plant Community Type description	Area in ha 2008	2015
Non-woody wetland	181	Common Reed – Bushy groundsel aquatic tall grassland of inland river systems	48	48
	181 & 205	Marsh Club-Rush very tall sedgeland/Common Reed–Bushy groundsel aquatic tall grassland	11	11
	182	Cumbungi rushland of shallow semi-permanent water bodies of the inland river systems	350	847
	182 & 205	Cumbungi rushland of shallow semi-permanent water bodies/Marsh Club-Rush very tall sedgeland	525	558
	182 & 53	Shallow freshwater wetland sedgeland/Cumbungi rushland	0	471
	204	Water Couch marsh grassland of frequently flooded inland watercourses	4 086	1 523
	204 & 205	Water Couch marsh grassland/Marsh Club-rush Tall sedgeland	0	11
	204 & 53	Water Couch marsh grassland/Shallow freshwater sedgeland	0	324
	205	Marsh Club-Rush very tall sedgeland of inland river systems	217	226
	238	Permanent and semi-permanent freshwater lakes; inland slopes and plains	92	112
	53	Shallow freshwater wetland sedgeland in depressions on floodplains on inland alluvial plains and floodplains	514	1 663
	Channel	Channel	129	125
	Total		**5 972**	**5 919**
River Red Gum forest and woodland	36	River Red Gum open forest of the DRP	9	9
	36A	River Red Gum woodland of the DRP	5 457	5 457
	Total		**5 466**	**5 466**
Flood-dependent shrubland wetland	241	River Cooba swamp/Lignum shrubland on regularly flooded alluvial clay depressions in BBS and DRP	4 386	3 915
	247	Lignum shrubland on regularly flooded alluvial clay depressions in BBS and DRP	190	190
	Total		**4 576**	**4 105**
Flood-dependent woodland	37	Black Box woodlands on floodplains of the NSW central and northern wheatbelt including the DRP	20 357	18 539
	39	Coolabah - River cooba - Lignum woodland wetland of frequently flooded floodplains mainly in the DRP	30 347	27 234

Hydro-ecological Functional groups/ Map Unit	Plant Community Type ID No.	Plant Community Type description	Area in ha	
			2008	2015
	40	Coolibah open woodland with chenopod grassy ground cover on grey and brown clay floodplains	58 217	52 137
	Total		**108 921**	**97 910**
Non flood-dependent floodplain vegetation	144	Leopardwood low woodland mainly on clayey soils in the semi-arid zone	8	8
	206	Dirty Gum,White Cypress Pine tall woodland of alluvial sandy lenses (sand monkeys) mainly of the DRP	252	228
	214	Native Millet – Cup Grass grassland of the DRP	9 434	8 566
	27	Weeping Myall open woodland of the DRP and BBS	15 589	13 227
	35	Brigalow - Belah open forest / woodland BBS	4	4
	378	Belah - Wilga dry viney scrub woodland the NSW BBS	1	1
	49	Windmill Grass – copperburr alluvial plains shrubby partly derived grassland of the DRP and BBS	2 045	2 204
	55	Belah woodland on alluvial plains in the central wheatbelt of NSW	3 158	2 973
	71	Carbeen - White Cypress Pine - River Red Gum - bloodwood tall woodland on sandy loam alluvial and eolian soils in the northern Brigalow Belt South Bioregion and Darling Riverine Plains Bioregion	7	7
	98	Poplar Box/White Cypress/Budda/Wilga shrubby woodland on sandy loam soils mainly of the NW plains	16 297	14 874
	Total		**46 795**	**42 092**
Cleared			**278 403**	**294 641**
Total			**450 133**	**450 133**

Figure 4 Spatial extent of the condition classes mapped in the Gwydir Wetlands for River Red Gum forest and woodland and other flood-dependent woodland Hydro-ecological Functional Groups in 2008 and 2015.

Table 4 Extent of condition classes for River Red Gum forest and woodland and other flood-dependent woodland Hydro-ecological Vegetation Communities in the Gwydir Wetlands mapped area in 2008 and 2015.

Hydro-ecological Functional Groups	PCT no.	Plant Community Type Name	Condition class	Area in ha 2008	Area in ha 2015
River Red Gum	36	River Red Gum open forest of the DRP	Good	0	9
			Intermediate	9	0
	36A	River Red Gum woodland of the DRP	Good	5 419	5 430
			Intermediate	38	17
			Intermediate/poor	0	10
	Total		**Good**	**5 419**	**5 439**
			Intermediate	**47**	**17**
			Intermediate/poor	**0**	**10**
Flood-dependent woodland	37	Black Box woodlands on floodplains of the NSW central and northern wheatbelt including the DRP	Good	19 964	18 160
			Intermediate	40	24
			Intermediate/poor	352	355
			Poor	1	0
	39	Coolabah - River cooba - Lignum woodland wetland of frequently flooded floodplains mainly in the DRP	Good	22 413	14 495
			Intermediate	7 123	10 492
			Intermediate/poor	765	2 170
			Poor	46	77
	40	Coolibah open woodland with chenopod grassy ground cover on grey and brown clay floodplains	Good	33 987	26 805
			Intermediate	24 017	23 992
			Intermediate/poor	137	796
			Poor	76	154
	Total		**Good**	**76 364**	**59 460**
			Intermediate	**31 180**	**34 508**
			Intermediate/poor	**1 254**	**3 321**
			Poor	**123**	**231**

4. Mapping recommendations

Periodic update of the vegetation extent and condition mapping allows ongoing monitoring of vegetation change in the Gwydir Wetlands. We make the following recommendations for the next iteration of the mapping product:

- Undertake a quantitative accuracy assessment using a large number of field observations that are randomly distributed and stratified between vegetation communities (Keith and Simpson 2008)
- Use the quantitative accuracy assessment to determine suitability of mapping non-woody vegetation communities when mapping intervals are greater than a single year (DLWC 2000)
- Evaluate the effectiveness of management interventions by relating the mapped vegetation extent and condition to environmental predictors such as climatic and inundation regime data.

5. References

Anon. 1999. Information sheet on Ramsar Wetlands (RIS): Gwydir Wetlands: Gingham and Lower Gwydir (Big Leather) Watercourses. World Wide Fund for Nature and NSW National Parks Association & National Parks and Wildlife Service, http://www.environment.gov.au/water/topics/wetlands/database/pubs/50-ris.pdf.

Armstrong, J. L., R. T. Kingsford, and K. M. Jenkins. 2009. The effect of regulating the Lachlan River on the Booligal wetlands - the floodplain Red Gum swamps. Australian Wetlands and Rivers Research Group, University of New South Wales, Sydney.

Benson, J. S. 2006. New South Wales Vegetation Classification and Assessment: Introduction - the classification, database, assessment of protected areas and threat status of plant communities. Cunninghamia **9**:331-382.

Bino, G., S. A. Sisson, R. T. Kingsford, R. F. Thomas, and S. Bowen. 2015. Developing state and transition models of floodplain vegetation dynamics as a tool for conservation decision-making: a case study of the Macquarie Marshes Ramsar wetland. Journal of Applied Ecology **52**:654-664.

Blackwood, A. J. 2009. The effect of river red gum decline on woodland birds in the Macquarie Marshes. University of New South Wales, Sydney.

Bowen, S. 2016. Environmental flow monitoring program: methods for survey and monitoring of flood dependent vegetation communities. NSW Office of Environment and Heritage, Sydney.

Bowen, S., M. Powell, S. J. Cox, S. L. Simpson, and P. Childs. 2011. Riverina Red Gum reserves mapping program - Stage 1. NSW Office of Environment and Heritage, Sydney.

Bowen, S., and S. L. Simpson. 2010a. Changes in Extent and Condition of the Vegetation Communities of the Gwydir Wetlands and Floodplain: Final Report to the NSW Wetland Recovery Program. NSW Department of Environment, Climate Change and Water, Sydney.

Bowen, S., and S. L. Simpson. 2010b. Changes in extent and condition of the vegetation communities of the Macquarie Marshes and Floodplain 1991–2008. Final report to NSW Wetland Recovery Program. Department of Environment, Climate Change and Water, Sydney.

Bowen, S., and S. L. Simpson. 2012. Vegetation mapping project, executive summary. NSW Rivers Environmental Restoration Program Subprogram II, Sydney.

Brander, D. 1987. Environmental changes in the Southern Macquarie Marshes: 1934 to 1987. UNSW, Sydney.

Bren, L. J. 1988. Effects of river regulation on flooding of a riparian red gum forest on the River Murray, Australia. Regulated Rivers: Research and Management **2**:65-77.

Casanova, M. 2011. Using water plant functional groups to investigate environmental water requirements. Freshwater Biology **56**:2637-2652.

Chesterfield, E. A. 1986. Changes in the vegetation of the river red gum forest at Barmah Victoria. Australian Forestry **49**:4-15.

DECCW. 2010. NSW Wetlands Policy. NSW Department of Environment, Climate Change and Water, Sydney.

DECCW. 2011. Gwydir Wetlands adaptive management plan: Synthesis of information projects and actions. Department of Environment, Climate Change and Water, Sydney.

DLWC. 2000. Historical vegetation mapping in the Macquarie Marshes 1949-1991. NSW Department of Land and Water Conservation, Dubbo.

Driver, P., and C. Knight. 2007. Macquarie Marshes 2005/06 Environmental Flow Responses of groundcover plants to environmental flows. Department of Natural Resources.

Keith, D. A. 2004. Ocean Shores to Desert Dunes: the native vegetation of New South Wales and the ACT. Department of Environment and Conservation NSW, Sydney.

Keith, D. A., and C. C. Simpson. 2008. A protocol for assessment and integration of vegetation aps, with an application to spatial data sets from south-eastern Australia. Austral Ecology **33**:761-774.

Keyte, P. A. 1994. Lower Gwydir wetland plan of management 1994 to 1997. NSW Dept. of Water Resources for the Lower Gwydir Wetland Steering Committee, Sydney.

Kingsford, R. T. 2000. Review: Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. Austral Ecology **25**:109-127.

Knapp, P. A., P. L. Warren, and C. F. Hutchinson. 1990. The use of large-scale aerial photography to inventory and monitor arid rangeland vegetation. Journal of Environmental Management **31**:29-38.

McCosker, R. O. 1997. Gwydir Wetlands Vegetation Mapping and explanation of the vegetation types of the Gwydir Floodplain. Department of Land and Water Conservation.

McCosker, R. O. 2007. Gwydir floodplain vegetation map 2005 and explanatory notes on vegetation communities. NSW Dept. of Environment and Conservation.

McCosker, R. O. 2009. Yanga vegetation mapping: historical community extent and condition. Department of Environment, Climate Change and Water, Sydney.

McCosker, R. O., and J. A. Duggin. 1993. Gingham watercourse management plan: final report. N.S.W Dept. of Ecosystem Management, University of New England, Armidale.

MDBA. 2014. Basin-wide environmental watering strategy. Murray-Darling Basin Authority.

Mitsch, W. J., and J. G. Gosselink. 2000. Wetlands. John Wiley, New York.

OEH. 2017. Vegetation Information System: Classification. Office of Environment and Heritage, http://www.environment.nsw.gov.au/research/Visclassification.htm

OEH. 2018. Gwydir Wetlands Ramsar site. Office of Environment and Heritage, Sydney.

Roberts, J., and F. Marston. 2011. Water regime for wetland and floodplain plants: a source book for the Murray-Darling Basin. National Water Commission, Canberra.

Rogers, K., and T. J. Ralph. 2011. Floodplain wetland biota in the Murray-Darling Basin: water and habitat requirements. CSIRO Publishing, Melbourne.

Specht, R. L. 1970. Vegetation. Pages 44-67 *in* G. W. Winthrop, editor. The Australian environment. Commonwealth Scientific and Industrial Research Organisation, Melbourne.

Thomas, R. F., S. Bowen, S. L. Simpson, S. J. Cox, N. C. Sims, S. J. Hunter, and Y. Lu. 2010. Inundation response of vegetation communities of the Macquarie Marshes in semi-arid Australia. Page 15 *in* N. Saintilan and I. Overton, editors. Ecosystem Response Modelling in the Murray Darling Basin. CSIRO Publishing, Melbourne.

Tickle, P. K., A. Lee, R. M. Lucas, J. Austin, and C. Witte. 2006. Quantifying Australian forest floristics and structure using small footprint Lidar and large scale aerial photography. Forest Ecology and Management **223**:379-394.

Torrible, L., G. Sainty, and H. D. 2009. Assessment of the Water Dependent Vegetation and Fauna of Mallowa Creek, results from a field visit Feb 2009 IRPEC Pty Ltd.

Walker, J., and M. S. Hopkins. 1990. Vegetation. Pages 58-86 *in* R. C. McDonald, R. F. Isbell, J. G. Speight, J. Walker, and M. S. Hopkins, editors. Australian soil and land survey: field handbook. Inkata Press, Melbourne.

Wassens, S., N. Ning, L. Hardwick, G. Bino, and J. Maguire. 2017. Long-term changes in freshwater plant communities following extreme drought. Hydrobiologia **799**:233-247.

Yang, X. 2007. Integrated use of remote sensing and Geographic Information Systems in riparian vegetation delineation and mapping. International Journal of Remote Sensing **28**:353-370.