Quantifying the water needs of flood-dependent plant communities in the Macquarie Marshes, south-eastern Australia

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August 2019

Submitted in fulfilment of the requirements of the degree of Doctor of Philosophy

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Sharon Maree Bowen declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Life Sciences, Faculty of Science, at the University of Technology Sydney.

The thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research has been supported by the Australian Government Research Training Program.

Production Note:
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Date: 14-08-2019

Acknowledgments

I would like to acknowledge the assistance I have received from some outstanding staff of the NSW Office of Environment and Heritage, most particularly Shannon Simpson, Darren Shelly, Jane Humphries, Tim Hosking, Paul Keyte, Terry Mazzer, Wayne Kuo and Joel Honeysett. I am also grateful for the invaluable support I have received from Dr Mike Maher, Dr Lisa Thurtell, Graeme Enders and Daryl Albertson. Thanks to the all the landholders and land managers of the Macquarie Marshes for their support for this work over the years.

I am grateful to my PhD supervisors; Dr Fraser Torpy, Professor Margaret Burchett, Dr Yoshi Kobayashi and Dr Patrick Driver. Thank you for your guidance.

To my family; Peter, Emma, Cara and Sam Bowen, thank you for all your support and for encouraging me in this long and arduous task.

Funding for this work came from several sources including the NSW and Australian Governments' Water for the Future Program and the Australian Governments' Murray-Darling Basin Plan implementation funding.

Thanks also to W.A. Mozart and ABC Classic FM.

Preface

This research outlines how to quantify measures of condition for flood-dependent plant communities in inland floodplain wetlands. This is critical for efficient ecological monitoring, use in predictive modelling, and to define vegetation restoration targets and management strategies for environmental water. This study has developed a quantitative framework for assessing flood-dependent vegetation community condition and has added to the empirical knowledge about the water requirements of these plant communities.

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Abstract

Inland floodplain wetland plant communities of the Macquarie Marshes occur in the lower reaches of the Macquarie River catchment in the Murray-Darling Basin in semi-arid South-eastern Australia. The natural flood regimes are no longer operating in the Marshes due to river regulation, and in periods of low catchment rainfall they are now sustained solely by delivered environmental water allocations. Flood-dependent plant communities can show considerable negative ecological consequences when natural flow and flooding regimes are significantly disrupted. For effective management of water resources to meet targets for the maintenance and restoration of flood-dependent plant communities, it is critical to know the condition or state of the component plant communities, and to quantify change in condition in response to inundation actions.

This research developed quantitative condition benchmarks derived from a long-term dataset and adds to the knowledge of water requirements for eight inland wetland flood-dependent plant communities of the Macquarie Marshes. It examines the benchmarks and key inundation predictors for forests and woodlands dominated by river red gum (*Eucalyptus camaldulensis*), woodlands of coolibah (*E. coolabah*), shrublands of lignum (*Duma florulenta*), and non-woody wetland communities of water couch (*Paspalum distichum*), sedges (*Eleochari*s spp.) and floodplain grasslands. Condition class schemas for measuring community and tree stand condition were developed and tested using Multivariate Regression Forest (MRF) analysis of data collected at 74 sites in the Macquarie Marshes from 2008 to 2016. The most important inundation regime predictor variables for these vegetation communities were identified from companion inundation data using MRF. Then Ecological Reference Models (ERMs) were developed using Generalised Linear Mixed Modelling (GLMM), of condition scores against inundation regime predictor variables.

The study of the Macquarie Marshes explores the assessment of flood-dependent vegetation community condition using species group responses to water regime and a wetland vegetation typology that can be applied to other flood-dependent vegetation communities and other wetlands. Both the condition class schemas and the ERMs could assist in data supported decision making about current and future ecological restoration activities by defining the appropriate species composition and structure for these and similar flood-dependent vegetation communities.

Chapter 1 Introduction

1.1. The Murray-Darling Basin

The Murray-Darling Basin (MDB) in south-eastern Australia, contains the longest river system in Australia at 3672 km, just over half that of the Nile River in continental Africa, the world's longest river system at 6695 km (Australian Government 2019). Other major river systems include; the Amazon, the Mississippi/Missouri system in the USA, the inner delta of the Niger in Mali and the Aral Sea in the former Soviet Republic (now Uzbekistan) (Finlayson and Pittock 2011).

The MDB extends through five States in south-eastern Australia and covers 1,059,000 square kilometres (14% of Australia's land area), with the majority in New South Wales (NSW) (Thoms et al. 2007; MDBA 2012a). It contains over 77,000 km of river courses along 23 river valleys (MDBA 2012a). Australia's three longest rivers, the Darling (2,740 km), Murray (2,530 km) and Murrumbidgee (1,690 km) are found in the MDB (MDBC 2005). The Murray and the Darling rivers and their tributaries extend from north of the town of Charleville in Queensland to meet the sea at the Murray mouth in South Australia (Figure 1).

Figure 1 the Murray-Darling Basin

(Source MDBA 2018a)

1.2 Inland floodplain wetlands of the Murray Darling Basin

Inland river floodplains are defined as low-lying areas of land that are '*subject to inundation by lateral overflow water from rivers with which they are associated*' (Junk and Welcomme 1990; Ramsar 2012). Wetlands are defined as '*land permanently or temporarily under water or waterlogged …at sufficient frequency to affect the biota*' (Paijmans et al. 1985). The inland floodplain wetland plant communities examined in this study are '*those that occur on floodplains, in which the dominant species depend on moist conditions or flooding for part or all their life cycle*' (DECCW 2010a). They are also referred to as *flood-dependent plant communities* and as '*water-dependent vegetation communities*' (MDBA 2014a). Wetlands are among the most productive and ecologically diverse systems on Earth (Gregory et al. 1991; Tochner and Stanford 2002; Erwin 2009).

In Australia, floodplain wetlands are associated with the flooding patterns of large semi-arid inland rivers and are large complex ecosystems, consisting of a mosaic of flood-dependent and dry land vegetation communities distributed in relation to the availability of groundwater and surface water (McCosker and Duggin 1993). Of an estimated 4.5 million ha of wetlands in NSW, 89% are inland floodplain wetlands and most (~30,000), occur in the MDB (Kingsford et al. 2004). Of these, 220 are listed in the *Directory of Important Australian Wetlands in Australia* (Environment Australia 2001; CSIRO 2008).

The most significant and largest wetlands (i.e. >200,000 ha) in NSW are; the lower and mid-Murrumbidgee floodplain, the lower Lachlan Wetlands, Gwydir Wetlands, Narran Lakes and the Macquarie Marshes. These wetlands support many species of native fish and iconic vegetation communities, are among the most important national wetlands for bird breeding and bird species diversity, and they have great cultural significance for Indigenous people and the broader community (MDBA 2011). Sixteen floodplain wetlands in the MDB including the Macquarie Marshes, are listed as internationally significant under the *Ramsar Convention on Wetlands* 1999 (Ramsar 2013; DECCW 2010b, DECCW 2011a, DECCW 2011b; OEH 2017a).

1.3 Water availability in the Murray-Darling Basin

Inland floodplain wetlands exert a strong influence on the hydrological cycle of the floodplain by reducing floods on floodplains, promoting groundwater recharge and keeping river flows more constant (Bullock and Acreman 2003). Australia is the driest inhabited continent in the world, rainfall is variable and droughts are common (NWC 2005). Most of the inland floodplain wetland catchments within the MDB are in within the semi-arid or arid zones, where average annual rainfall generally less than 470 mm, and historically wetlands are dependent on natural river flows (Davies et al. 1994; Kingsford et al. 2006).

Latest available figures (2009), showed that the annual agricultural output of the MDB was valued at $AUD 7 billion, 90 percent of the water diverted from the rivers was used to produce 70% of Australia’s irrigated agricultural output, and 84% of the land in the MDB was owned by businesses engaged in agriculture year (ABS et al. 2009). In 2009, 67% of the MDB was used for growing crops and pasture, and 39% of the total national income derived from agricultural production came from the MDB, which contained 65% of Australia’s irrigated agricultural land (ABS et al. 2009).

Most water in the MDB comes from a small region in the east near the headwaters of the Murray River (Davies et al. 2008). The MDB receives an average annual rainfall of 530,618 Gigalitres (GL). One GL = 10^9 Litres and is equivalent to 400 Olympic sized swimming pools. It is estimated that 94% of rainfall runoff evaporates, or is transpired through plants, and 2% drains into the ground, leaving only 4% as runoff available for natural flow to wetlands and other uses (Chiew et al. 2008). Total run-off within the MDB averages around 24,000 GL/year but only about 5,000 GL/year reaches the sea in South Australia at the Murray Mouth, and this is a very low annual discharge for a major river system by world standards (CSIRO 2008). Around 86% of the MDB contributes almost no runoff to the river system, except in during very large floods (MDBA 2018b).

Predicted trends in future climate for south-eastern Australia are for significantly less rainfall, increases of annual temperature of 0.4-2.0ºC, increased drought frequency and reduced runoff for many Australian rivers (Kothavala 1999; CSIRO 2007; CSIRO 2008; Chiew et al 2008). These climatic trends will exacerbate the effects of water extraction and diversion of water in wetland ecosystems dependent of river flows (Hughes 2003).

The MDB is Australia's most developed river basin with 240 dams storing 29,893 GL of water (Kingsford et al. 2017). Many inland floodplain wetlands are constrained in their ability to react spatially to temporal changes in flooding regimes and many no longer receive natural flows from their rivers, mostly due to floodplain diversions and regulation of river flows by human made structures and mechanisms such as levy banks and channels, dams and weirs that contain and divert river flows for irrigation (Finlayson and Rae 1999; Kingsford 1995; Erwin 2009). Over the last four decades and particularly during the *Millennium Drought* period of 1996–2010, prolonged droughts exacerbated the effects of land and water management practices in these regulated river floodplains (Australian Government 2015; Davies et al. 2008).

Significant declines have been recorded in the abundance of key wetland dependent biota in inland floodplain wetlands of the MDB following river regulation, including colonial nesting waterbirds (e.g.: Kingsford and Thomas 1995; Kingsford and Johnson 1998; Kingsford and Auld 2005); fish (e.g., Spencer 2009; Spencer et al. 2010) and frogs (e.g., MacNally et al. 2009; Wassens and Maher 2010). Extensive decreases in the spatial extent and condition of flood-dependent wetland vegetation communities have been reported for several inland floodplain wetlands in the MDB e.g.; Gwydir (McCosker and Duggin 1993; DECCW 2010a; Bowen and Simpson 2010b; DECCW 2011a), Lower Murrumbidgee (Bowen and Simpson 2012), Murray (Overton et al. 2006; Cunningham et al. 2007; Overton and Doody 2007), and the Macquarie Marshes (Bowen and Simpson 2009; DECCW 2010b; Bowen and Simpson 2010a; DECCW 2011b).

1.4 Governance and management of Murray-Darling Basin water resources

The deleterious effects of the Millennium Drought (1996–2010) on water availability in the MDB, led to the Australian Government making an amendment to the *Water Act* in 2008 which gave effect to the July 2008 *Intergovernmental Agreement on Basin Reform* between the Australian Government and the five states and territories that contain areas of the MDB (Queensland, NSW, Victoria, the Australian Capital Territory and South Australia) (COAG 2004; Comlaw 2013; COAG 2013). This agreement created the *Murray-Darling Basin Authority* (MDBA) and initiated the preparation of the *Murray-Darling Basin Plan* (Basin Plan) (MDBA 2012a; MDBA 2012b; MDBA 2012c, MDBA 2012d). As part of its measures of water management reform, the Australian Government commenced a program to purchase irrigation water to the value of $AUD 3.1 billion stored in dams in the MDB for the use as '*environmental water'* (Kingsford et al. 2011).

Environmental water is; '*water that is allocated and managed specifically to improve the health of rivers, wetlands and floodplains'* under statutory plans (OEH 2017b). As part of the Basin Plan, the MDBA set *Sustainable Diversion Limits* (SDLs) that determined the amount of water extracted from the rivers for agriculture, and the amount of water available for the environmental (MDBA 2011). To manage the environmental allocations

Environmental Watering Plans (EWPs) were prepared for the key inland floodplain wetlands of the MDB, which are known as *key environmental asset areas* (KEAs) (MDBA 2012a).

Each of the MDB States also has its own state water management legislation and policies. In NSW this is the *Water Management (WM) Act 2000* which requires that water in regulated river valleys is governed under Water Sharing Plans (WSPs) (Driver et al. 2013). In NSW the *Department of Industry – Water* (DoI-Water) and the *NSW Office of Environment and Heritage* (OEH), manages both environmental water allowances (established under the WSPs) and NSW environmental water holdings (DECCW 2011b). OEH also delivers environmental water held by the *Commonwealth Environmental Water Office* (CEWO) (OEH 2015). Some areas of the MDB, such as the Macquarie Marshes, had been receiving water for environmental purposes from the 1980s for support of wildlife conservation, including colonial nesting waterbird breeding events (Kingsford and Thomas 2004).

1.5 Inland floodplain wetland plant community relationships with water

Floodplain plant species have evolved life history strategies in direct response to natural flow regimes and can thus suffer negative ecological consequences when these regimes are significantly disrupted by upstream river regulation and abstraction (Blanch et al. 1999; Kingsford 2000; Bunn and Arthington 2002). Flood-dependent vegetation is a sensitive measure and indicator of anthropogenic impacts on wetland ecosystems, and many human-related alterations to the environment that act to degrade wetland ecosystems cause shifts in plant community composition that can be quantified (U.S. EPA. 2002; Johnston et al. 2009).

As wetland plants respond to patterns of water presence over time, their continued survival can provide an indication of the historical water regime, and analysis of their distribution and abundance can be a useful tool for determining the ecological water requirements of sites in a catchment (Casanova and Brock 2000; Casanova 2011).

Inundation or hydrologic regime; the fluctuation in the rate of water flow over time, is a master variable with respect to the structure and function of wetland plant communities (Gosselink and Turner 1978; Mitsch and Gosselink 2000), particularly in relation to species richness and percentage cover of species (Barrett et al. 2010).

Increases in hydrological connectivity and inundation duration or frequency can change the structure and composition of plant communities towards more flood-reliant species in the extant community and in the soil seed bank (Casanova and Brock 2000; Leck and Brock 2000; Porter et al. 2007; Capon and Brock 2006; Reid and Capon 2011; Reid et al. 2015; Bino et al. 2015; Wassens et al. 2017). Conversely, an increase in drying promotes the establishment of more terrestrial species (Thomas et al. 2010; Webb et al. 2015; Webb et al. 2018), and a decrease in the health of the overstorey trees (Chesterfield 1986; Cunningham et al. 2006; Cunningham et al. 2007; Overton and Doody 2007; Cunningham et al. 2009a; Cunningham et al. 2009b; Bowen and Simpson 2010).

Flood-dependent plant communities differ in their in their inundation regime requirements. They range from those that require permanent standing water to those which may only be inundated very infrequently (Casanova 2015). Response time for vegetation varies with plant growth-form. For communities dominated by long-lived tree species (e.g. river red gum, coolibah and black box), structural changes are expected to be slow, while the changes can occur relatively quickly in communities dominated by herbaceous species (Bino et al. 2015). However, most studies agree on the importance of the cumulative effects of inundation events over several years (Reid and Quinn 2004; Cunningham et al. 2013; Cunningham et al. 2014).

1.6 Research aim

Flood-dependent plant communities are an important component of inland floodplain wetlands, and the condition of these communities can be used as a surrogate for habitat suitability for other biotic groups (Stokes et al. 2010). *Condition* is an indirect measure of ecosystem health and habitat suitability for native flora and fauna, and therefore a surrogate measure for biodiversity (Minato 2009). Vegetation condition refers to; *'the state of vegetation relative to some specified benchmark*' (Thackway et al. 2006).

The aim of this research is to develop a quantitative framework for assessing and tracking the condition of inland wetland plant communities. The framework defines benchmarks and condition classes for the assessment of condition of inland floodplain wetland PCTs at multiple scales. Benchmark or excellent condition in this study is defined as; '*the state in which water availability meets the life history needs of all diagnostic indicators most of the time*' whereas poor condition is defined as; '*the state in which water availability meets the life history needs of non-diagnostic indicators most of the time'*.

This research could assist in decision making about current and future ecological restoration activities for managed wetland plant communities, with the goal of attaining a diagnostic species composition and structure for that plant community. It is a novel approach as it quantifies inland floodplain plant communities' temporal dynamics in relation to the parameters of inundation, to develop quantitative models of these relationships that can be used for restoration target setting, adaptive ecological monitoring and decision making.

This ability to make decisions at appropriate scales is important because the provision of environmental water to inland floodplain wetlands of the MDB, are predicted to become increasingly crucial, as projected changes in climate of south-eastern Australia are for increase in temperature and lower rainfall (CSIRO 2008; Davis et al. 2015). Even currently, in low catchment rainfall periods, the environmental water available in storage is often insufficient to water all of the flood-dependent ecosystems requiring water allocations in the floodplain. Thus, water managers are often required to prioritise environmental water deliveries to maintain the ecological condition of the system over time (e.g.; DECCW 2010c, DECCW 2011a, DECCW 2011b; Driver et al 2013; Davis et al. 2015).

1.7 Research approach

Many previous studies on plant-water relationships and vegetation dynamics have focused on the water requirements of individual wetland or flood-dependent plant species and their seedbanks (e.g. Grace 1989; Brock 1991; Blanch and Brock 1994; Blanch et al. 1997; Bacon 1994; Bacon 1996; Nichol and Ganf 2000; Roberts 2002; Bell and Clarke 2002; Nichol 2003; George et al. 2005; Murray 2011; Murray et al. 2012; Catelotti et al. 2015; Hanke et al. 2015; Nichol et al. 2018).

Others have looked at the response of flood-dependent plant species to water availability at the in terms of changes in species richness or assemblages (e.g. Chesterfield 1986; Blanch et al. 1994; Capon 2003; Capon 2005; Reid and Quinn 2004; Fensham et al. 2004; Capon and Brock 2006; Nichol et al. 2013), or detecting change in species presence and assemblages in response to environmental flows (e.g. Driver and Knight 2007; Stokes et al. 2010; Nicol et al. 2010a; Nicol et al. 2010b; Nicol 2012; Halford and Fensham 2014, Gehrig et al. 2015; Moxham et al. 2016; Nicol et al. 2017; Nicol et al. 2018; Moxham et al. 2018), or classifying plant response to water regimes of groups of species (e.g. Brock and Casanova 1997; Casanova 2011; Bino et al. 2015; Deane et al 2017; Johns et al. 2015).

However, some key flood-dependent plant species in inland floodplain wetlands are ubiquitous and can occur in range of inundation regimes, making management of resources for their continued health and survival at the landscape scale problematic if their water needs are defined only at the species level. An important example is river red gum (*E. camaldulensis*). River red gum is found throughout the MDB in several plant communities and in a range of landscape positions. Each physiologically distinct form of river red gum (or sub-species) is likely to require a different inundation regime, as the environment that the tree has matured in will dictate its water requirements (Dawson and Ehlringer 1991; Kath et al. 2014; Casanova 2015). For example, trees in grassy woodland communities on the outer floodplain are likely to be maintained in good condition with a different inundation regime that those in forest with a wetland plant understorey located on channels.

It is also much more efficient to manage for plant communities than for the species, and concentrating on the species level ignores the importance of the other species that constitute the community, and the structural forms of those communities that are intrinsically linked to ecological functions and processes, for example providing habitat for wetland and woodland fauna (Seiben et al. 2018).

This research studied the dynamics of identified plant communities in relation to inundation drivers, rather than an autecological study or study of change in species assemblages only. A quantitative framework was developed for assessing and tracking the condition of eight key NSW Plant Community Types (PCTs); river red gum (*Eucalyptus camaldulensis*) forest (PCT 36), woodland (PCT 36A), and grassy woodland (PCT 454), Coolibah (*E. coolabah*) woodland (PCT 40), lignum (*Duma florulenta*) shrubland (PCT 247), water couch (*Paspalum distichum*) marsh grassland (PCT 204), mixed marsh (*Eleocharis spp*.) sedgeland (PCT 53), and native millet – cup grass floodplain (*Panicum decompositum* and *Eriochloa crebra)* grassland (PCT 214). PCTs are defined under the '*NSW BioNet Vegetation Classification: Classification'* (BVC) (OEH 2019; Benson 2006; Benson 2008; Benson et al. 2010).

Thus, this study employs two branches of vegetation science; landscape scale vegetation community ecology and vegetation community dynamics, to develop an effective way to measure and track the condition of identified flood-dependent PCTs, using key indicators of condition and their quantified relationship to inundation variables at the regime scale. In this study community dynamics are not only used as an indicator of response, but the response of the community has a set of parameters within which change is measured. Thus condition is measured by a suite of response variables that have predefined ranges within which change can be quantified and compared against a known scale of predicted outcomes.

1.8 Research questions

For this study the following questions were defined:

1. What are the key indicators of condition (response variables) for floristic community condition and tree stand condition in selected inland floodplain wetland plant communities?
2. What is '*optimal*' or '*benchmark*' for floristic community condition and tree stand condition for each inland floodplain wetland plant community?
3. What inundation regime does each inland floodplain wetland plant community need to be maintained in optimal or benchmark community condition and tree stand condition?

1.9 Review of inundation regime requirements of dominant species of inland floodplain wetland plant communities in the Macquarie Marshes

A review was undertaken of the published inundation regime requirements and assignation to Water Plant Functional Groups (WPFGs) (Brock and Casanova 1997) of the dominant species of the flood-dependent NSW PCTs (NSW Government 2018), examined in this study(e.g. Roberts and Marston (2000), Roberts and Marston (2011) and Casanova (2015)) .Much of the available information is derived from studies undertaken in the

Southern MDB or overseas and may not be directly applicable to PCTs occurring in the Northern MDB, where the study area is located, however are included here as constituting the best information available.

1.9.1 Flood-dependent woody communities

Coolibah (*E. coolabah*), (WPFG; Terrestrial damp (Tda), PCT 40; Coolibah grassy woodland)

The average inundation frequency for coolibah is largely unknown although the species is found in areas that are more frequently flooded, and for longer, than the literature suggests would be the case (Casanova 2015). Anecdotal sources indicate that best inundation duration is likely to be 1 to 2 months and although flood timing unknown, it is probable that shallow flooding in late summer is required (OEH 2012). The distribution pattern of coolibah woodlands suggests that an inundation frequency of 1 in 10 to 20 years for several weeks is required (Foster 2015; Casanova 2015). The inundation frequency for Coolibah woodlands on the lower Gwydir floodplain is 1 in 10 to 1 in 20 years (Wilson et al. 2009).

River red gum (*E. camaldulensis*), (WPFG; Amphibious Tolerator – woody (ATw), PCTs 36, 36A; River red gum forest and woodland and 454; River red gum grassy woodland)

To maintain health of forest river red gum trees (equivalent to PCT 36), the average inundation frequency required is 1 in 3 years, with average duration of 1 to 7 months, maximum 2 years, in winter–spring, with soil drying/aeration between flood cycles. A large flood extending well into summer followed by a wet winter– spring or shallow and brief flooding in winter–spring or in summer is the optimum timing (OEH 2012). Four years is the maximum inter-flood period (Casanova 2015) or 2 years (Doody et al. 2015). In Victoria, river red gum forest with an aquatic or sedge understorey is said to require a flooding frequency of seven years in ten, for a minimum of 4 to 7 months, with a maximum dry interval of 3 years (DSE 2008).

For river red gum trees in open woodland (equivalent to PCT 36A), optimum inundation frequency is likely to be less than 5 in 15 years with a duration of 2 to 7 months with 4 years maximum inter-flood period (Casanova 2015).

In Victoria, for woodland with a grassy or shrubby understorey, occurring further out on the floodplain (equivalent to PCT 454), the optimum inundation frequency is 3 to 4 times in 10 years, for up to 2 months, with a maximum dry interval of 5 to 7 years (DSE 2008).

Lignum (*D. florulenta*), (WPFG ATw, PCT 247; Lignum shrubland wetland)

Lignum shrubland requires an average flood frequency of 1 in 3 to 10 years, with an average duration of 1 to 6 months and maximum duration of 12 months, probably best in spring–summer, with soil drying/aeration required between floods (Casanova 2015). Deep inundation of greater than 60 cm is associated with an absence of lignum (OEH 2012). Lignum spreads predominantly via vegetative growth, particularly in more frequently flooded areas (Capon et al. 2009; Murray et al. 2012).

1.9.2 Non-woody wetland and understory species

Water couch (*P. distichum*), (WPFG; Amphibious Tolerator – emergent (ATe), PCT 204; Water couch marsh grassland)

Duranel et al. (2007) found that water regime and nutrient loads were important factors in the establishment of wet grassland communities (i.e. those analogous to water couch marsh grasslands) in the Thames valley.

In Australia water couch requires moist to wet soil conditions for 75% of the year. Floods can be shallow (5–15 cm), at least 20 to 30 cm but less than 60 cm unless only briefly (Roberts and Marston 2011). Flooding can be continuous and lasting 4 to 6 months, or 2 to 3 times per year (Casanova 2015), or for 5 to 8 months (Roberts and Marston 2011). Water couch can recover from a one to three-year dry period but cannot tolerate repeated dry spells (Roberts and Marsden 2011). A flood frequency of once in every 2 to 8 years is optimal but this varies geographically, duration is 5 months in the south and 6 to 12 months in the north of the MDB (Foster 2015; Casanova 2015). Water couch grasslands on the lower Gwydir floodplain in the northern MDB are estimated to require flooding every one to two years (Wilson et al. 2009) or 85 per cent of years (Bennett and Green 1994).

Timing of flooding is critical in late winter or spring, as flooding is needed over summer, thus winter flooding is best avoided unless it is long-lasting. Water couch needs flooding after 2 to 3 years to maintain vigour, but if the dry interval is longer, then sites may require a sequence of good conditions to recover (Roberts and Marston 2011). In the Gwydir wetlands in NSW, inundation increased the cover of water couch in the field, and glasshouse trials showed that the exotic species lippia (*Phyla canescens*), had a competitive advantage under dry soil conditions, and therefore in water couch grasslands, dry conditions favoured lippia over water couch (Price et al. 2011).

Germination and seedling requirements of water couch are unknown however, germination cannot take place underwater and regeneration is probably from rootstock rather than seed, as seeds are short-lived (2 years), and the seed bank must be replenished almost annually if regeneration is dependent on seeds (Roberts and Marsden 2011). Rootstock of water couch persists for about 5 to 7 years in heavy clays, so the dry interval should not exceed this time, and vegetative regeneration from fragments or buried nodes may be important, therefore, moist soil conditions for extended periods is essential for both sexual and vegetative reproduction (OEH 2012).

Sedge (*Cyperus exaltatus*), (WPFG ATe, PCT 53; Mixed marsh sedgeland)

Cyperus exaltatus requires annual flooding with duration of 135–200 days (8 months). Flood timing is preferably late winter and low turbidity is required for growth (OEH 2012).

Sedge (*Cyperus gymnocaulos*), (WPFG ATe, PCT 53)

Cyperus gymnocaulos forms a persistent seed bank and seedlings were observed in the field on newly exposed sediment (Nicol 2004). Nichol et al. (2018) found that optimal conditions for growth for *C. gymnocaulos*, were non-flooded conditions though it survived in several experimental hydrological regimes and elevations however, plants subjected to complete inundation senesced to rhizomes that remained dormant until flooding pressure ceased. The species showed an ability to rapidly switch between dormant and actively growing states with stems sprouting from rhizomes within 1 week when exposed to the atmosphere (Nichol et al. 2018). *C. gymnocaulos* rhizomes were observed sprouting in Lake Cawndilla (lower Darling River) at elevations where the sediment had been submerged for nearly eight years by water up to 7 m deep, though plants that had not developed rhizomes were intolerant of complete submergence (Nicol 2004).

Common spike rush *(Eleocharis acuta*), (WPFG ATe, PCT 53)

Common spikerush requires annual flooding with a duration of 3–10 months (OEH 2012). Inundation is required every 1 to 3 years, to 30 to 40 cm for 4 to 6 months, with the dry phase in late summer to autumn, as regeneration occurs on flood recession or following drawdown, but succeeds only if substrate remains moist (Roberts and Marston 2011). Seedling growth is sensitive to drying conditions and establishment is optimal in moist conditions or shallow water, so establishment may require a brief, shallow follow-up flood (or rainfall) (Roberts and Marston 2011).

Tall spikerush (*E. sphacelata*), (WPFG ATe, PCT 53)

Tall spikerush typically forms dense monospecific stands, and is tolerant of a range of water depths, but not of rapid drawdown (Roberts and Marsden 2011). It is found at sites that are permanently flooded in wetlands that flood annually for 6 to 8 months and have a seasonal drying phase and in wetlands that flood only infrequently (Williams and Ridpath 1982; Roberts and Marsden 2011).

Water primrose (*Ludwigia peploides*), (WPFG ARp; Amphibious Responder - plastic, component of PCTs 204, 53, and understorey of most PCTs in the study)

Water primrose requires annual inundation of 8 to 10 months to a depth of 1 m in winter to summer as seeds can germinate in 5 days given water or wet soil, light and warmth (30°C) (OEH 2012)). *L. peploides* can cope with flooding to a depth of 70 cm (Nichol et al. 2018). *L. peploides* only requires a short dry interval to reproduce via seed, and the high degree of phenotypic plasticity of *L. peploides* enables it acclimatise rapidly to rising water levels. Thus this species may have the ability to preferentially allocate the immediate products of photosynthesis to aboveground organs when flooded (Nichol et al. 2018).

Common reed (*Phragmites australis*), (WPFG Se; Perennial – emergent, dominant of PCT 181; Common reed tall grassland, component of PCT 53, understorey of most PCTs in the study)

Common reed is a grass that tolerates a range of flood frequencies from permanent inundation to infrequent flooding. To maintain vigour, a 1 to 2-year flood frequency is required (OEH 2012).

Cumbungi (*Typha domingensis*), (WPFG Se, dominant of PCT 182; Cumbungi reedland, component of PCT 53, understorey of most PCTs in the study)

Typha domingensis grows to 3 m tall, tolerates flooding to a depth of 80 cm and can produce ~250 000 wind-dispersed seeds per inflorescence (Chambers et al. 1995). Cumbungi requires annual inundation, of 8 to 12 months, and the species is more likely to occur where water levels are stable. Flood timing is best in winter–spring to early summer. Shallow water (0–5 cm) or saturated mud is required for seed germination. Deeper water (5–15 cm) required for seedling growth and continuously moist conditions for 3 months in summer and 6 months in winter is required for seedling establishment, although rhizomes can survive without flooding for up to 2 years if established (OEH 2012). Typha will germinate and grow in quite deep water providing it is clear and it can eventually reach the surface and has a broad regeneration niche with seeds germinating in many hydrologic regime treatments (Nichol and Ganf 2000).

Native millet (*Panicum decompositum*) WPFG; Terrestrial dry (Tdr), WPFG Tdr, Cup grass (*Eriochloa crebra*) WPFG Tdr, grassland PCT 214.

Floodplain grassland dominated by native millet and cup grass (PCT 214), are part of the vegetation class called *Semi-arid Floodplain Grasslands* described as; *closed tussock grasslands with occasional chenopods and other shrubs, that occur on black clay soils on elevated parts of riverine plains that are only occasionally flooded, and where mean annual rainfall of 375-500 mm is predominantly in summer* (OEH 2018a). Hydrological parameters may have a major impact on species composition of floodplain grasslands (Hettrich and Rosenzweig 2003; van Eck 2004; Leyer 2005; Taylor and Ganf 2005). For example the abundance of species characteristic of traditional management was found to increase with frequency of flooding in sites in the northern Elbe River valley (Härdtle et al. 2006). Bischoff et al. (2009), found a negative correlation between elevation and the abundance of floodplain grassland indicator species, indicating that the indicator species occurred in the lower lying and therefore wetter areas. A native grass species that occurs in floodplain grassland Rat's Tail Couch (*Sporobolus mitchellii*) will tolerate inundation for quite some time in experiments with samples taken from the southern MDB (Taylor and Ganf 2005).

1.10 Conceptual model of inland floodplain wetland plant community condition in response to inundation regime

A conceptual model is a diagrammatic representation of how '*key components of a target ecosystem interact and/or influence each other'* (Lindenmeyer and Likens 2009). For this study a conceptual model was developed that recognises the key drivers of change in condition of flood-dependent inland floodplain wetland plant communities in the Macquarie Marshes.

The most important components of the water regime for wetland plants are depth, duration, and season at an annual time scale, while frequency, inter-flood interval and variability (or its converse, regularity) are most important over longer time-scales (Roberts et al. 2000). Differences observed between macrophyte assemblages at wetlands in the Murray River region reflected the importance of the cumulative effect of flood events over several years (i.e. regime) (Reid and Quinn 2004). Change in inundation frequency and duration have been identified as key drivers of the dynamics of flood-dependent plant communities in the Macquarie Marshes at the regime (>5 years) scale (Thomas et al. 2011, Bino et al. 2015).

Many flood-dependent inland floodplain wetland plant communities do not fit the classical theory of ecosystem resilience, i.e. as a single stable state driven by biodiversity and functional redundancy, and where loss of resilience is indicated by the transition to an alternative stable state (e.g. Clements 1938). However, change to an alternative stable state is possible under very extreme climactic or regime scale changes and in this model is *State 1 Permanent terrestrial community* or *State 3 Permanent aquatic community*.

Inland floodplain wetland plant communities are considered to follow the response model of Colloff and Baldwin (2010), i.e. a single state with two alternative phases, the wet phase and the dry phase. The stability of the system (its resilience), is represented by its capacity to fluctuate between the phases while constantly reinstating the structure and function typical in each phase i.e. *Excellent* or *Optimal* condition. Optimal condition is defined as the state in which water availability meets life history needs of all key indicator species/groups.

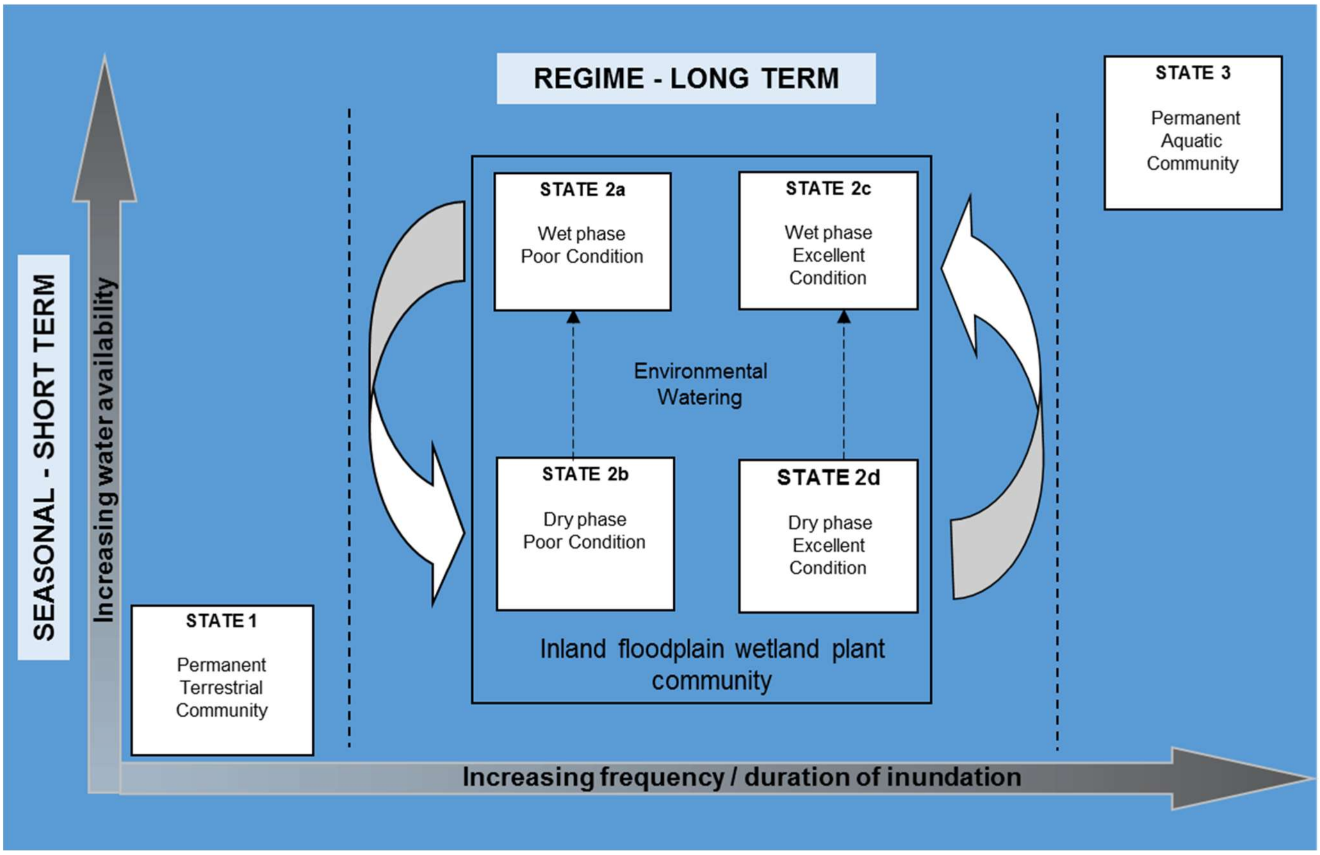

Figure 2 Conceptual model

The model has two temporal dimensions and two hydrological dimensions for hydrological conditions (water availability), long-term, referred to as '*REGIME- LONG TERM*' from left to right, and short-term referred to a '*SEASONAL SHORT TERM*' from bottom to top. Regime relates to the frequency and duration of inundation at a ≥ five- year timeframe, Seasonal relates to a ≤ one-year time frame. Both the regime and seasonal hydrologic dimensions are scalable for each inland floodplain wetland plant community.

The conceptual model has four simplified condition states; '*State 2a: Wet phase / Poor condition'*, '*State 2b: Dry phase / Poor Condition*', '*State 2c: Wet phase / Excellent Condition'*, and '*State 2d: Dry phase / Excellent Condition* (Figure 2). This is because these plant communities are highly dynamic, i.e. they change their relative proportions of extant plant species in response to changes in water availability. This does not mean that these species are absent but that they may be present in a dormant form (e.g. as seed, tuber or rhizome). This acknowledges that an inland floodplain wetland plant community can be in a dry phase in a seasonal timeframe, but still exhibit excellent condition if it receives appropriate inundation in the regime timeframe, and conversely, a wetland plant community can be in a wet phase but still exhibit suboptimal condition if the regime scale water requirements of the dominant species are not being met.

A management driver *environmental water* is identified that can to change the state of the plant community in that season from a dry phase to wet phase. However, the environmental water may only change the phase not the state within the season, and it is the regime scale of environmental watering that can be manipulated to shift and maintain the plant community to excellent condition within both phases.

Thus, optimal condition for a PCT is defined by the community structure and species composition and community structure consistent with *NSW BioNet Vegetation –*

Classification' (BVC) diagnostics for the PCT (NSW Government 2018). The proportions of percentage cover diagnostic species are as would occur under an optimal inundation regime.

1.11 Thesis outline

This theses is structured with an introductory chapter (Chapter 1), three stand-alone data analysis chapters that are able to be read as separate studies (Chapters 2, 3 and 4), and a discussion chapter (Chapter 5). While the data chapters are independent of one another they are also complimentary studies and are linked through the use of the same data and underlying hypotheses about that data.

In this current chapter I review the current state of water availability for inland floodplain wetlands in the MDB. I described the study approach. I reviewed the published water regime requirements available for some of the key species of the eight NSW Plant Community Types (PCTs) examined this study. I presented a conceptual model of the water related drivers of condition states in inland floodplain wetland plant communities in the landscape, and define the causal linkages between components of the inundation regime and PCT structure to direct the experimental design.

In Chapter 2, I described the study area and give a brief history of water availability and water management in the Macquarie Marshes. I introduced the eight PCTs examined in this study. I discussed the measures currently used to assess condition of PCTs in NSW and the need for specific methods and benchmarks for flood-dependent PCTs. I described the response variables that I will use to define benchmarks for floristic community and tree stand condition and the underlying hypotheses these are based on.

I described the survey design and field sampling methods employed. I outline the method to used test actual trends in the data collected in the period 2007/08 to 2016/17 against those hypothesised, using a Multivariate Regression Forest (MRF) analysis.

In Chapter 3, I developed and tested a condition classification schema for floristic and tree stand condition for the seven PCTS, applying outcomes of the hypothesis testing by MRF analysis in Chapter 2. These condition schemas were validated using preclassified site response data (grouping of floristically similar sites) against the inundation predictors found to be most important to those wetland types in the MRF analysis.

In Chapter 4, the floristic condition and tree stand data was transformed into condition scores using the condition class schemas developed and validated in Chapter 3. This condition score data was used to develop *ecological reference models* (ERMs) for the eight PCTs using Generalised Linear Mixed Models (GLMM). The use of ERMs as predictive models of ecosystem response to inundation, to inform the setting and monitoring of restoration targets was discussed.

In Chapter 5, I discussed the results of the studies in Chapters 2 to 4, and tied together the findings of the three studies. I discussed the limitations of the data and the requirements for further sampling. I also discuss the importance of the outcomes of the study and the use of these outcomes and possible addition products derived for the research.

Chapter 2 Modelling condition response variables of inland floodplain plant communities in relation to inundation predictor variables

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2.1 Introduction

In this chapter, the key floristic community and tree stand condition response variables are identified, using Multivariate Regression Forest (MRF) analysis of floristic, tree stand and inundation data collected in the Macquarie Marshes from 2008 to 2017. Several hypotheses regarding the response of these variables to predictor variables (inundation duration and frequency) were tested.

Survey sites were classified into groups and these groups were related to predictor variables (inundation regime variables). The floristic condition response variables were modelled using the predictor variables as; i) a combined data set modelled for each stratum in the plant community and, ii) separately for eight key inland floodplain wetland NSW Plant Community Types (PCTs) in the Marshes; river red gum (*Eucalyptus camaldulensis*) forest (PCT36), woodland (PCT 36A), and grassy woodland (PCT 454), Coolibah (*Eucalyptus. coolabah*) woodland (PCT 40), lignum (*Duma florulenta*) shrubland (PCT 247), water couch (*Paspalum distichum*) marsh grassland (PCT 204), mixed marsh (*Eleocharis* spp.) sedgeland (PCT 53), and floodplain grassland (PCT 214).

The same MRF analysis was undertaken using condition scores derived from tree stand condition response variables for the tree dominated forest and woodland wetland types.

2.1.2 The Macquarie Marshes

2.1.2.1 Location

The Macquarie Marshes (the Marshes), are a complex inland floodplain wetland system at the lower reaches of the Macquarie River, approximately 250 km north of Dubbo in Central Western NSW, in the MDB in semi-arid South-eastern Australia (OEH 2012) (Figure 3). The Marshes cover approximately 200,000 ha and have been a wetland system for the last 6000 to 8000 years (Yonge & Hesse 2002). The Marshes is the country of the Wailwan people (Peckham & Molsher 2005; Jenkins et al. 2012).

The Marshes are one of the largest freshwater wetlands in the MDB (OEH 2012). The Marshes are recognised nationally and internationally for their biodiversity values. The Marshes contain the largest occurrence of river red gums in northern NSW, the most southern occurrence of coolibah, and the largest area of common reed (*P. australis*) tall grassland in NSW (NSW Environment Protection Authority 1995). The Marshes are of international importance as waterbird habitat, with at least 76 waterbird species (44 breeding), recorded (Kingsford and Auld 2005). A species of invertebrate, the rotifer *Lecatie shielii,* discovered in the Marshes, has been found nowhere else in Australia (Kobayashi et al. 2007).

Approximately 10 per cent of the Marshes are within the *Macquarie Marshes Nature Reserve*, gazetted in January 1971, and managed by NSW OEH under the *NSW National Parks and Wildlife Act* (1974) (NPWS 2004; OEH 2012). The Marshes are listed in the '*Directory of Important Wetlands in Australia'* (Environment Australia, 2001). The Macquarie Marshes Ramsar site was listed in 1986 and covers 19,850 ha of the Marshes (DECCW 2010d). It consists of the Macquarie Marshes Nature Reserve both '*Northern*' and '*Southern*' portions (19,078 ha), and parts of the private properties, '*Wilgara*' (Wilgara

Wetland, 583 ha), listed in 2000, and '*The Mole*' (U-block, 189 ha), listed in 2012 (OEH 2012; OEH 2013; Australian Government 2017a) (Figure 4).

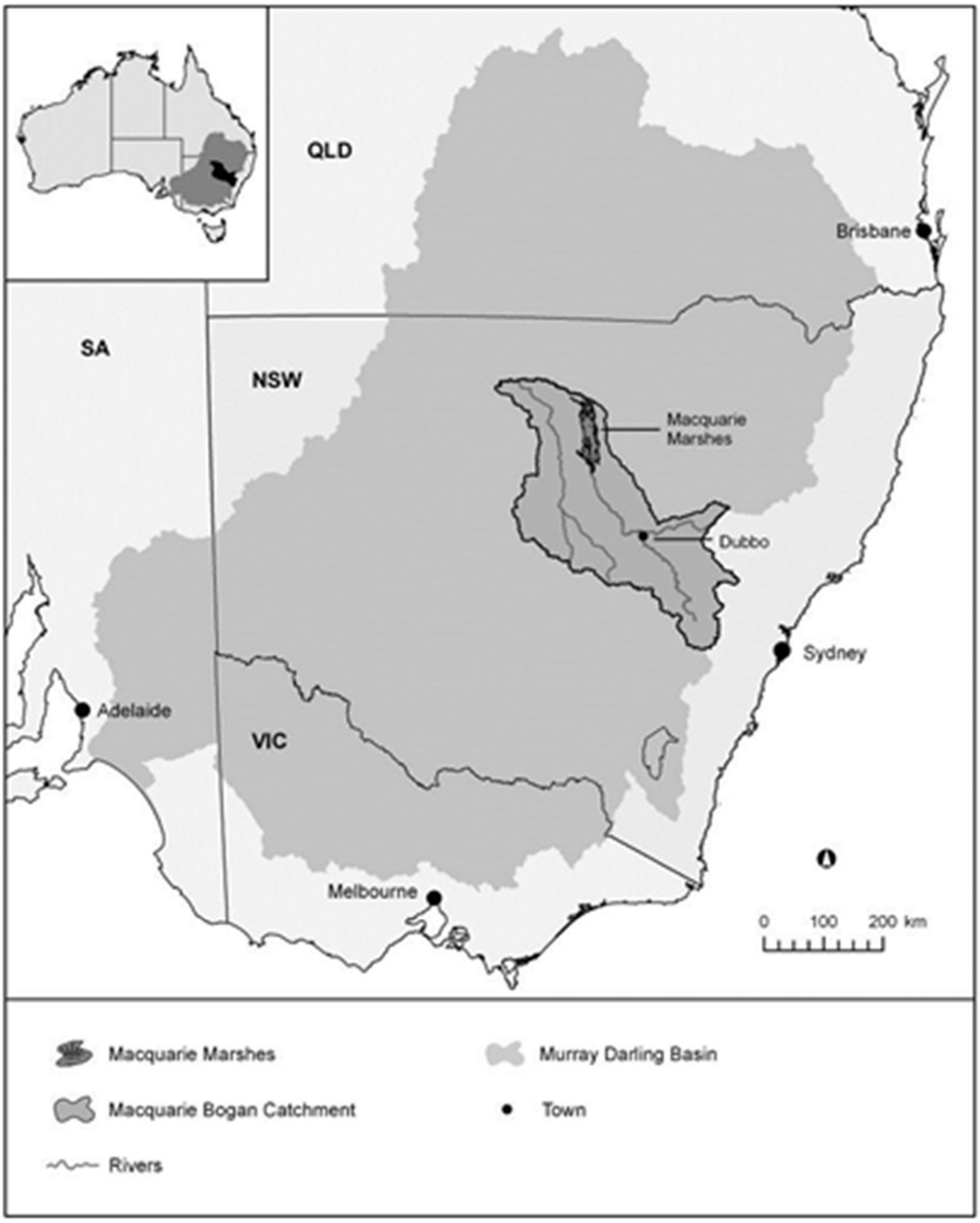


Figure 3 Location of the Macquarie Marshes in the MDB

2.1.2.2 Hydrology

The extent of the Marshes is defined by flood patterns and vegetation types. The Marshes is inundated by flows from the Macquarie River and its distributary streams and anabranches. When water reaches the Marshes from the Macquarie River, a complex distributary system of creeks branches out to different parts of the floodplain. The Macquarie River has a major split (the Marebone Break), that separates flow between the Macquarie River and three creek systems: the Bulgeraga Creek, Gum Cowal/Terrigal Creek and the Long Plain Cowal. The Terrigal Creek system flows east then north through the Wilgara Ramsar site and joins the Marthaguy and Merri creek system. The Bulgeraga Creek and Long Plain Cowal flow north back towards the main channel of the Macquarie River (Figure 4).

In the south, the Macquarie River branches into Monkeygar Creek and Buckiinguy Creek. The Macquarie River loses its channel in the floodplain of the Southern Nature Reserve before reforming as the '*Old Macquarie'* channel downstream. The Monkeygar Creek, has formed by avulsion (i.e. lateral relocation of channels on the floodplain), of the channel of the Macquarie River within the last 200 years (Ralph et al. 2011). In the south wetlands associated with the Old Macquarie River and Monkeygar Creek have contracted and some have been inactive since the 1920s as river changed the distribution of water and sediment (Ralph et al. 2016).

The Old Macquarie River flows north along the western boundary of the Southern Nature Reserve but, as it no longer flows regularly, the Monkeygar system is the major flow path. However, an erosion channel, known as '*The Breakaway'*, flows in a westerly direction from the Monkeygar Creek to the Old Macquarie River. This and another channel off The Breakaway, continues to erode and carry water from the Monkeygar into the largely dry Old

Macquarie River, bypassing the erosion control structures that were put in place in 2002 (Ralph 2008; NPWS 2004; OEH 2012; OEH 2013) (Figure 4).

The Monkeygar Creek system flows north through the eastern section of the Southern Nature Reserve. The Old Macquarie River, Monkeygar Creek and Bulgeraga Creek then join up upstream of the U block (The Mole) Ramsar site and reform the Macquarie River. The Macquarie River then flows into the Northern nature reserve. It continues to the north before the braided channels of Bora Channel and Ginghet Creek run through the western half of the northern Nature Reserve. There the Macquarie River braids out of its channel and becomes the main large reed bed in the southern part of the northern Nature Reserve, before reforming as a channel in the northern part of the Northern Nature Reserve (Figure 4). The Northern Nature Reserve also has a constructed channel that causes water to bypass the Marshes on its eastern side, the '*Bypass Channel*', which takes low flows downstream most of the time. During large floods the Long Plain Cowal also provides flows to the northern section of the nature reserve (Figure 4) (OEH 2012). During high flows, water flows through the Macquarie Marshes can reach the Darling River (OEH 2012).

The Marshes are divided into three water management regions; North, encompassing the northern wetland areas of the North Marsh, Mole Marsh and the northern section of Monkeygar Swamp, South, including Buckiinguy Swamp, Monkey Swamp and the southern section of Monkeygar Swamp, and East; the wetlands of the Terrigal Creek, Gum Cowal, Bulgeraga Creek and Long Plain Cowal (DECCW 2010b; Figure 4).

2.1.2.3 Climate

The climate of the lower Macquarie River catchment is hot and semi-arid; with summer-dominant rainfall averaging about 400 mm per year and evaporation of about 2,000 mm per year. Mean monthly temperatures range from 26.5° C in January to 12° C in July.

The highest recorded temperature is 48.9° C and the lowest -4.2° C (Jenkins et al. 2012; Australian Government 2015).

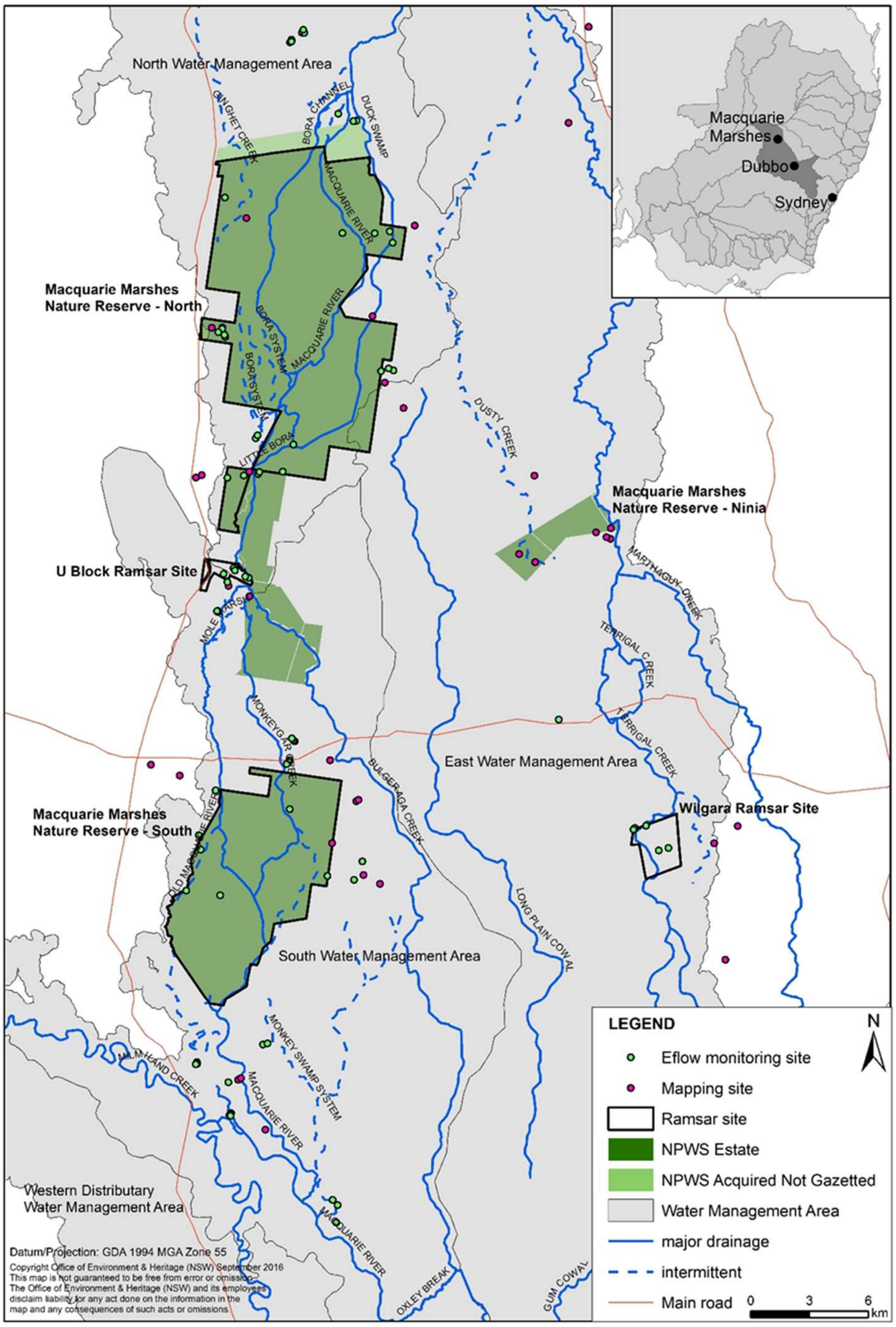


Figure 4 Location of the Macquarie Marshes Nature Reserve and Ramsar sites and survey sites

2.1.2.4 Soils

The soils of the Marshes are heavy-textured deep, cracking, grey brown and black silts and clays, to depths of between two and nine metres (Brereton 1994; Ralph 2008; Yonge 2000). These soils are poorly drained and fairly low in nutrients. Sand content is usually less than 20%, and the proportion of organic materials is only 5–10% (Ralph 2008). As these clay-rich soils dry out, they develop deep cracks, mostly in areas of the floodplain away from the main channels where inundation is the most variable. This leads to *gilgai* topography, the natural low mounds and shallow depressions formed by shrinking and swelling of clay-rich soils (OEH 2012).

2.1.3 History of change in water availability in the Macquarie Marshes

Grazing by domestic animals and the establishment of cattle stations began in the 1830s and floodplain graziers still occupy the Marshes (OEH 2012; Jenkins et al. 2012).

Irrigated agriculture began not long after European settlement in the 1840s in the South Marsh however, it was not until the completion of Burrendong Dam in 1967 that large scale irrigation began (MRAC 1994). The Marshes have been under ecological stress since the construction of Burrendong Dam, and this has been made worse by periods of drought and changes in land and water management practices (MRAC 1978; WRC 1981; Brander 1987; Bray 1994; Kingsford and Thomas, 1995; NSW Government 2003; Johnson 2005; Bowen and Simpson 2010b; DECCW 2010b Thomas et al. 2010, Pittock et al. 2010; OEH 2013). Since regulation of the Macquarie River in the late 1960s there has been a shift in the timing of flooding, primarily from winter–spring to spring–summer (Brereton et al. 2000). A significant reduction in the frequency of flooding has also been recorded, with the loss of three or more spring floods in each nine-year period, despite no change in catchment and local rainfall over a 27-year period (1979-2006) (Thomas et al. 2011). It is likely that the

Millennium Drought period (MD) (1996 - 2010) increased the rate of decline as large areas of wetland were not flooded for several years (OEH 2013). These changes have adversely impacted waterbird populations (Kingsford and Thomas 1995; Kingsford 2000).

The extent of all plant communities present in the Marshes was mapped in 1991 by Wilson (1992), in 2008 by Bowen and Simpson (2009), and in 2013 by Bowen et al. (2014). In the period 1991 to 2008, the total area of non-woody wetland vegetation (i.e. water couch marsh grasslands, common reed tall grasslands, mixed marsh sedgeland and cumbungi rushlands), was reduced by 67 percent from the area that had been mapped in 1991. Most had been replaced by the invasive native terrestrial chenopod shrubs; buckbush (*Salsola kali*) and black roly poly (*Sclerolaena muricata*), and some areas had been cleared for cultivation. In 2008 only 38 percent (2,378 ha) of the remaining 6,213 ha of non-woody wetland vegetation was in good condition. These areas were located within the northern Macquarie Marshes Nature Reserve and Monkeygar Swamp (Bowen and Simpson 2010).

In the same period (1991 to 2008) there was a reduction in the extent and a marked decline in the condition of flood dependent woody vegetation communities; river cooba, lignum and river red gum forest and woodland. In 2008, 40 percent of the 38,428 ha of river red gum communities in the Marshes were in poor condition (more than 80 % dead canopy), 55 percent were in intermediate condition or declining in condition, and only 1,932 ha or 5 percent of the total extent of river red gum communities was in '*good*' condition (less than 10 % of the canopy dead) (Bowen and Simpson 2010; Thomas et al. 2010).

In response to these changes, a notification of a '*likely change in ecological character'* of the Macquarie Marshes Ramsar site was submitted under Article 3.2 of the Ramsar Convention, to the Ramsar Secretary General on 17 July 2009. This change was described as a '*likely change*' from a semi-permanent wetland system to an ephemeral wetland system in parts of the Macquarie Marshes Ramsar site (OEH 2013). The change had mostly taken place in the reed bed of the southern Nature Reserve and in the river red gum forests and woodlands in the northern Nature Reserve. The was deemed to be outside the '*Limits of Acceptable Change'* set for the time of Ramsar listing (1986), because of changes to the flow regime and drought conditions from 2001 to 2010 (OEH 2012).

2.1.4 Water resource management in the Macquarie Marshes

In 1962, public concern regarding the effect on the Marshes of the then proposed Burrendong dam led to an announcement that '*40,000-acre feet'* (about 50,000 Megalitres (ML)) of water would be set aside annually for the Marshes (National Trust 1985: cited in Johnson 2005). Small environmental water allocations have been provided for under statutory plans since 1980. The first delivery (675 ML) of held (licenced) environmental water under the *Water Management Act* (2000) (WM Act (2000)), was delivered to the Marshes in the 2008/09 water year. In 2016 the total discretionary environmental water allowance was 160GL (160,000 ML) General security entitlement under the regulated Water Sharing Plan, plus 174GL General Security entitlement, in held environmental water between NSW OEH and the Commonwealth Environmental Water Office (CEWO) (OEH 2016).

In the Marshes the total recovery of water for the environment under the Basin Plan was 75.5 GL (DAWR 2018). In the 2017/18 water year this was worth around $AUD 5 to 13 million to the NSW public, depending on water prices on the open market (Aither 2018). In NSW, environmental water is managed in accordance with '*Water Sharing Plans'* established under the NSW Governments' WM Act (2000) and *'Water Resource Plans' prepared under the* Basin Plan, legislated in 2012 under the Australian Governments' *Water Act* (2007). Under the Basin Plan, environmental watering plans for the Macquarie Valley are prepared annually with environmental water management objectives that vary with water availability each year (OEH 2015). Also, as part of the Basin Plan a '*Long-term Water Plan'* (LTWP) for the Marshes will guide environmental watering activities to meet medium and long-term targets in an adaptive management framework (OEH 2015).

Under the Basin Plan, the *Basin-wide Environmental Watering Strategy* (BWS) released in 2014, describes the expected outcomes to maintain the extent and to improve the condition of '*water-dependent*' (i.e. flood-dependent) vegetation in the Marshes (MDBA 2014b). The environmental objectives, outcomes and targets described in the BWS scopes the management of environmental water in the Marshes including undertaking ecological restoration where required. The Basin Plan also includes environmental monitoring, evaluation and reporting (MER) responsibilities for the Marshes in relation to environmental water delivery and long-term water planning (OEH 2017b).

2.1.5 Inland floodplain wetland plant communities in the Macquarie Marshes

In the BWS, water-dependent vegetation has been classified into three structural groups or '*Wetland types*': forests and woodlands, shrublands and non-woody vegetation (Figure 5). These vegetation types have been adopted in this study. These wetland types are classified on the basis of plant species composition. As plants are key primary producers, ecosystems are often classified on the basis of the communities of vascular plants (Kent

2012; Seiben et al. 2018).

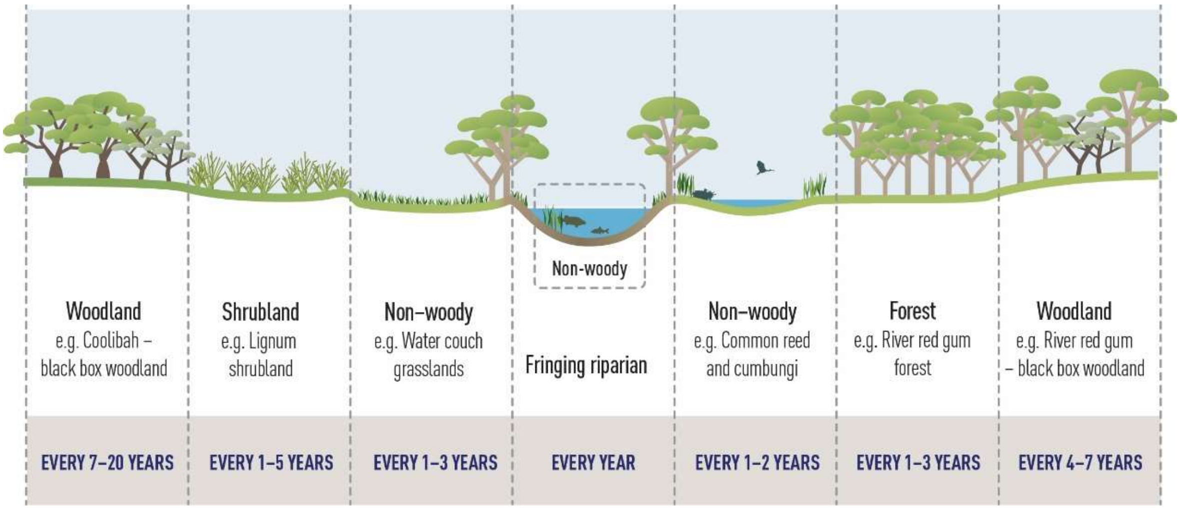


Figure 5 A stylised example of structural groups of flood-dependent vegetation, (Source: MDBA, 2014b)

This study also uses '*Hydrological Functional Groups'* (HFGs) analogous to BWS '*Wetland Types*' (Bowen and Simpson 2009; Bowen and Simpson 2010a; Bowen and Simpson 2010b; Bowen et al. 2014), based on the wetland species functionality, watering and life history requirements of the dominant species (Casanova and Brock 1997; Roberts and Marston 2000; Casanova 2011), and the structural characteristics of the PCT (OEH 2019) are also used as a wetland specific classification system in this study:

Non–woody wetland: Communities that depend on frequent flooding (once per year), to maintain their structural integrity and condition. These include: water couch (*P. distichum*) marsh grasslands, mixed marsh (*Eleocharis* spp.) sedgelands, common reed (*P. australis*) tall grasslands and cumbungi (*T. domingensis*) rushlands.

Flood-dependent woody communities: Forests, woodland and shrublands that are dependent on sufficient flooding for the dominant over-storey species to complete their life cycle. This includes: forests and woodlands dominated by river red gum (*E. camaldulensis*), woodlands of black box (*E. largiflorens*) and coolibah (*E. coolabah*), and shrublands of river cooba (*Acacia stenophylla*) and lignum (*D. florulenta*).

This study also uses Plant Community Types (PCTs), the finest scale of the NSW BioNet Vegetation Information System– Classification (BVC), a hierarchical classification system for use in vegetation survey, mapping and conservation assessment in NSW (OEH 2018b; OEH 2019), see https://www.environment.nsw.gov.au/research/Visclassification.htm

This classification system follows the structural classification rules for vegetation types of the '*Australian Vegetation Attribute Manual'* (Australian Government 2003).

For example, the hierarchical classification for PCT 204 '*Water Couch Semi-permanent wetland of frequently flooded watercourses*' is at Figure 6 . This community is classed as an '*Inland Floodplain Swamp'* and is in the formation '*Freshwater Wetlands'*.

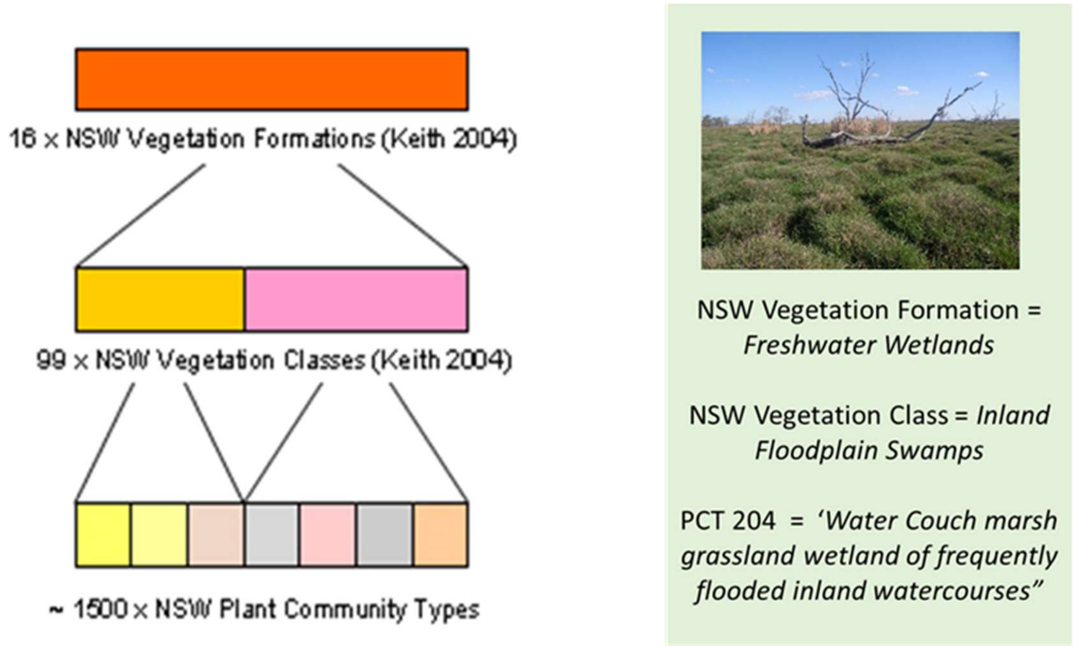


Figure 6 NSW vegetation classification hierarchy

Thus, a survey site can be classified as '*PCT 204 Water couch marsh grassland',* if the grass water couch (*P. distichum*), is the dominant species (i.e. >30% of cover, OEH 2019;

Walker and Hopkins 1990), and the site is classified as a 'grassland' as the dominant species is a grass of 1 m or less in height on average (Australian Government 2003; OEH 2019), and it is 'marsh' because the dominant species water couch requires frequent inundation to complete its life history.

Eight key inland floodplain wetland NSW Plant Community Types (PCTs) were sampled in this study; river red gum (*Eucalyptus camaldulensis*) forest (PCT36), woodland (PCT 36A), and grassy woodland (PCT 454), Coolibah (*Eucalyptus. coolabah*) woodland (PCT 40), lignum (*Duma florulenta*) shrubland (PCT 247), water couch (*Paspalum distichum*) marsh grassland (PCT 204), mixed marsh (*Eleocharis* spp.) sedgeland (PCT 53), and floodplain grassland (PCT 214). The eight PCTs sampled in this study are shown in Figure 7 (Photo credit: Sharon Bowen), and descriptions and diagnostics of each can be accessed here (OEH 2018b):

https://www.environment.nsw.gov.au/NSWVCA20PRapp/LoginPR.aspx

PCT 204: Water couch Marsh Grassland – Macquarie Marshes

PCT 241: River Cooba – Lignum Shrubland – Macquarie Marshes

PCT 247: Lignum Shrubland – Macquarie Marshes

PCT 40: Coolibah Grassy Woodland – Macquarie Marshes

PCT 36: River red gum forest – Macquarie Marshes

PCT 36A: River red gum woodland – Macquarie Marshes

PCT 53: Mixed Marsh sedgeland – Macquarie Marshes

PCT 454: River red gum grassy woodland – Macquarie Marshes

Figure 7 Flood-dependent Plant Community Types in the Macquarie Marshes

2.2 Methods

2.2.1 Measures used to assess plant community condition in NSW

The NSW '*Biodiversity Assessment Methodology'* (BAM), is a method for the assessment of '*vegetation integrity*' (condition) of a native vegetation community against a '*benchmark*' for the identified NSW Plant Community Type (PCT) (State of New South Wales 2017; State of New South Wales 2018). Under the BAM, benchmarks are defined as; '*the quantitative measures that represent the 'best-attainable' condition, which acknowledges that native vegetation within the contemporary landscape has been subject to both natural and human-induced disturbance*' (State of New South Wales 2017; State of New South Wales 2018). Benchmarks describe the reference state to which sites are compared to score their site scale biodiversity values. The three primary attributes of biodiversity; composition, structure and function are described by benchmarks scored against the benchmark data for the relevant PCT and these are combined into a *vegetation integrity score* (State of New South Wales 2017; OEH 2017c).

Vegetation Integrity Score is composed of a composition condition score; native species richness (by growth form) and a structure condition score; percent cover (by growth form), for PCTs that are freshwater or saline wetlands, grasslands, arid shrublands, or heaths. It also includes a function condition score; (number of large trees, length of logs, litter cover, tree regeneration and tree stem size) for other PCTs (State of New South Wales 2017). PCT quantitative benchmarks are described in the NSW BioNet Vegetation Classification (BVC) (OEH 2017c). These variables were developed from those under previous NSW legislation (e.g. Ayres et al., 2009; Gibbons 2008; Benson 2006; Benson 2008; Oliver et al. 2007; Benson et al. 2010; DECCW 2011c).

However, the BAM benchmarks do not cater for temporal dependency on flooding. Current available composition and structure benchmarks are predicted as the annual average for an average rainfall year (OEH 2017c). Thus, they are not fit for purpose for monitoring the change in condition of inland floodplain wetland (flood-dependent) PCTs in response to water availability, or to track change in response to restoration actions based on response to inundation regimes.

2.2.2 Floristic community condition response variables to define benchmarks

Both terrestrial and aquatic plant ecology structural terms are necessary to describe the vegetation structure of floodplain wetlands (Roberts et al. 2000). To model relationships between water availability and condition, benchmarks for inland floodplain wetland plant community types need to incorporate wetland specific indicators in addition to those in the BAM. The wetland specific indicators proposed are; i) percent cover of PCT indicator species, ii) percent cover of '*Wetland Plant Functional Groups*' (WPFGs), (Brock and Casanova, 1997), iii) percent cover of bare ground and iv) percent cover of wetland invasive terrestrial species. A similar approach is used in the Victorian Governments' *Index of Wetland Condition*; (NSW DIPNR, 2003; Papas and Moloney, 2012; DELWP 2016; Roberts et al. 2017a), and by the US EPA (US EPA 2002; Lopez and Fennessy 2002).

The response variables for inland floodplain plant community floristic condition assessment selected were: percentage cover of Plant Community Type (PCT) key indicator species, percentage cover of species in each Water Plant Functional Group (WPFG), exotic and native invasive native species and percentage bare ground and litter.

2.2.2.1 Plant Community Type (PCT) indicator species

The key condition indicator species and community structural characteristics of each PCT were derived from the NSW BVC diagnostics for that PCT (OEH 2019). These are defined in the PCT descriptions contained within the hierarchical vegetation classification system used in vegetation survey, mapping and conservation assessment in NSW (OEH 2019).

2.2.2.2 Water Plant Functional Groups

Wetland species can be very diverse and endemism and variation in regional distribution of species, restricts the use of individual species at the landscape level (Casanova 2015). Grouping of species into plant functional types is a useful tool for predicting changes in vegetation and as a consequence of environmental and disturbance changes and land-use shifts at regional and global scales (Rusch et al. 2003). Plant functional group classifications are used in many branches of vegetation ecology, from response of plant communities to fire (e.g. Noble and Slatyer 1980; Noble and Gitay1996; Bradstock and Kenny 2003) to wetland plant dynamics. A similar system called *Wetland Indicator Categories* (Reed 1997), are widely used in North America (Casanova 2015). In Australia, this approach was pioneered for wetland plants by Brock and Casanova (1997) who developed a protocol for the classification of wetland plant species into Water Plant Functional Groups (WPFGs), to enable comparison between wetland sites with different species composition and abundance (Casanova 2011). These WPFGs were developed further by Leck and Brock (2000), Casanova and Brock (2000) and Casanova (2011).

WPFGs have been used to compare water plant responses to different depths, durations and frequencies of flooding (Casanova and Brock 2000; Leck and Brock 2000; Deane et al. 2017; Nicol et al. 2018), to compare wetlands (Liu et al. 2006; Porter et al. 2007; Alexander et al. 2008; Casanova 2011), to interpret and predict change in wetland community dynamics (Reid and Quinn 2004; Stokes et al. 2010; Boulangeat et al. 2012; Campbell et al. 2014; Casanova 2015; Moxham et al. 2018), compare resilience to stress (Colloff and

Baldwin 2010), to reduce data-set variability (Campbell et al. 2014; Johns et al. 2015), to communicate ecological responses (Nielsen et al. 2013; Campbell et al. 2014), and response to environmental water allocations (Reid and Quinn 2004; Nicol et al. 2010a; Nicol et al. 2010b, Nicol et al. 2012; Gehrig et al. 2015; Nicol et al. 2016; Nicol et al. 2017; Nicol et al. 2018). WPFGs have been utilised in former government wetland monitoring programs such as the *NSW Integrated Monitoring of Environmental Flows* (IMEF) (NSW DIPNR 2003; Cottingham et al. 2005; Driver and Knight 2007).

The WPFG method has been found to be more effective at demonstrating differences in wetland plant communities based on water regimes than species, growth forms or wetland indicator categories (WICs) (Johns et al. 2015), or species assemblages, or taxonomic data (Campbell et al. 2014). The use of WPFGs have allowed detection of the effects of environmental flooding and were found to be good at indicating response to inundation (Reid and Quinn 2004). Colloff and Baldwin (2010) used WPFGs to assess floodplain vegetation resilience and response to flooding and found that functional diversity (and biodiversity resilience), was related to the number of species in each functional group. Stokes et al. (2010) used WPFGs to distinguish the differences between exotic and native understory species responds to flooding.

As WPFGs classify species with similar hydrological niche preferences together, they allow a qualitative means to generalize community responses to changes in hydrology (Deane et al. 2017). The WPFG approach could help to develop benchmarks or measures of ecological response to water regime (Campbell et al. 2014).

A WPFG was assigned to all species recorded during this study using the most recent list compiled in NSW (M. Casanova pers. com.). The percentage cover of WPFGs was then able to be used as a condition indicator for each PCT (Table 1).

Table 1 NSW Wetland plant functional groups (WPFGs) (from Casanova 2011)

Wetland Plant Functional Group	Description	Examples, Native	Examples, Exotic
Terrestrial Dry (Tdr)	Terrestrial species intolerant of flooding	e.g. terrestrial grasses and chenopod species (e.g. *Sclerolaena muricata*, *Salsola kali*)	most terrestrial weeds: e.g. *Conyza bonariensis* (flaxleaf fleabane), *Echium plantagineum* (Paterson's curse)
Terrestrial Damp (Tda)	Terrestrial species tolerant of damp conditions but not flooding for extended periods and require flooding to complete their lifecycle.	e.g. grasses: swamp wallaby grass, (*Amphibromus* spp.) and forbs.: *Alternathera* spp., and *Rumex* spp., coolibah (*Eucalyptus coolibah*)	e.g. *Phyla canescens* (Lippia), *Conyza sumatrensis* (tall fleabane), *Rorippa* spp. (cress).
Amphibious Tolerators: emergent (ATe) or low growing (ATl)	Non-woody species tolerant of being flooded that don't change morphology but are not tolerant of drying out completely for extended periods.	e.g. marsh grasses: *Paspalum distichum* (water couch) and *Pseudoraphis spinescen*s (spiny mud grass), sedges: *Eleocharis* spp., *Cyperus* spp., rushes: *Typha* spp., *Juncus* spp., forbs: *Ranunculus* spp. (buttercup), *Centipeda cunninghamii* (sneeze weed)	e.g. *Sorghum halepense* (Johnson grass) and *Veronica catenata* (pink water-speedwell)
Amphibious Tolerators - Woody (ATw)	Woody species tolerant of being flooded that don't change morphology but are not tolerant of drying out completely for extended periods and require flooding to complete their lifecycle.	e.g. river red gum (E. camaldulensis), black box (*E. largiflorens*), river cooba (A*cacia stenophylla*), lignum (*Duma florulenta*)	e.g. *Salix babylonica* (willow)
Amphibious Responders: Plastic (ARp), or floating (ARf)	Non-woody species that change their morphologies (plastic), or float, or are supported by water in response to flooding – intolerant of dry conditions for medium periods	e.g. *Triglochin* spp. (water ribbons), *Eleocharis sphacelata* (tall spikerush), *Myriophyllum* spp. (water milfoil), *Ludwidgia* spp. (water primrose) *Nymphoides* spp. (marshwort), *Elatine* spp. (waterwort) *Marsilea* spp, (nardoo) *Azolla* spp.	e.g. *Eichhornia crassipes* (water hyacinth)
Aquatic Obligates (Sr, Sk, Se)	Non-woody species that require flooding and/or permanent bodies of water	e.g. *Lemna* spp. (duck weed), *Vallisneria* spp. (eel weed), *Potamogeton* spp. (pond weed), *Najas* spp, (water nymph)	e.g. *Bartsia trixago, Elodea canadensis* (Canadian pond weed)

2.2.2.3 Exotic species

The percentage foliage cover (%FC) of exotic species was included as a community condition variable. Exotic species are usually non-flood-dependent or require inundation regimes of less frequent and shorter duration than most native wetland plant species, even though some exotic species such as lippia (*Phyla canescens*) will tolerate inundation for quite some time (Taylor and Ganf 2005). The presence of invasive exotic species has been related to reduced flood frequency in wetland vegetation communities (Stromberg et al. 2007; Stokes et al. 2010; Bowen and Simpson 2010; Price et al. 2010; Price et al. 2011; Horner et al. 2012; Greet et al. 2013), an indication of decrease in condition and increased human disturbance (U.S. EPA. 2002; DELWP 2016), and in response to levels of grazing in wetlands (Fleischner 1994; Jansen and Robertson 2001; Lunt et al. 2012).

2.2.2.4 Invasive native species

A direct relationship between the cover of invasive native chenopods in wetland communities and changes in the inundation regime, usually reduced frequency and or duration of events, has been identified (Johnson et al. 1992; Stromberg et al. 2007; Thomas et al. 2010; Bowen and Simpson 2010; Stokes et al. 2010; Horner et al. 2012; McGinness et al. 2012; Bino et al. 2015). Therefore, the percentage cover of invasive native chenopods black roly poly (*Sclerolaena muricata*) and soft roly poly (*Salsola kali*), was included as an indicator of condition in this study.

2.2.2.5 Litter and bare ground

Litter is defined as dried plant matter and coarse woody debris with a cross sectional diameter of less than 10 cm, and is usually disintegrated non-woody remnants of plants that cannot be identified to genus level. Although there is no evidence that % FC litter is a response to water availability at the regime scale, it was included in the response variables because it is included was a BAM benchmark variable (State of New South Wales 2017).

Modification of flow regimes can alter the degree of lateral hydrological connectivity onto the floodplain, resulting in altered soil nutrients and generating bare substrate (Stokes et al. 2010). The percentage cover of bare ground was included as an indicator of condition.

2.2.3 Tree stand condition response variables to define benchmarks

Maintaining trees in good condition is important for the continued persistence of communities of floodplain and riparian trees. Trees in poor condition (usually caused by water stress), can result in poor flowering, reduced fruit development (Jensen 2009), low seed set (George 2005, Jensen et al. 2007; Jensen et al. 2008) and longer seed retention on the tree (George et al. 2005).

Condition variables for flood-dependent tree species have been derived and used for management purposes (e.g. Dexter 1978; Grimes 1987; Cunningham et al. 2006, 2007, 2009; Horner et al. 2009; Roberts 2007; Armstrong et al. 2009; Souter et al. 2009; Bowen et al. 2011; Souter et al.2010a; Souter et al. 2010b; Souter et al. 2012; McGinness et al 2012; Roberts and Robertson 2014), to assess time series changes in condition (MDBC, 2003; MDBC 2005), to model spatial distribution of condition classes in the landscape using environmental parameters, (Bacon et al. 1993; Bacon 1994, 1996, 2004; DLWC 2000; Robertson et al. 2001), and to interpret the signatures generated from satellite imagery to model spatial distribution of condition classes (Cunningham et al. 2006; Cunningham et al. 2009a; Cunningham et al. 2009b; Cunningham et al. 2011; Evans et al. 2012; Cunningham et al. 2014a; Cunningham et al. 2014b; Shendryk et al. 2016; Newell et al. 2017).

Many studies have used field measures of tree health to assess time series changes in condition and/or to model spatial distribution of condition classes in the landscape using environmental parameters (e.g. Bacon et al. 1993; Bacon 1994, 1996, 2004; DLWC 2000;

MDBC 2003, 2005; Cunningham et al. 2013, Cunningham et al. 2014a; Newell et al. 2017), or to assess habitat for faunal biodiversity (e.g. review by McElhinny 2002).

The effects of stress that is high enough to limit tree growth will be exhibited most dramatically within the tree canopy (Grimes 1987). Horton et al. (2011) found that 'primary crown dieback' defined as '*the proportion of primary branches that have died back*' was the most useful parameter for assessment of eucalypt crown condition as it was as almost as accurate as as assessing a number of other highly correlated parameters. Catelotti et al. (2015) measured crown density, crown size, dead branches and epicormic growth derived from a diagrammatic guide (Grimes 1987), in their study of the the condition of river red gum forests in the Macquarie Marshes to be consistent with previous data collection protocols.

Evans et al. (2012) assessed four crown-condition indices that measured canopy dieback in terms of the density, transparency, extent and in-crown distribution of foliage combined into a single index called the Total Crown Health Index (TCHI) in temperate Eucalypt forest in western Australia. Cunningham et al. (2007), examined a range of structural, morphological and physiological response variables, in stands of river red gum of contrasting condition along the Murray River in south-eastern Australia. They found that percentage live basal area, plant area index and crown vigour were reliable, objective indicators of stand condition, as they estimate the characteristic symptoms of tree decline, such as canopy dieback (Plant Area Index, crown vigour) and tree mortality (percentage live basal area). All of these condition classification systems identify that the desirable state for trees are: to have intact live green canopies (low canopy die back), and live trunks, limbs and branches (low tree mortality) (Cunningham et al. 2007). The metrics of Cunningham et al. (2007) have been adopted in the monitoring of woody vegetation condition under Basin Plan (Newell et al 2017).

In this study, tree stand condition variables slightly modified from those of Cunningham et al. (2007) were chosen; Plant Area Index (PAI) or percentage foliage cover, Percentage dead canopy; (the opposite metric to the 'Crown vigour' of Cunningham et al. (2007)), expressed as a mean for all the trees of that species in the plot, Percent live basal area; defined as the percentage of the total basal area that represents live trees within the plot (as in Cunningham et al 2007; Cunningham et al 2009a). Percentage dead limbs, defined as; *the percentage of dead limbs expressed as a mean for the plot*. These tree stand condition indicators can be linked directly to observations made through Aerial Photo interpretation (e.g. Bowen et al. 2011, Bowen et al. 2014).

Plant Area Index (PAI) is an important metric to allow the comparison of on ground condition with remotely sensed metric of tree health such as Normalised Difference Vegetation Index (NDVI). It is very responsive to short-term water availability. It is important to note however, that recovery state can also influence tree canopy density and therefore PAI in the short term, e.g. trees in the early stages of re-establishing their canopy after stress will be characterised as having a 'tufted or bunchy canopy of epicormic re-growth' and although foliage density may be relatively high, these recovering trees usually have small canopy extent and crown size (Overton et al. 2014).

Flood-dependent trees are very long-lived species and the canopy density varies between PCTs, within PCTs and from season to season. For example, red gum woodlands have a more open canopy than red gum forests, and coolabah woodlands are generally less dense than red gum woodlands. Thus, using the variable PAI requires that there are separate scoring ranges for forest or woodland, consistent with the diagnostic %FC ranges for the determination of vegetation structure as either a forest or woodland (Specht 1970; Walker and Hopkins 1990; Hnatiuk et.al 2009; Sivertsen 2009).

The variable, percentage dead limbs, is a way to quantify the extent of decline of a stand of trees even if it is not reflected in the live basal area, and is a development on the categorical visual assessment scoring systems such as that of Grimes (1987), and follows on from the findings of Horton et al. (2011). Percentage dead limbs reflects the fact that losing a large limb is a critical loss of invested resources for a tree. Recovery from limb loss requires that the tree rebuild woody tissue (limb and branches), as well as foliage to regain its condition (Overton et al. 2014).

2.2.4 Hypotheses – floristic condition

In this study several existing hypotheses regarding wetland condition indicators in relation to water availability were tested to support the selection of floristic condition response variables for inland floodplain plant community types:

Hypothesis 1. Inland wetland plant communities consist of key diagnostic indicator species and species from amphibious, semi-aquatic and aquatic '*Water Plant Functional Groups'* (WPFGs), and these respond to identifiable inundation regimes,

Hypothesis 2. The percentage cover of species in the *Amphibious* and *Submerged* (Semi-aquatic and Aquatic) WPFGs will be higher in inundation regimes with longer duration and/or frequency of inundation,

Hypothesis 3. The percentage cover of species in the *Terrestrial dry* and *Terrestrial damp* WPFGs including exotic species, will be lower in inundation regimes with longer duration and/or higher frequency of inundation,

Hypothesis 4. Increased cover of bare ground and or litter indicates that the inland floodplain wetland plant community is receiving a sub-optimum inundation regime.

2.2.5 Hypotheses – tree stand condition

Several existing hypotheses regarding tree stand condition indicators in relation to water availability largely based on the work of Cunningham et al. (2007) and Grimes (1997) were treated in the selections of tree stand condition response variables for PCTs:

Hypothesis 1. Less of the total potential canopy will be dead (i.e. lower percentage dead canopy), in sites where most trees' water requirements are met in a five-year period

Hypothesis 2. In sites where their water requirements are met in a five-year period, larger canopy trees and/or more trees denser will be supported per ha/ tree canopies will be denser (i.e. higher Plant Area Index (PAI)),

Hypothesis 3. In sites where their water requirements are met in a five-year period, less trees will die; therefore, the stand will have a higher ratio of live trees to dead trees by total basal area (i.e. higher percentage live basal area),

Hypothesis 4. In sites where their water requirements are met in a five-year period, trees will retain more of their large limbs: main structural elements arising from the trunk, (i.e. lower percentage dead limbs).

2.2.6 Survey design

Survey sites were chosen using a targeted stratified random sampling design, randomisation ensures that sites are representative and unbiased, while stratification ensures that all areas of interest are covered (Chessman and Jones 2001).Survey sites were stratified on: i) historic PCT and ii) end of Millennium Drought condition as mapped in 2008 (Bowen and Simpson 2009).

Historic PCT was determined using a digital scan of 1991 vegetation mapping (Wilson 1992) in a GIS package (ArcGIS 9.1). The 1991 mapping represented the extent of the PCTs before the Millennium Drought (MD); a period of extended below average rainfall in south–eastern Australia from late 1996 to mid-2010 (Australian Government 2015). Using Pre-Millennium Drought (Pre-MD), i.e. prior to 1996, vegetation mapping, allowed selection of sites based on their original PCT even if the extant vegetation had changed in 2007/08. This allowed the identifying sites that had changed in species composition and/or structure during the Post-Millennium Drought (Post-MD) study period.

The 2008 (starting) condition of each site was derived from overlaying point data of locations of survey sites as AMG grid co-ordinates on digital vegetation condition and extent mapping in ArcGIS 9.1. The vegetation condition mapping was undertaken by visual Aerial Photo Interpretation (API) of high resolution aerial photography captured in 2008 (Bowen and Simpson 2009) Sites of the same PCT in different starting condition classes were selected.

Sites were also located across the three key environmental water delivery areas of the Marshes (North, South and East) (See Figure 4 in Chapter 1), to maximise the range of inundation regimes likely to occur during the Post-MD study period, as decisions regarding the delivery of environmental water and the timing and magnitude of natural occurring floods were outside the control of the study design.

At 54 survey sites, 74 0.04 ha (20m × 20m) floristic survey (community condition) plots were established in seven wetland types: flood-dependent shrubland, floodplain grassland, river red gum forest, river red gum grassy woodland, river red gum woodland, coolibah woodland and non-woody wetland. Eight PCTs were sampled: PCT 247; Lignum (*D. florulenta*) shrubland, PCT 214*;* Native millet/cup grass floodplain grassland, PCT 36; river red gum (*E. camaldulensis*) forest, PCT 36A woodland, and PCT 454 grassy woodland, PCT 40; Coolibah (*E. coolabah*) woodland, PCT 53; mixed marsh (*Eleocharis* spp., *Juncus* spp., *Cyperus* spp.) sedgeland and PCT 204; water couch (*P. distichum*) marsh grassland (Appendices 1 and 2, Table 2).

Table 2 Wetland types sampled in the Macquarie Marshes

Wetland Type	NSW Plant Community Type (PCT) ID no.	NSW Plant Community Type (PCT) name and dominant species	Mapped Condition 2008 (Bowen and Simpson 2009)	No of Plots
Flood-dependent shrubland	247	*Lignum shrubland (Duma florulenta)*	Good	1
			Intermediate	2
			Poor	1
Floodplain grassland	214	*Panicum decompositum / Eriochloa crebra* grassland	Poor	2
			Very Poor	2
River Red Gum forest	36	*Eucalyptus camaldulensis* forest	Good	2
			Intermediate	2
River Red Gum grassy woodland	454	*Eucalyptus camaldulensis grassy woodland*	Intermediate	4
			Poor	2
River Red Gum woodland	36A	*Eucalyptus camaldulensis* woodland	Intermediate	13
			Intermediate /poor	3
			Poor	10
Flood-dependent woodland	40	Coolibah woodland (*Eucalyptus coolabah)*	Intermediate	4
			Very Poor	1
Non-woody wetland	53	Mixed marsh sedgeland (*Eleocharis spp., Juncus spp., Cyperus spp.*)	Intermediate	6
			Poor	2
			Very Poor	3
	204	Water couch marsh grassland *(Paspalum distichum*)	Intermediate	7
			Very Poor	5
Grand Total				74

A floristic survey was undertaken annually from 2007/08 to 2016/17. This sampling period encompassed the end of the MD (i.e. 2007/08 and 2008/09) and a Post-MD study period (2009/10 to 2016/17).

A tree stand condition survey was also undertaken annually from 2010/11 to 2016/17 at 41 of the plots in tree dominated PCTs. In these plots the floristic (community condition) survey plots were nested within 0.1 ha (20m ×50m) tree stand condition plots (Figure 8).

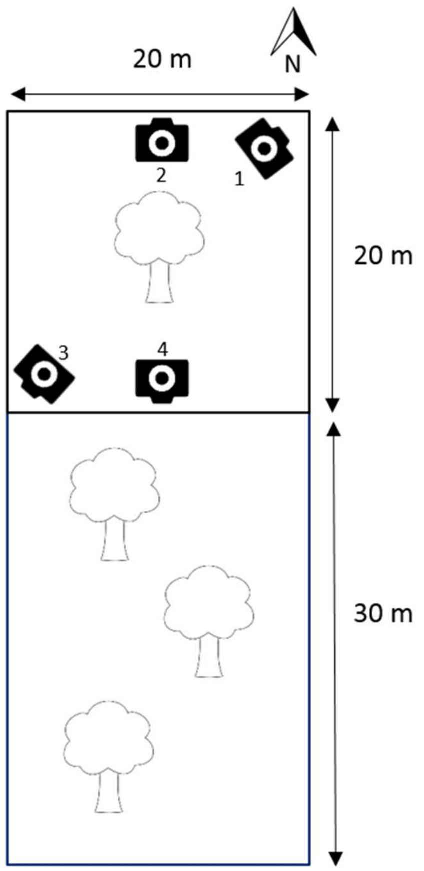


Figure 8 Nested floristic (community condition) 0.04 ha and tree stand condition plots (Camera icon indicates direction of site photograph)

2.2.7 Timing of sampling

In drier environments, duration and season of flooding influence germination and establishment of wetland plants, and the completion of the life cycle through to sexual or asexual reproduction. Allowing sufficient time between flooding and sampling allows this to be observed (Warwick and Brock 2004). Sites were surveyed annually in autumn (March – May) after natural flood events, or after water had been delivered from managed or planned environmental flows (winter-spring-summer). Surveying in autumn each year allowed for consistency in the phase of the annual wetting-drying cycle at the time of sampling. In autumn the inundation phase that usually started in early spring, was complete and the drawdown phase (i.e. the recession of the flood water and the exposure of damp substrate with waterlogged soil), was sufficiently advanced to maximise the number of observable species at the site. Sampling at drawdown also meant that species that germinate on wet mud or in shallow water, '*Amphibious*' functional species (Casanova and Brock 1997; Casanova 2011), were more likely to be present in an adult state, and evidence of '*Submerged*' functional species (Casanova 2011), i.e. '*Aquatic*' and '*Semi-aquatic*' species, (that require standing water) (Casanova 2011), would likely still be present. Warwick and Brock (2003) found that amphibious fluctuation tolerator (ATf) species were only capable of reproducing in damp treatments, and that prolonged submergence or immersion slowed or prevented reproduction.

Sampling in autumn also gave the maximum time possible for perennial species and tree species to respond to inundation that usually occurred in spring, and increased the opportunity for growth of stems and canopy over the summer months before winter frosts began. This timing of sampling was arrived at after trial sampling in spring and during the inundation phase that found that most annual species were germinants at a very young cotyledon stage at that phase of the wetting-drying cycle, and therefore difficult to identify, or that little or no germination of semi-aquatic or amphibious species had yet occurred, and/or the flooding prevented access and the cover of bare ground was high.

Some sites were surveyed every year, while others were surveyed less, owing to changes in access, or due to addition of new sites in later years. Sites were surveyed regardless of receiving inundation in that water year.

2.2.8 Community condition survey

Percentage foliage cover (%FC) for all vascular species in each structural component (stratum) of the vegetation, was collected from each community condition survey 0.04 ha plot. A stratum is a distinct height class in the vegetation. In non-woody vegetation, there is no '*Tallest*' stratum only the '*Lower*' (ground cover) stratum exists, although an emergent '*Middle*' stratum also can be present (Sivertsen 2009). In tree dominated PCTs, the lower stratum applies to species up to 1 m tall, middle stratum are species between one and five metres in height and tallest stratum is those species over five metres high, or the tallest layer in a two-layer structural form (Walker and Hopkins 1990; Sivertsen 2009; Gibbons 2005; DECCW 2011c; NSW Government 2017).

The percentage cover of litter (organic matter of plant origin, including fallen timber of less than 10 cm cross-sectional diameter), percentage flooding extent, water depth and percentage cover of bare ground were also recorded. In non-woody wetland types, two or three duplicate plots were located within 100 m and the data from the duplicates were averaged for analysis.

Each 0.04 ha plot was also given a grazing pressure category (high, medium or low). The grazing severity category was a visual assessment of site disturbance and removal of vegetation due to herbivore activity and was also categorised as native or cattle/sheep grazing. Full survey methods are contained in Appendix 3.

2.2.9 Tree stand condition survey

A stand is a forestry term for an area that contains trees that are relatively homogeneous in size or have a common set of characteristics, due to a disturbance such as flood or fire creating a vacant space for germinants (Smith et al. 1997). In this study, two duplicate tree stand condition plots were located at a site that constituted a homogeneous unit analogous to a stand.

Variables recorded for every tree (live or dead), greater than 10 cm '*Diameter at breast height over bark'* (DbHoB) in the 0.1ha, (20m x 50m) tree stand condition plot, were;

DbH (cm), *canopy openness* (the percentage of the sky that is obscured by foliage and small branches), *percentage dead canopy* (defined as percentage of the potential crown of the tree that is denuded or occupied by dead foliage), and *percentage dead limbs*, the number of dead limbs over the total number of limbs per tree. A limb is defined as a major secondary structural component of a tree after the main stem or trunk. In mature trees, there may be multiple limbs arising from a main trunk, while in young trees, limbs and stems are usually synonymous), and *canopy extent* (m^2).

Canopy openness and canopy extent are used to calculate *percentage foliage cover (%FC)* and *Plant Area Index (PAI)*. Full survey methods are contained in Appendix 3.

2.2.10 Annual inundation duration data

The number of days flooded in a water year was the basic inundation metric from which all other inundation-based predictor variables were derived. To derive annual duration, (i.e. days flooded per year), for each site for the years 2008/09 to 2016/17, point data of location of survey sites (AMG grid co-ordinates), were overlain using a GIS package (ArcGIS 10.3), on inundation duration mapping produced by analysis of satellite imagery in the Macquarie Marshes (e.g. Thomas and Heath 2017; Thomas et al. in prep). Days flooded per inundation event in each water year were summed to give number of days flooded per year.

2.3 Data analysis

2.3.1 Data preparation

2.3.1.1 Inundation predictor variable preparation

From the annual inundation data (see Section 2.2.9), the inundation predictor variables required for the MRF analyses; number of days inundated and number of times inundated per year, were calculated for each site for three time periods: i) Pre-MD period (1988/89 to 1997/98) (i.e. *Duration 88-98* and *Floods 88-98*), ii) the MD period (1998/99 to

2007/08) (i.e. *Duration 98-08* and *Floods 98-08*), and iii) the Post-MD study period (2008/09 to 2016/17) (i.e. *Duration 08-17* and *Floods 08-17*) (Table 3).

The predictor variable '*years since last flood*' (i.e. *Last flood*) was derived by counting the number of consecutive years prior to and including that year when the number of days inundated was equal to 0, for each site, for the years 1988/89 to 2016/17.

A variable designed to reflected water availability at the site at a regime scale (≥five years), the 'five-year moving average inundation' was derived at each site for the period 1992/93 – 2016/17, (starting in 1992, as 1988/89 to 1992/93 were the first five years of the available inundation duration record). This was calculated by averaging the number of days inundated in each year plus the four previous years (i.e. days flooded in five consecutive years/5).

The five-year moving average inundation was also used to derive the predictor variables; *'Slope 92-08*' and *Slope 08-17*' i.e. the the rate of change in the number of floods occurring before and after the Millennium drought (MD). This variable is represented by the slope of the trend of inundation rate for the 5-year moving average number of floods. Thus *Slope 92-08* provides a proxy estimate of how quickly flood inundation regimes changed over the period 1992/93 to 2007/08, the Pre-MD and MD period, and '*Slope 08-17'* provides a proxy estimate of how quickly flood inundation regimes changed over the period 2007/08 to 2016/17 Post Millenium drought period (Post-MD).

These variables are correlated with the '*Floods'* variables. For example, a lower *Slope '92-08'* value at a site (i.e. a steeper downward slope of the 5-year moving average), indicates that sites went from frequent inundation i.e.; higher *Floods 88-98*, to less frequent inundation quickly during the MD (1997/98-2007/08), See Appendix 4 for *Slope 92-08* and *Slope 08-17* for each site.

2.3.1.2 Floristic community condition response variable preparation

Each species was assigned to a WPFG. Species percentage cover data was averaged from plot data for each WPFG, calculated separately for each stratum for each site. The percentage cover of bare ground and litter (lower stratum only), was averaged from plot data for each site. Grazing pressure at each plot scored as High, (1) Medium (2) or Low (3) and the median value was obtained for each site (Table 3, Appendix 3).

2.3.1.3 Tree condition response variable preparation

Percentage dead canopy and percentage dead limbs plot data was averaged from the replicates for each site. Percentage live basal area for the plot was calculated from the sum of the DbH of all live trees converted to basal area, divided by the sum of the DbH of all trees converted to basal area, and then averaged for the site.

Plant Area Index (PAI), was calculated from; percentage foliage cover converted to a percentage of the area of the plot, divided by the total area of the plot. PAI plot data was then averaged from plot data from each site (See Appendix 3 and Table 3).

2.3.2 Multivariate Regression Forests (MRF)

'Multivariate Regression Forests' (MRF) is a tool widely used in ecology for classification or regression, that is particularly useful for predicting responses for new data given a set of predictor variables (Cutler et al. 2007). MRF is an ensemble approach, where the results of multiple '*Classification and Regression Trees'* (CART) are combined to determine the 'best' classification or regression. MRF extends the univariate method to handle multiple response variables. MRF was also chosen for this analysis as MRF can generate a '*Proximity Matrix'* for sample clustering analysis, and can generate '*Variable*

Importance matrices' to allow the selection of the most important predictor variable/s. MRF are also robust to correlated predictors, have good predictive ability, and are relatively simple to communicate (Hedge and Clark 2016).

2.3.2.1 Model building

For each of a predefined number of '*Classification and Regression Trees'* (trees), the first step of the MRF procedure is the selection of '*training*' samples. The training data is a random sample (with replacement) from the total data set. This subsample is then used to grow a decision tree by progressively splitting of data at nodes. At a node, a random subset of the predictor variables is selected from the total list of predictors. From this subset, the best split of the data is determined. This splitting process continues 'down' the newly generated branches, gradually building a '*tree*'. This is repeated until the tree is fully grown or further splits of the data result in zero information gain.

2.3.2.2 Model validation

To validate the model, for each tree approximately 1/3 of the data was left as 'out of the bag' (OOB) test data. This data is used to estimate prediction error and variable importance. MRF has an in-built validation procedure used to calculate prediction error. After a tree is calculated, each OOB data is sent 'down' the tree to generate a classification or prediction. Essentially, each sample will be part of the OOB for approximately 1/3 of the trees, for which an average prediction (in the case of regression), is generated. Using this predicted average for each sample, the overall error rate of the regression forest can be determined.

2.3.2.3 Determining the importance of predictor variables

OOB data is also used to determine the importance of predictor variables. For each tree, the values of a particular variable are permuted in the OOB samples and sent 'down' the tree. The OOB prediction of this permuted data is compared to the original OOB predictions for that tree, and this is averaged over all the trees to determine importance. An important variable will have a large difference between the OOB error for permuted and original data. Figure 9 is an illustration of a standard regression tree (CART) for the floristic percentage cover dataset, using the Lower stratum subset and a single species; water couch (*P. distichum),* in the '*rpart'* package in *R* (Therneau et al. 2015). The first split separates by the flood predictor of number of floods in the MD period; 1998-2008 (Floods 98-08). The predicted percent cover of *P. distichum* is presented in each terminal node. Note that this is an illustrative example only, the full MRF uses up to 500 of these trees.

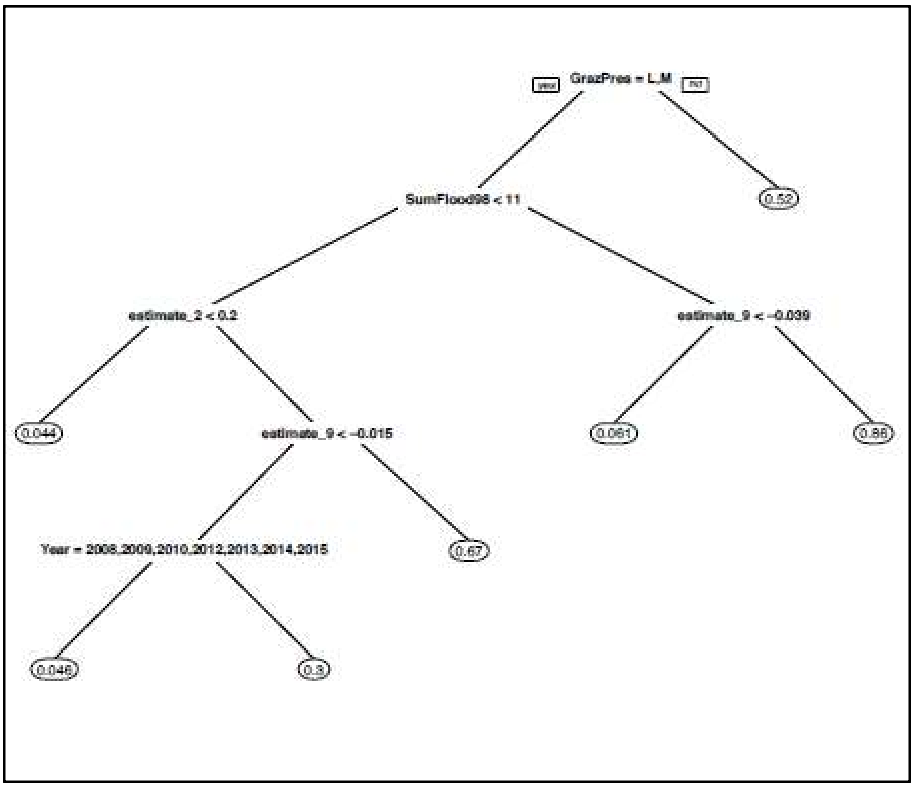


Figure 9 Illustration of a standard regression tree (CART) using water couch data

2.3.2.4 Proximity matrix and site clustering (site similarity profiles)

A key benefit of using MRF is the computation of a '*proximity matrix'* that underpins supervised clustering of sites. All data (training and OOB), are run 'down' all trees in the ensemble to their designated terminal node. If cases *i* and *j* are assigned to same terminal node, then their proximity measure is incremented by one ($pv_{i,j}$). The proximity measures are normalised by dividing by the number of trees. The result is an $n \times n$ matrix of *pv's* that is symmetric, positive definite, and bounded by 1. Subtracting the *pv*'s from one is generally treated as (squared) distances for subsequent clustering. Clustering involves using an algorithm to group entities of a similar nature (usually Euclidean distance). This study used the PAM (Partition Around Medoids) algorithm (Kaufman and Rousseeuw 1990). The algorithm partitions the dataset of *n* objects into *k* clusters. In this case, the dataset was the proximity matrix generated by the MRF on the community condition variable dataset; percentage cover of species in each WPFG, percentage cover of bare ground and litter, and also separately on the tree stand condition variables dataset: PAI, percentage dead canopy, percentage live basal area and percentage dead limbs. The algorithm works with a dissimilarity matrix and seeks to minimize the overall dissimilarity between representative data points assigned to the *k* clusters.

Visualising clusters is often accomplished by plotting the clusters in two-dimensional space. As this data has nine different site clusters, plotting in this number of dimensions is not informative. Figure 10 is an example of cluster plotting on a random subset of the community condition data. The number of clusters is chosen iteratively to maximise '*Rousseeuw's Silhouette'* width as higher silhouette value indicates more dissimilarity between clusters than within clusters (Kaufman and Rousseeuw 1990). Thus, each cluster represents sites that are more similar to each other than to those in separate clusters. Nine clusters were used for each stratum. Note that this cluster diagram is illustrative only and was constructed using only a subset of variables using middle stratum data only. It is meant only to highlight the methodology used in constructing species and predictor profiles. Clustering was done in the cluster package in R (Maechler et al. 2017).

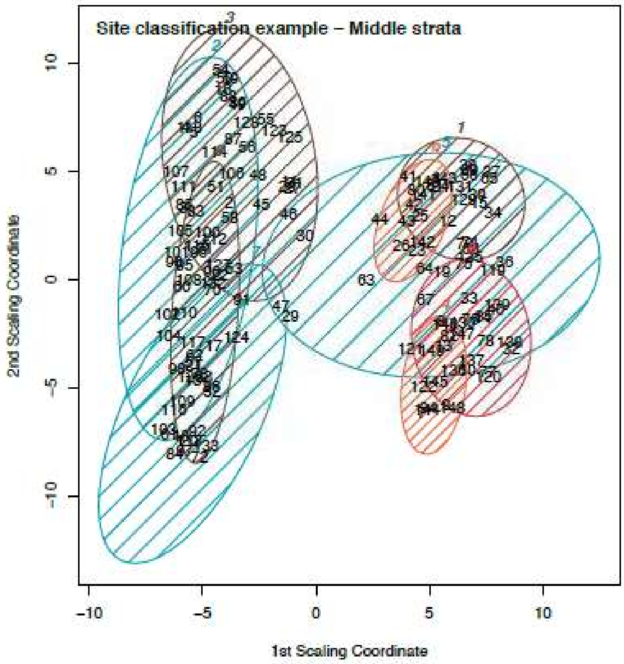


Figure 10 Cluster Diagram (Illustrative only)

2.3.2.5 Model interpretation

Interpretation of MRF is not as straightforward as other regression methods such as CART, however, by clustering sites according to similarity, using variable importance, and plotting trends across sites, a holistic interpretation of the data can be achieved (Segal and Xiao 2011). An analytic framework for examining condition indicator profiles and predicting profiles in different inundation scenarios is in Figure 11. Similar frameworks can be found in Segal and Xiao (2011), and Xiao and Segal (2009). Cutler et al. (2007) also provide a good overview of using MRF in ecological settings.

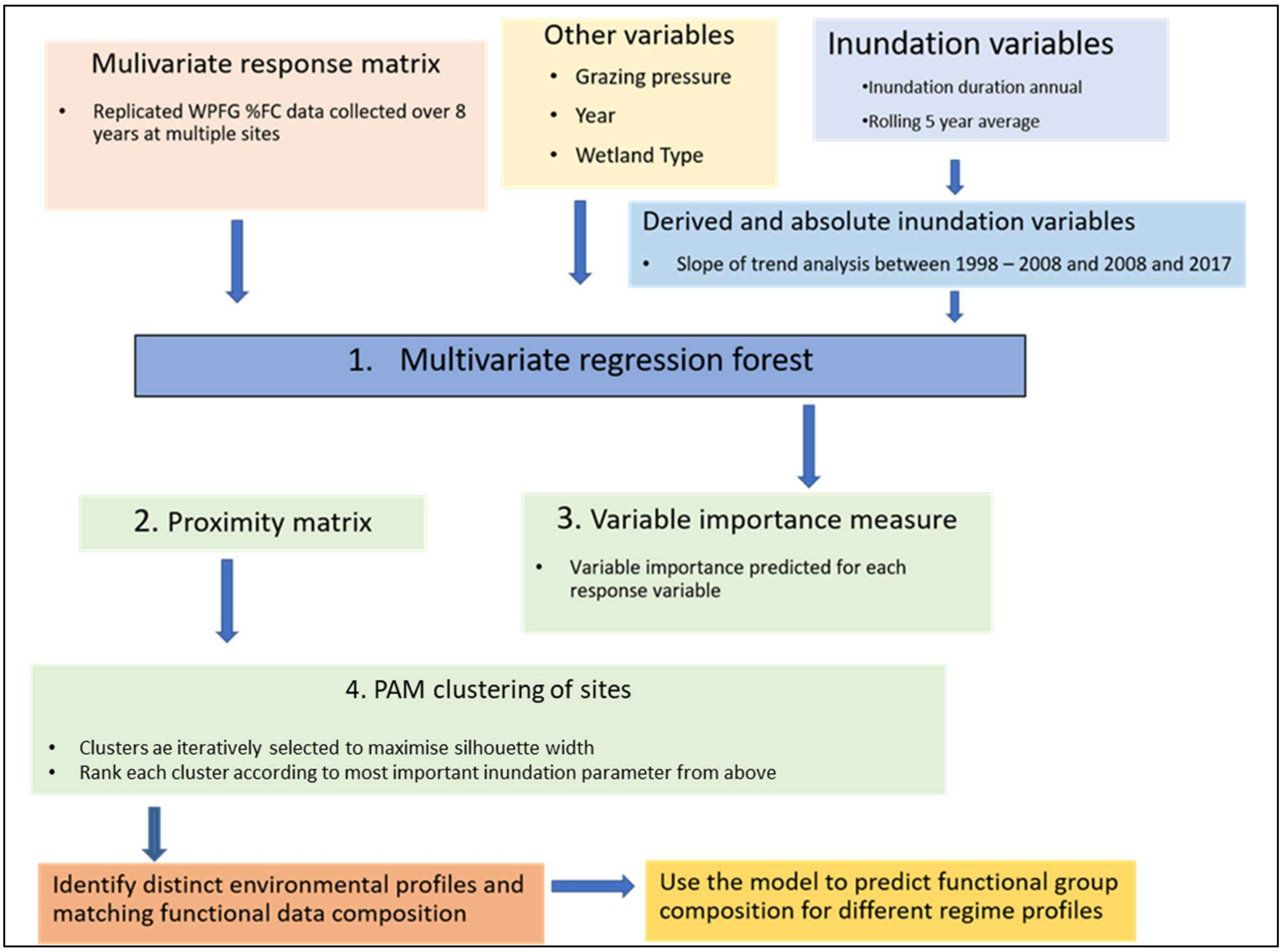


Figure 11 Analytic framework

2.3.3 Inundation variable importance for community condition variables

An MRF variable importance measure analysis (see Section 2.3.2.3), was conducted to derive the importance of each of the derived predictor (inundation) variables to each of the community condition response variables (percentage cover of all species in each of the WPFGs, litter and bare ground), for each of the three strata (Table 3).

The predictor variables tested were: mean days of inundation duration and number of inundation events (floods) in the pre-MD period (1988/89-1997/98); called *Duration 88-98* and *Floods 88-98*, the MD period 1997/98-2007/08; called *Duration 98-08* and *Floods 98-08*, the post-MD data collection period (2008/9-2016/17); called *Duration 08-17* and *Floods 08-*

17, the number of years since last flood for each site; called *Last flood*, and grazing pressure (lower stratum data only).

For middle and tallest strata, the rate of change in the number of floods occurring before (*Slope 98-08*), and after the MD (*Slope 08-17*) were also included in the analysis as these strata were often dominated by long lived woody plant species such as river red gum (Table 3).

Table 3 Model variables

Inundation regime variables
Number of days each site was inundated (*Duration*) and, number of times each site was inundated (*Inundation frequency*) per year in: • Pre-Millennium Drought (Pre-MD) period - (1988/89 to 1997/98) • Millennium Drought (MD) period– (1998/99 to 2007/08) • Post-Millennium Drought (Post-MD) / data collection period – (2008/09 to 2016/17) • Number of years since last inundation each year at each site (1987/88 – 2016/17) • Rate of change of the five-year moving average inundation at each site (1992/93 – 2016/17) • Local rainfall
Response variables (from community condition plot (0.04 ha)
Recorded each year in autumn in end of Millennium Drought period (2007/08 and 2008/09) and Post-Millennium Drought period (2007/08 to 2016/17). • Percentage cover of each plant species (combined for each WPFG) per stratum • Percentage cover of bare ground • Percentage cover of litter • Median grazing pressure category
Response variables (from tree stand condition plot (0.1 ha)
Recorded for each tree live or dead, greater than 10 cm DbH in the 0.1ha, (20m x 50m) plot, each year in autumn in the Post-Millennium Drought period (2010/11 to 2016/17). • Percentage dead canopy (site) • Percentage live basal area (site) • Percentage dead limbs (site) • Plant area index (derived from percentage foliage cover for site)

2.3.4 Inundation variable importance for tree stand condition variables

To assess the impact that varying inundation regimes had on the tree stand condition variable scores, an MRF analysis was performed using the same primary predictor variables as those used to in the community condition analysis including *Slope 98-08*, and *Slope 08-17*. The response variables measured were the tree stand condition variable scores for each site for each year by wetland type (see Section 2.3.4).

2.3.5 Deriving floristic community condition variable profiles

2.3.5.1 Cluster of all sites

A set of site cluster profiles (i.e. a set of means and ranges of response variables), of all sites regardless of wetland type, were derived from the MRF analysis (see Section 2.3.2.2) using community condition response variable data (percent cover of WPFGs, bare ground and litter). Each site cluster had an inundation regime profile derived from the inundation predictor variables for that cluster (called '*flooding environment*'). The clusters were then ordered based on the most important inundation predictor variables derived from the predictor variable importance analysis. Separate models were developed for each stratum: lower, middle and tallest.

2.3.5.2 Cluster of sites by Wetland Type

A set of site cluster profiles for each wetland type were derived from the MRF analysis, using response variable data analysed separately based on wetland type, to inundation regimes that represented a range of scenarios that have occurred in the last three decades in the Marshes. These profiles can identify trends in the community condition variables in response to predictor variables and assist to identify 'benchmark state' and the inundation regime required for that state. Then these profiles can also assist to define 'condition classes' to classify vegetation structure of the sampled PCTs.

2.3.6 Deriving tree stand condition variable profiles

2.3.6.1 Cluster of all sites

A set of site cluster profiles (a set of means and ranges of response variables) of all sites regardless of wetland type were derived from the tree stand condition data. As tree data was insufficient to allow the use of raw tree variable response data in the model, an MRF analysis was conducted (see Section 2.3.2), using tree stand condition variable scores derived from the raw data, (i.e. scores for PAI, percent live basal area, percent dead canopy and percent dead limbs), as the response variables. The clusters were ordered based on the most important inundation predictor variables derived from the variable importance analysis for percentage cover of the tallest stratum.

2.3.6.2 Cluster of sites by Wetland Type

A set of site cluster profiles for each wetland type were also derived from the MRF analysis, using response variable data, to inundation regimes that represented a range of scenarios that have occurred in the last three decades in the Marshes. The aim of this analysis was to derive ranges for tree stand condition response variables linked to inundation regime scenarios (Table 3), using the models constructed during the MRF analysis and to identify the optimal condition or benchmark state and the inundation regime required for that state.

As the tree stand condition variables include percent dead limbs and percent live basal area, they are robust to seasonal changes in canopy density that may not be linked solely to inundation regime, thus relate to the tree community condition in response to the inundation regime (5 yearly) of the site, not just to short-term changes in foliage cover.

2.3.7 Predicting condition variable profiles under different inundation regimes

A key benefit of using MRF is the computation of model predictions. The models constructed by the MRF analysis for each stratum of the community were used to predict the WPFG, bare ground and litter composition under different inundation scenarios for each wetland type. The inundation scenarios were constructed using the clustering analyses (See section 2.3.2.3) and a general understanding of the drivers of vegetation change in the Marshes. A model was also constructed for tree stand condition variable scores using the cluster analysis (see Section 2.3.2.3).

2.3.7.1 Floristic community condition variable ranges

To predict the responses of the condition response variables (WPFGs, bare ground and litter) to different inundation histories, a set of inundation 'regimes' was derived from the inundation predictor variables (See Table 3) from each site in the period 1988/89 to 2016/17. Three scenarios (Maximum, Moderate (mean), and Minimum) were defined for the three periods Pre-MD (1988/89-1997/98), MD (1997/98-2007/08) and post-MD (2008/09-2016/17) (Table 4). The floristic (community condition) survey dataset was divided into three subsets by stratum, and data from component PCTs were combined under their Wetland Types (see Table 2).

2.3.7.2 Tree stand condition score ranges

Preliminary analysis found that there were too few trees sampled and therefore data was insufficient to allow the use of raw tree response variable data (i.e. PAI, percentage live basal area, percentage dead canopy and percentage dead limbs) in the mode. Therefore, a MRF analysis was conducted using tree stand condition variable scores derived from the raw data, i.e. scores for PAI, live basal area, dead canopy and dead limbs, as the response variables. For this analysis, data from component PCTs are combined under their Wetland Type (see Table 2).

To predict the potential tree stand condition score ranges under different flow regimes, the two inundation scenarios actually experienced by tree dominated sites were used. Under Scenario One, sites received the maximum inundation duration possible during the Pre-MD and MD periods and post-MD. Under Scenario Two, sites received the Minimum inundation duration regime with no inundation during the MD and little recovery in inundation post 2008 (Table 4). For both scenarios, the mean inundation event frequency was used.

2.3.7.3 Inundation regimes modelled

In *Scenario One* is the maximum inundation regime, sites received the maximum frequency and duration recorded during the Pre-MD and MD periods and regular inundation (at least once per year), during the Post-MD study period. For the purposes of prediction, the variable 'Year' was set to 2014 as varying the year had negligible effect on model predictions (Table 4). In *Scenario Two* (lower and middle stratum analysis only), sites experienced a moderate inundation regime; mean number of floods and moderate duration, had minimum time between events during the Pre-MD and MD periods, and continued to have moderate duration flooding in the Post-MD study period, and for the lower stratum analysis, the minimum time since last flood (Table 4).

Under *Scenario Three* (lower and middle stratum analysis only), (and confusingly equal to *Scenario Two* in the tallest stratum), sites received the minimum number of floods in the pre-MD period, maximum time since last inundation and no inundation during the MD or post-MD study period (Table 4). The Middle stratum analysis also had, *Scenario Four* where sites received the same moderate inundation regime as those in *Scenario Two* but had high grazing pressure as grazing was considered likely to be a compounding factor in the response of juvenile trees in the middle stratum (Table 4).

Table 4 Inundation regime scenarios tested

Inundation variable	Lower stratum community condition			Middle stratum community condition				Tallest stratum community condition/Tree stand condition score	
	Scenario One	Scenario Two	Scenario Three	Scenario One	Scenario Two	Scenario Three	Scenario Four	Scenario One	Scenario Two (equals middle stratum Scenario Three)
Sum of floods Pre-MD	12	6.1	2	12	6.5	3	6.5	12	3
Sum of floods MD	9	3.1	0	9	3.4	0	3.4	7	0
Sum of floods Post-MD	12	5.7	0	12	6.3	0	6.3	12	0
Years since last flood	0	0	3	0	1.06	3	1.06	-	-
Grazing pressure	-	-	-	Low	Low	Low	High	-	-
Slope of inundation decline	-	-	-	Max (-0.07)	Mean (-0.04)	Mean (-0.08)	Mean (-0.04)	Max (-0.07)	Min (-0.01)
Slope of inundation growth post 2008	-	-	-	-0.18	-0.07	Mean (-0.03)	-0.07	Max (-0.13)	Min (-0.03)
Mean days duration Pre-MD	124.1	42.5	0.2	124.1	46.8	1.9	46.8	105	1.9
Mean days duration MD	83	27.6	0	83	31.2	0	31.2	83	0
Mean days duration Post-MD	139.3	55.8	0	139.3	62.9	0	62.9	139	0

2.4 Results

2.4.1 Floristic community survey

Over the Post-MD study period 2008/09 – 2016/17, a total of 620 species (490 native and 130 exotic) were recorded from 81 plant families. A full list of species collected and their WPFG attribution is in Appendix 5. Terrestrial dry (Tdr) species were the most numerous (369, 76% native), followed by terrestrial damp (Tda) (143, 78% native). Of the true wetland plant functional groups i.e. Amphibious, and Submerged (aquatic and semi-aquatic), Amphibious tolerator - emergent (ATe) were the most numerous (57), of which 91% were native species, followed by Amphibious Responder – plastic (ARp) (15) of which 93% were native species (Table 5).

Table 5 Numbers of species in each WPFG, Macquarie Marshes 2008/09 -2016/17

Water plant functional group	Description	No of Exotic Species	No of Native Species	Total No of Species
Tdr	Terrestrial dry	89	280	369
Tda	Terrestrial damp	31	111	143
ATe	Amphibious Tolerator – emergent	4	53	57
ARp	Amphibious Responder – plastic	1	14	15
ATl	Amphibious Tolerator - low growing	3	8	11
Se	Submerged semi-aquatic perennial – emergent	0	8	8
ARf	Amphibious Responder – floating	1	7	8
ATw	Amphibious Tolerator – woody	0	5	5
Sk	Submerged - k selected (aquatic species)	0	3	3
Sr	Submerged - r selected (semi-aquatic species)	0	2	2
Total		130	490	620

The best represented exotic families were: *Asteraceae* (26), *Poaceae* (24) and *Fabacea*e (10). The best represented native families were: *Poaceae* (81), *Chenopodiaceae* (67), *Asteraceae* (54) and *Cyperaceae* (23). The best represented families in the natives were: *Poaceae* (81), *Chenopodiaceae* (67), *Asteraceae* (54) and *Cyperaceae* (23) (Table 6).

Table 6 Number of species in the ten best represented plant families, Macquarie Marshes 2008/09 -2016/17

Family	No of Exotic Species	No of Native Species	Total No of Species
Poaceae	24	81	105
Chenopodiaceae	1	67	68
Asteraceae	26	54	80
Cyperaceae	0	23	23
Fabaceae (Faboideae)	10	11	21
Malvaceae	4	17	21
Polygonaceae	5	13	18
Brassicaceae	8	8	16
Amaranthaceae	1	10	11
Fabaceae (Mimosoideae)	0	10	10

There were 106 species of wetland plants (ATe, ARp, ATl, ARf, Se, ATw, Sk and Sr) recorded in the study period. The best represented WPFG was ATe (56 species) 87% of these were native, followed by ARp (15) of which 85%were native species (Table 4). Most species in the true wetland plant functional groups were in the genera *Cyperus* (6), *Eleocharis* (6) *Persicaria* (6) *Juncus* (5) in the group ATe and *Myriophyllum* (5), in the group (ARp). All were native species (Table 7).

Table 7 Best represented amphibious, semi-aquatic and aquatic genera, Macquarie Marshes 2008/09 -2016/17

Genus	WPFG/s	No of Exotic Species	No of Native Species	Total No of Species
Cyperus	ATe	0	6	6
Eleocharis	ATe	0	6	6
Persicaria	ATe/ATl	0	6	6
Juncus	ATe	0	5	5
Myriophyllum	ARp	0	5	5
Ranunculus	ATe/ATl	1	3	4
Bolboschoenus	ATl/Se	0	2	2
Echinochloa	ATe	0	2	2
Eucalyptus	ATw	0	2	2
Limosella	ATl	0	2	2
Mentha	ATe	0	2	2
Najas	Sk	0	2	2
Stellaria	ATe	0	2	2
Triglochin	Se	0	2	2
Typha	Se	0	2	2
Azolla/Lemna/Nymphoides	ARf	0	1	1

Most species in the terrestrial damp functional group (Tda) were in the genera *Brachyscome* (5), *Centipedia* (5), *Alternathera* (5), *Rumex* (4) and *Rorippa* (5) most of which were native species (Table 8). Most species in the terrestrial dry functional group (Tdr) were in the genera *Sclerolaena* (17), *Atriplex* (11), *Maireana* (9), all native species and *Chenopodium* (9) most of which were native species (Table 8 and Table 9).

Table 8 Best represented terrestrial damp genera, Macquarie Marshes 2008/09 -2016/17

Genus	No of Exotic Species	No of Native Species	Total No of Species
Brachyscome	0	5	5
Centipeda	0	5	5
Alternanthera	1	4	5
Rumex	1	3	4
Rorippa	2	2	4
Convolvulus	0	3	3
Eragrostis	0	3	3
Haloragis	0	3	3
Ranunculus	0	3	3
Echinochloa	2	1	3

Table 9 Best represented terrestrial dry genera, Macquarie Marshes 2008/09 -2016/17

Genus	No of Exotic Species	No of Native Species	Total No of Species
Sclerolaena	0	17	17
Atriplex	0	11	11
Maireana	0	9	9
Chenopodium	1	8	9
Austrostipa	0	8	8
Sida	0	7	7
Vittadinia	0	7	7
Senecio	1	6	7
Panicum	2	5	7
Medicago	7	0	7

2.4.2 Inundation variable importance for community condition

2.4.2.1 Lower stratum

Figure 12 is a series of plots of the inundation variable importance measure (y axis) against each of the inundation predictor variables using data from the lower stratum (x axis), for each of the response variables (WPFGs, bare ground and litter).

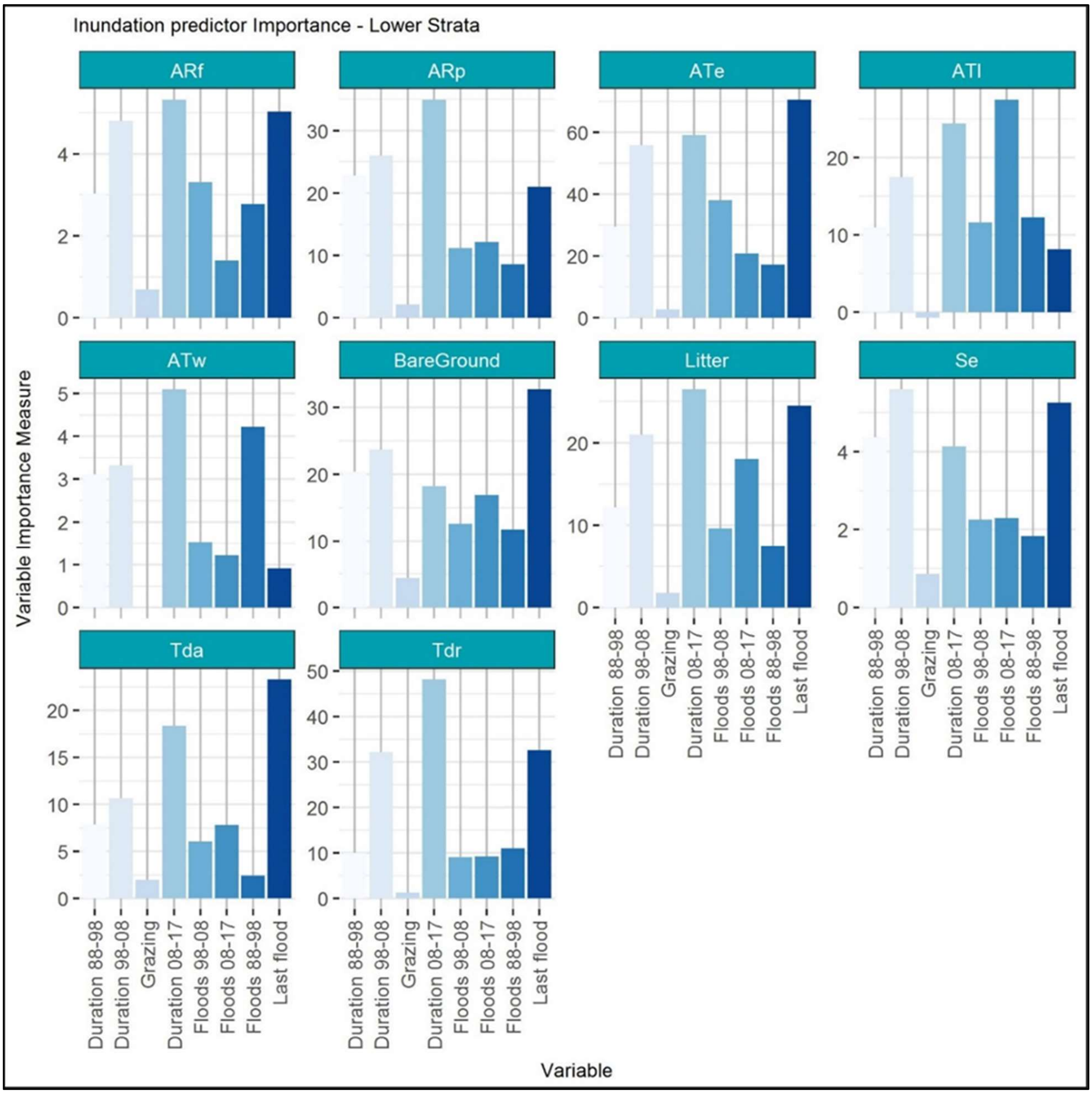


Figure 12 Importance of predictor variables for the lower stratum

The rank scores for each of the eight predictor variables (ranked 8–0), by response variable are in Table 10. Overall for species in the wetland FGs; ARf, ARp, ATl, ATe, ATw, Se and Tda and litter in the lower stratum, the mean days flooded during the Post-MD period (2008/09-2016/17) (*Duration 08-17*), the mean days flooded in the MD period (1998/89-2007/08) (*Duration 98-08*), and the number of years since last flood (*Last flood*) were the most important predictor variables (i.e. have the highest importance scores and were ranked highest overall). For Tdr species, the number of years since last flood (*Last flood*) was the most important predictor variable. Grazing pressure was the least important variable overall (Figure 12, Table 10).

Table 10 Rank scores for importance of predictor variables by response variable – Lower stratum

Water plant functional group	Duration 88-98	Duration 98-08	Duration 08-17	Years since last flood	Floods 88-98	Floods 98-08	Floods 08-17	Grazing
ARf	4	6	8	7	3	5	2	1
ARp	6	7	8	5	2	3	4	1
ATl	3	6	7	2	5	4	8	1
ATe	4	6	7	8	2	5	3	1
ATw	5	6	8	2	7	4	3	1
Se	6	8	5	7	2	3	4	1
Tda	4	6	8	7	5	2	3	1
Total Wetland FGs	32	45	51	38	26	26	27	7
Tdr	5	6	7	8	2	3	4	1
Litter	4	6	8	7	2	3	5	1

2.4.2.2 Middle stratum

Figure 13 is a series of plots of the inundation variable importance measure (y axis), against each of the inundation predictor variables using data from the middle stratum (x axis), for each of the response variables WPFGs: ATe, ATw, Se, Tda and Tdr. The rank scores for each of the nine predictor variables (ranked 9–0), by response variable are in Table 11.

Overall, for wetland FG species in the middle stratum, the most important predictor variables were; mean number of days flooded (mean duration) in the pre-MD period (*Duration 88-98*), number of floods in the pre-MD (*Floods 88-98*) and the mean days flooded during the Post-MD period (2008/09-2016/17) (*Duration 08-17*). For ATw species the mean number of days flooded in the pre-MD period (*Duration 88-98*) and the rate of change of the inundation rate in the post-MD period (*Slope 08-17*) were the two most important predictor variables (Figure 13, Table 11).

For Tdr species, the rate of change of the inundation rate in the post-MD period (Slope 08-17) and in the MD period (*Slope 92-08*) were the most important predictor variables. The variable years since flood (*Last flood*), was of lesser importance to all response variables in the middle stratum, in comparison to the lower stratum (Figure 13, Table 11).

Table 11 Rank scores for importance of predictor variables by response variables – Middle stratum

Water plant functional group	Duration 88-98	Duration 98-08	Duration 08-17	Slope 92-08	Slope 08-17	Years since last flood	Floods 88-98	Floods 98-08	Floods 08-17
ATe	7	9	6	1	5	4	8	2	3
ATw	9	6	7	3	8	1	5	2	4
Se	5	6	7	3	2	1	9	4	8
Tda	8	6	9	1	4	3	7	2	5
Total Wetland FGs	29	27	29	8	19	9	29	10	20
Tdr	2	3	6	8	9	7	4	1	5

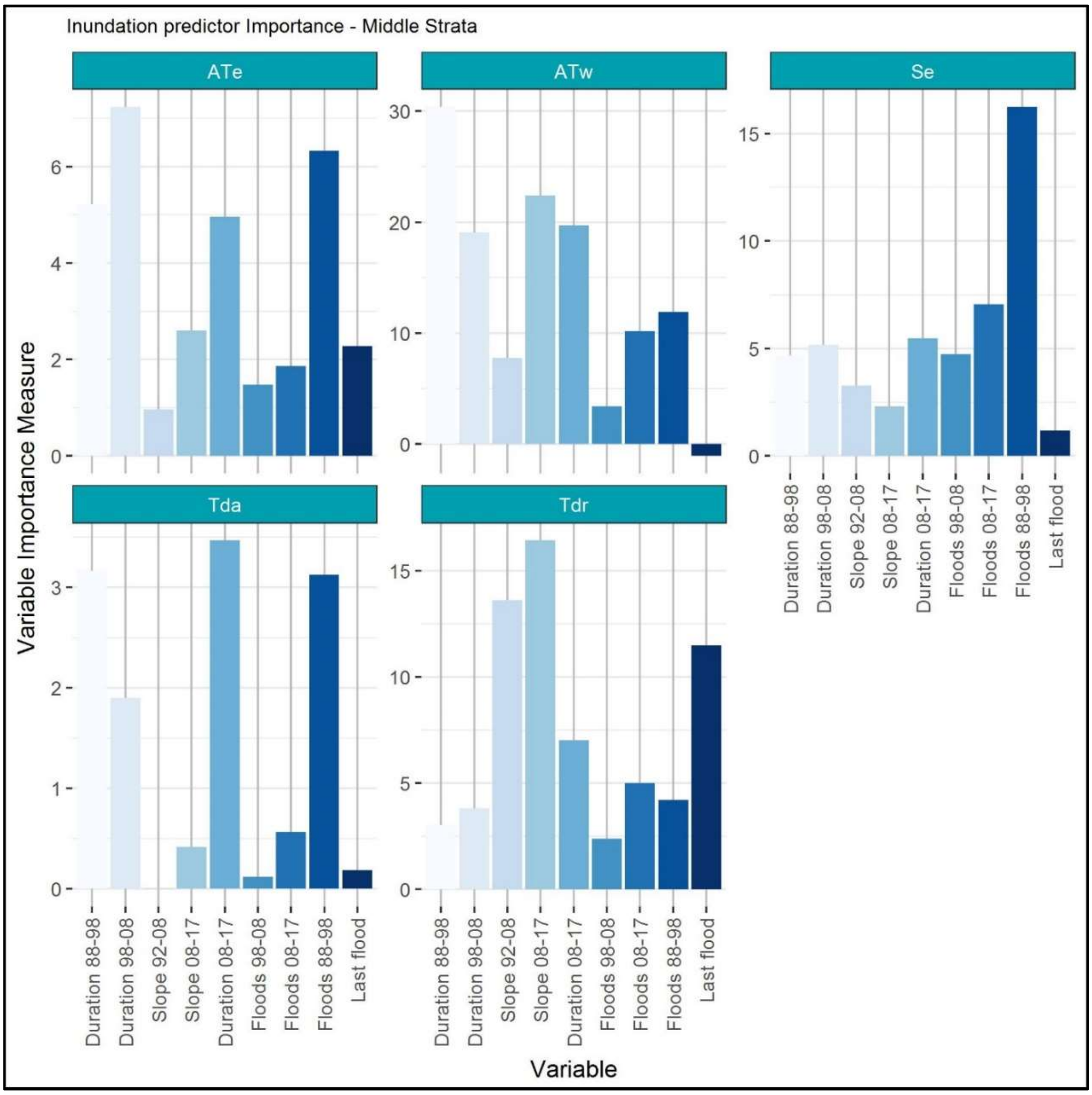


Figure 13 Importance of predictor variables for the middle stratum

2.4.2.3 Tallest stratum

Figure 14 is a series of plots of the inundation variable importance measure (y axis) against each of the inundation predictor variables (x axis), for each of the response variables (WPFGs: ATw and Tdr). The rank scores for each of the nine predictor variables (ranked 9–0), by response variable are in Table 12. In the Tallest stratum, the number of days flooded in the pre-MD period (*Duration 88-98*), was the most important variable in predicting the percent cover of the WPFGs ATw (river red gum) and Tda (coolibah). The next most important predictor was the variable *'Slope 92-08'* which represents the slope of the trend of change in inundation frequency for the 5-year moving average flood data (i.e. how fast the inundation rate increased or decreased frequency from the Pre-MD to the end of the MD period) (Figure 14, Table 12).

Table 12 Rank scores for importance of predictor variables by response variables – Tallest stratum

Water plant functional group	Duration 88-98	Duration 98-07	Duration 08-17	Slope 92-08	Slope 08-17	Last flood	Floods 88-98	Floods 98-07	Floods 08-17
ATw	9	7	6	8	3	1	5	2	4
Tda	9	7	4	8	5	1	2	3	6
Total	18	14	12	16	8	2	7	5	8

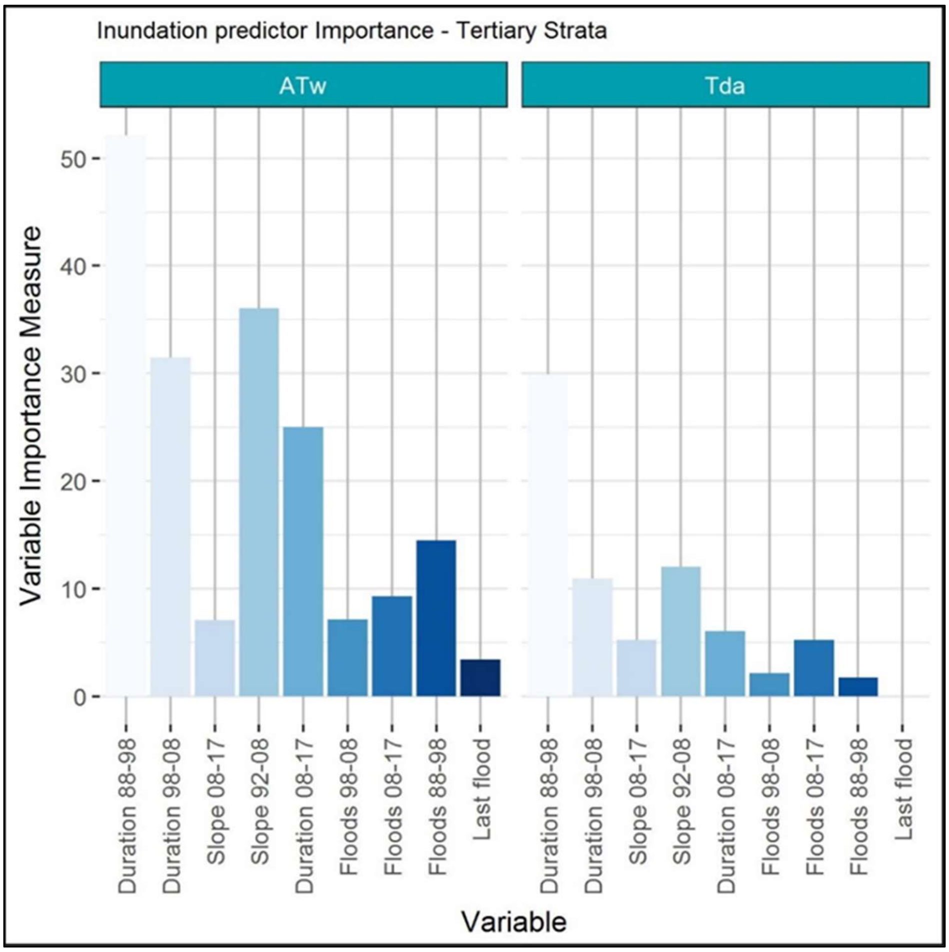


Figure 14 Importance of predictor variables for the tallest stratum

2.4.3 Floristic community condition site clustering profiles by stratum

2.4.3.1 Lower statum

The predictor variable importance analysis found that mean days flooded during the Post-MD period (2008/09-2016/17) (*Duration 08-17*), and the number of years since last flood (*Last flood*), were the two most important predictor variables species in most WPFGs for the lower stratum (see Section 2.4.2.1) Site clustering profiles for site for the lower stratum data is shown in Figure 15.

The top row of Figure 15 orders the nine clusters of sites generated by the MRF by the mean days flooded during the post-MD period, decreasing from left to right (i.e. most days inundated to least). Note: cluster numbers are not sequential but serve only to name the groupings as each numbered cluster represents groups of sites with similar inundation regime history.

The middle row of Figure 15 is the WPFG profile of each of the site clusters defined in MRF for the lower stratam data. The midline of each box is the mean percentage cover, box edges are the 1st and 3rd quantiles, and the whiskers represent 1.5 times the interquartile range. The percentage cover of most Amphibious species (e.g. ARf, ATl, ATe) was lower in site clusters with shorter mean duration of inundation (mean days flooded) during the study period (See Cluster 6 far left compared to Cluster 9 far right). Conversely, the percentage cover of Terrestrial dry species (Tdr) and bare ground and litter during the study period was higher in the shorter mean duration of inundation (mean days flooded) clusters (See Cluster 9 far right compared to Cluster 6 far left).

The bottom row of Figure 15 is a management summary of the cluster analysis for each WPFG. Points are mean (±1 SE) percentage cover from each observation at each site in the cluster. The x-axis represents three *inundation duration classes*. To derive these classes the ordered nine clusters were aggregated into thirds: *Class 1* represents the three clusters of sites with longest mean days flooded per year (mean duration) was longest, *Class 2* are the three clusters where sites had moderate mean days flooded per year, and *Class 3* where the three clusters with the lowest mean number days flooded per year.

The percentage cover of amphibious functional group species (ARf, ATe and ATl), was highest in Class 1 and lowest in site in Class 3. Conversely, sites had a higher percentage cover of Terrestrial dry species (Tdr), Terrestrial damp (Tda) species, and bare ground in sites in Class 3. The percentage cover of ARf, ATl and ATe species decreased in a linear fashion from highest to lowest duration class, but the WPFGs ARp, ATw and Se have a less linear response. The percentage cover of ARp and ATw species was almost constant in all three inundation classes, and the percentage cover of Se species was slightly higher in the moderate inundation class (Class 2).

The percentage cover of litter (organic matter of plant origin, including fallen timber of less than 10 cm diameter), and Tda species did not significantly alter across inundation classes.

Figure 16 shows the percentage cover of species in each WPFG analysed by wetland type, for sites in each of the nine site clusters, ordered by decreasing duration of flooding over the post-MD study period (2008/09-2016/17). The percentage cover of amphibious WPFG species in response to mean inundation duration varies between wetland types, but is generally lower in clusters with lower mean duration of inundation. For example, the percentage cover of ATe species in non-woody wetlands and flood-dependent shrubland wetlands, is lower in clusters of sites with a lower mean inundation duration (see cluster 9) than in sites in clusters with a longer mean flooding duration (see clusters 6 and 4).

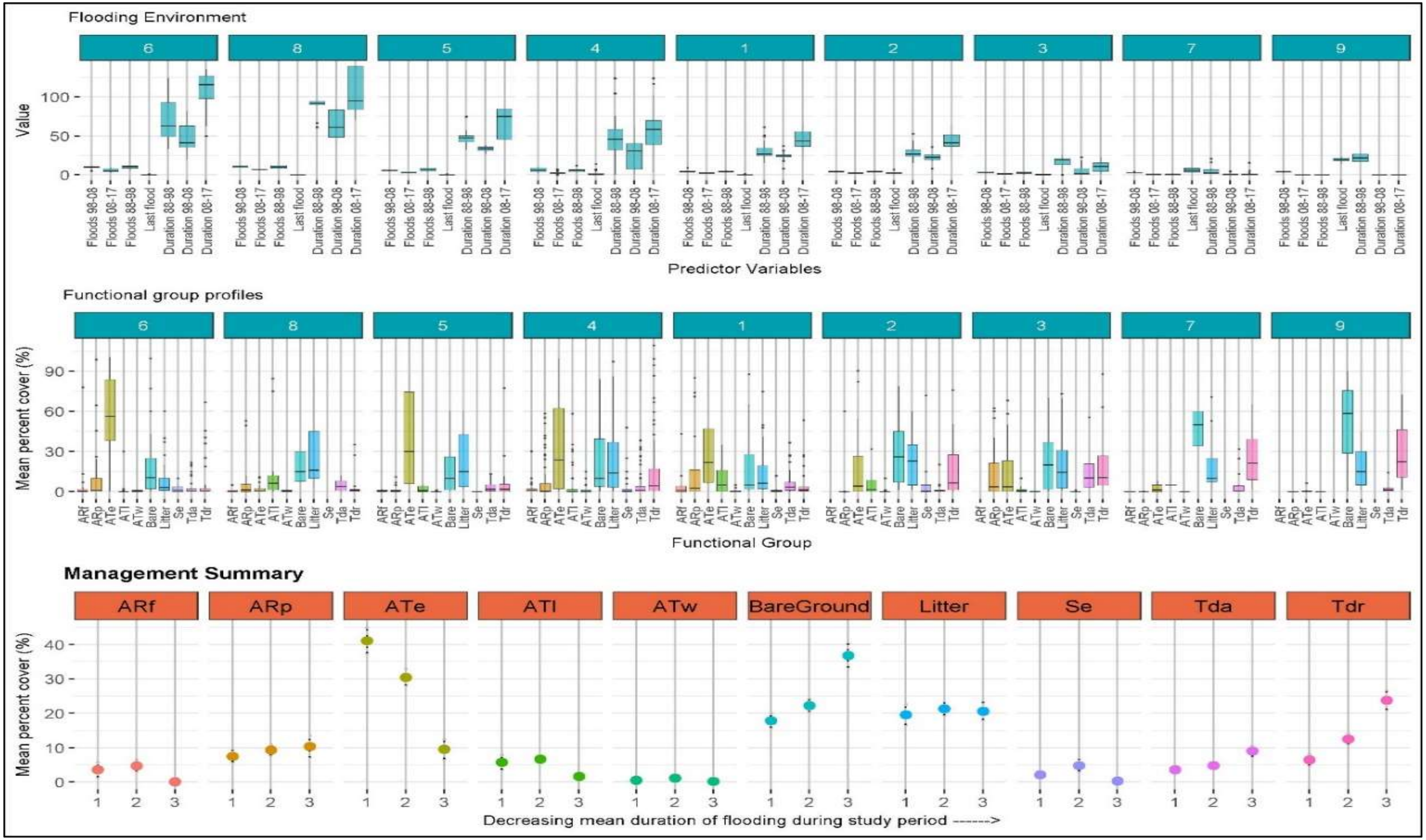


Figure 15 Site clustering profiles – lower stratum

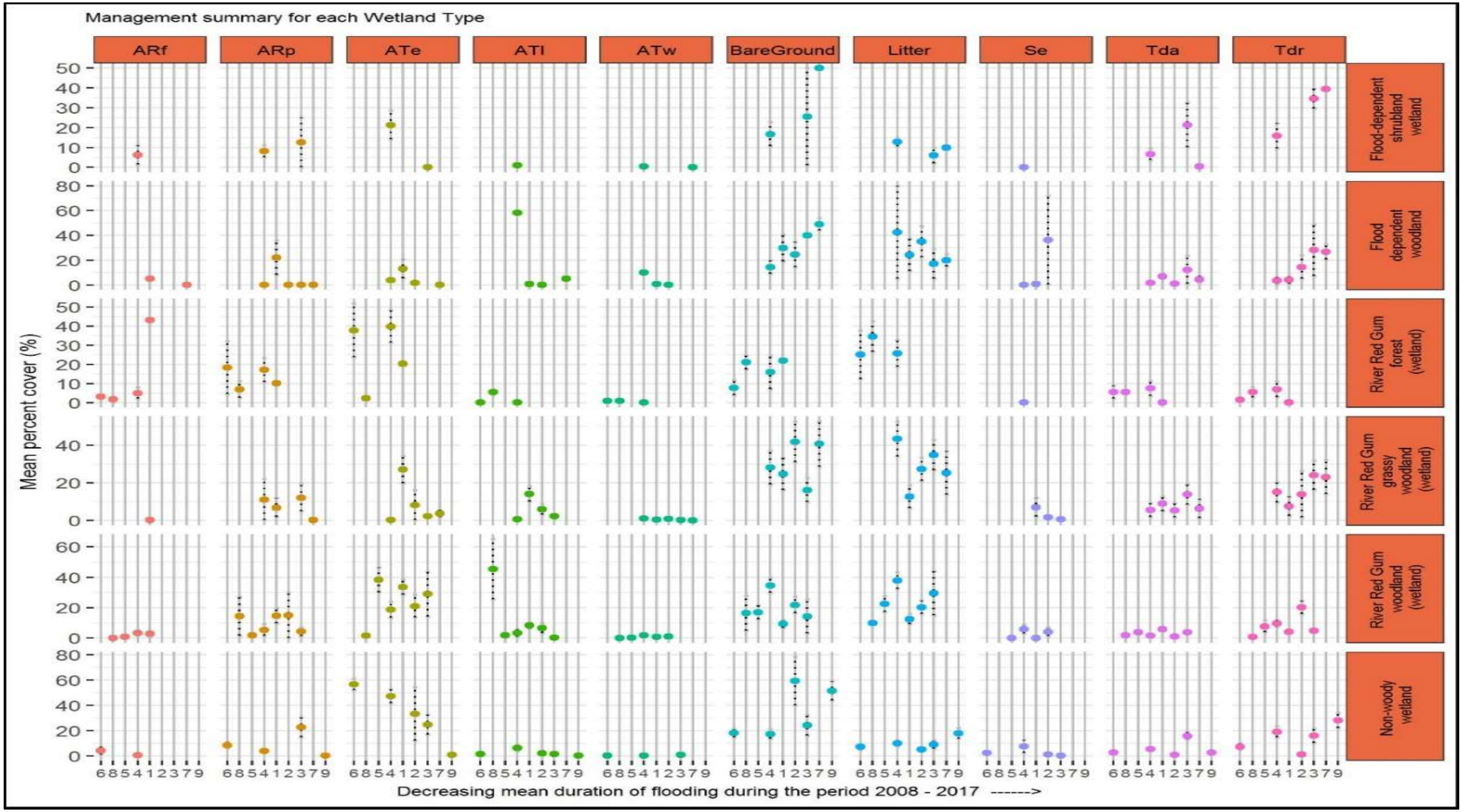


Figure 16 Management summary by wetland type for the lower stratum

2.4.3.2 Middle stratum

The nine clusters derived from middle stratum data are ordered by decreasing mean days flooded during the MD period (1998/99 – 2007/08) (left to right) (Figure 17). The flooding environment of each cluster is shown in the top row.

The bottom row of Figure 17 shows the WPFG profiles for each of the nine clusters, ordered by decreasing mean days flooded during the MD period. The x-axis represents the WPFGs modeled in the MRF for the middle stratum and the y-axis is the mean percentage cover . The midline of each boxplot is the mean percentage cover, box edges are the 1st and 3rd quantiles, and the whiskers represent 1.5 times the Interquartile range

The total percentage cover of species in the groups ATe and Se are lower in clusters of sites with shorter mean inundation duration than those in clusters of sites with longer mean inundation duration during all time periods (Pre, during and Post MD) (e.g. clusters 6 and 7, compared to clusters 8 and 5). Percentage cover of species in the ATw group was higher in clusters of sites that had received moderate flooding duration during the three time periods (e.g. clusters 1, 3 and 4). Percentage cover of species in the FG Tdr were generally highest in those sites with moderate inundation duration during all three periods (e.g clusters 1,3 and 2).

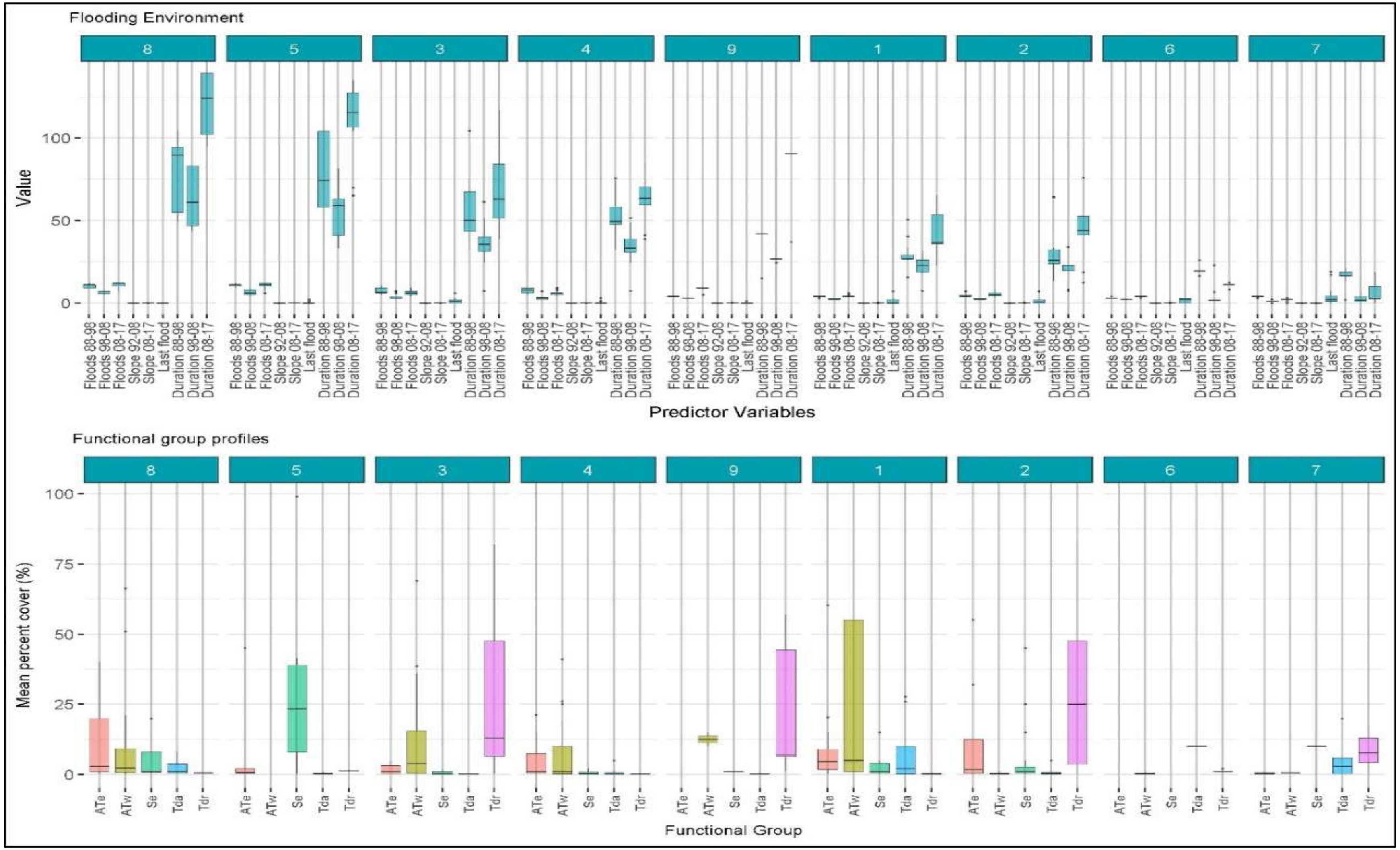


Figure 17 Site clustering profiles – middle stratum

Figure 18 is a management summary for each response variable (percentage cover of WPFGs) for the Mid stratum ploted against inundation classes 1 to 3, derived by amalgamating the nine clusters into three groups. Points are mean (±1 SE) percent cover for each observation of functional group.

In the top row the x-axis represents the three inundation duration classes derived from the number of flood events in the Pre-MD period (1997/88 – 1997/98) The percentage cover of species in Se group, were higher in sites that had more inundation events in the pre-MD period (labeled 1988-1997 period), though this response was not linear. Sites that had fewer inundation events during the pre-MD period had higher percentage cover of Tda species. Species in the the Amphibious WPFGs ATw and ATe were higher in the moderate inundation regime (Class 2).

The percentage cover of Tdr species were significantly lower in sites with most floods during the pre-MD period but there was a higher percentage cover of Tdr species in sites in Class 2 than the sites in the cluster with the lowest number of inundation events (Class 1) (Figure 18).

Inundation classes were ordered (1-3) in decreasing mean duration in the MD period (1998/99-2007/08) in the middle row of Figure 18. The percentage cover of Amphibious Tolerators-woody (ATw) species were highest in Class 2, and the percentage cover of Se and Tdr species were highest in Class 1, those site clusters with the longest mean duration in the MD period. Percentage cover of ATe and Tda species remained relatively constant across classes.

Inundation classes were ordered (1-3) by increasing rate of change in flood frequency during the MD period 1992/93-2007/08 in the bottom row of Figure 18. A lower '*Slope 92-08'* value (steeper downward slope of the 5-year moving average) indicates that sites went from frequent inundation (higher sum of floods), to less frequent inundation, quickly during the MD (1998/89-2007/08). The sites in class 1 had a more stable inundation regime than those in Classes 2 and 3.

The percentage cover of species in the semi-aquatic group Se, was highest in Class 1, the most stable inundation regime before and during the MD period. The percentage cover of the amphibious species in the groups ATe and ATw and the terrestrial group Tdr, were highest in the sites with a moderate rate of change in inundation frequency. In contrast the percentage cover of species in the terrestrial group Tda, were highest in the sites with the greatest rate of change in inundation frequency in the MD period.

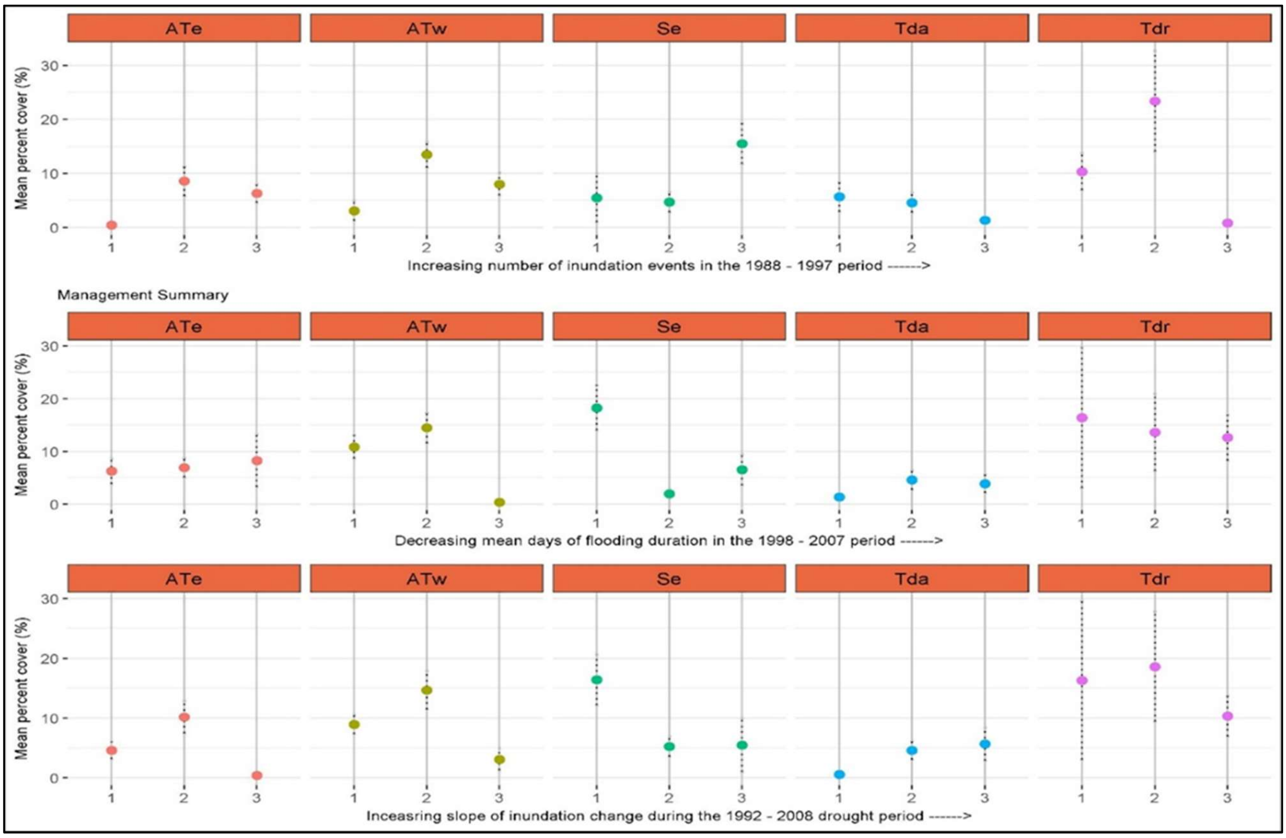


Figure 18 Management summary – middle stratum

2.4.3.3 Tallest stratum

The MRF analysis found that for species in the tallest stratum the number of days flooded in the pre-MD period (*Duration 88-98*) and *'Slope 92-08*' were the most impportant predictor variables (Section 2.4.2.3). The inundation profile of each derived site cluster from the MRF, was ordered by increasing '*Slope 92-08'* variable, i.e. the slope of the trend of inundation rate for the 5-year moving average flood data (Figure 19 top row). A lower '*Slope 92-08'* value (steeper downward slope of the 5 yearly moving average), indicates that sites went from more frequent inundation (higher sum of floods), to less frequent inundation, quickly during the MD (1998/89-2007/08).

The predictor Sum of floods, was subset into the mean number of inundation events in the pre-MD period (1988/89 – 1997/98) , and the mean number of inundation events in the MD period (1998/99 – 2007/08), to better highlight the change in slope for the 5-year moving average (bottom row of Figure 19). The y axis is number of floods. This better highlights the differences between site clusters, and demonstrates the relationship between the slope of the 5-year moving average, and the total number of inundation events per cluster in the period 1988/89-2007/08.

If there were many inundation events in the Pre-MD period and inundation frequency declined rapidly through the MD period, the slope 92-08 value is lower (it is a negative value) (see cluster 3). Conversely, if sites were had little change in inundation frequency throughout the 1992-2008, period the slope 92-08 value is higher (see cluster 5).

Figure 20 is the mean (±1 SE) percentage cover of the one species in the group ATw, river red gum, in the tallest stratum by wetland type; red gum forest, woodland and grassy woodland. The site clusters are ordered by rate of inundation frequency change from Pre-MD to the MD period (1992-2008).

River red gum forest sites were only in clusters with the highest flood duration and where the change in inundation frequency was greater between the pre and MD periods (lower slope 92 values) (clusters 8, 6 and 3) (Figure 20). Highest values for percentage cover occurred in sites in cluster 6. These sites also had the highest frequency of inundation in the pre-MD and second highest in the MD periods (Figure 19).

River red gum woodland wetland sites had higher percentage cover in clusters where the inundation frequency before and during the MD was highest, and the rate of inundation frequency change during the MD was moderate (clusters 1 and 8). Mean percentage cover was less in clusters where the inundation frequency before and during the MD was moderate and the rate of inundation frequency change during the MD was most rapid (clusters 9 and 3). Woodland wetland sites that had lower inundation frequencies both pre and during the MD, and that did not change much during the MD had lowest mean percentage cover (clusters 4 and 2) (Figure 20,

Figure 19). This indicates that river red gum woodland wetland occurs across a range of inundation frequencies but had highest percentage cover at sites that received more frequent inundation. River red gum grassy woodland sites predominately occurred in clusters that received the lowest inundation frequencies pre and during the MD and that did not change greatly during the MD (Clusters 5, 7), and sites with moderate change only (Clusters 4 and 2), (Figure 20, Figure 19).

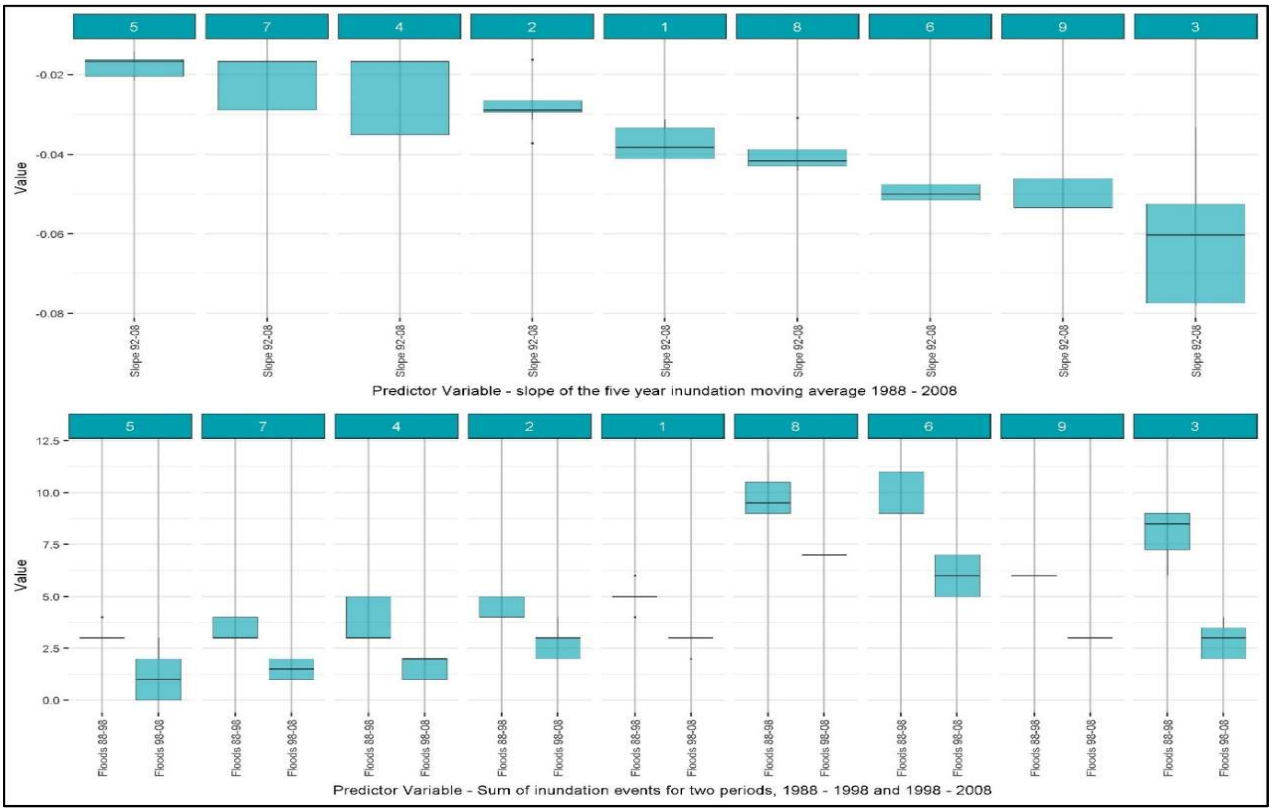


Figure 19 Site clustering profiles - tallest stratum

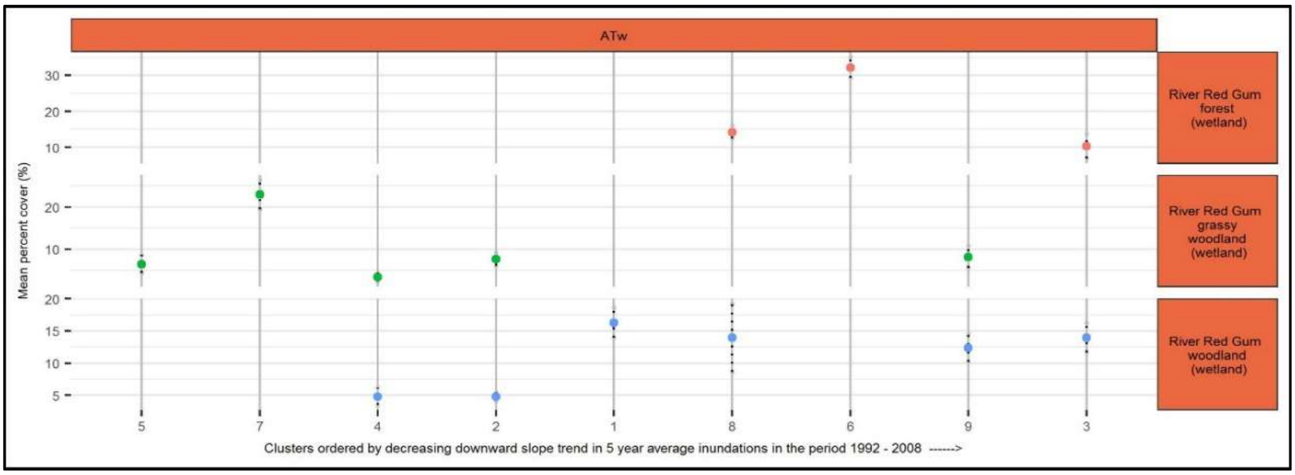


Figure 20 Management summary with change in inundation frequency regime– tallest stratum

Figure 21 is the mean (±1 SE) percentage cover of river red gum in the tallest stratum by wetland type (red gum forest, woodland wetland and grassy woodland). The site clusters are ordered by decreasing mean days flooded during the pre-MD period (1988-1998). The percentage cover of in the tallest stratum of river red gum forest was highest in the sites in the cluster with the longest inundation duration in the pre-MD period (1988/89-1997/98) (Cluster 8). The percentage cover of the tallest stratum of river red gum woodland, was highest in the sites in the cluster with a moderate inundation duration in the pre-MD period (1988/89-1997/98) (Cluster 1). The percentage cover of the tallest stratum of river red gum grassy woodland, was highest in the sites in the cluster with a low inundation duration in the pre-MD period (1988/89-1997/98) (Cluster 7), (Figure 21, Figure 19).

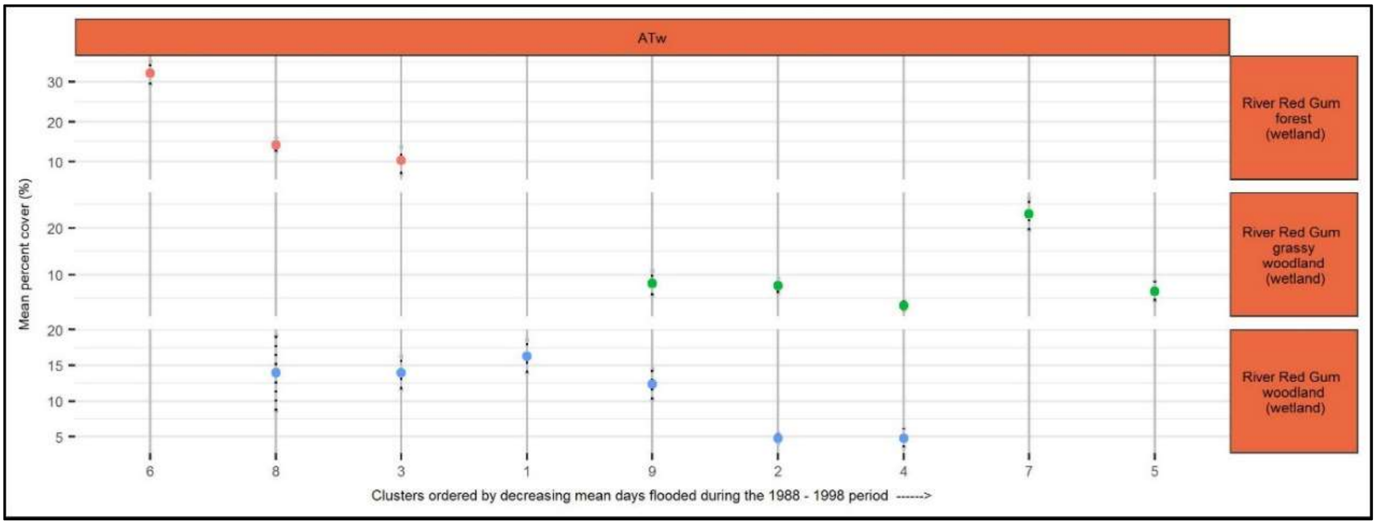


Figure 21 Management summary with change in inundation duration– tallest stratum

2.4.4 Modelling floristic community condition variable ranges under different inundation regimes by wetland type

2.4.4.1 Lower stratum

The model output plot of data from the lower stratum only, with sites combined by wetland type in each inundation scenario (1-3), shows the total percentage cover of species of the amphibious WPFGs (ATp, ATf, ATl, ARf and Se), was higher in the scenarios with the longest inundation duration (Scenario One) in all wetland types. Percentage cover of ATe species was highest in the moderate inundation regime (Scenario Two), particularly in the non-woody wetland type (Figure 22).

The percentage cover of bare ground and Terrestrial dry species (Tdr) were highest in sites in the minimum inundation regime (Scenario Three). For all wetland types, percentage cover of bare ground is lowest under the moderate (mean) inundation regime (Scenario Two). The relative proportion of percentage cover of litter is different between tree dominated, shrubland and non-woody wetland types (Figure 22).

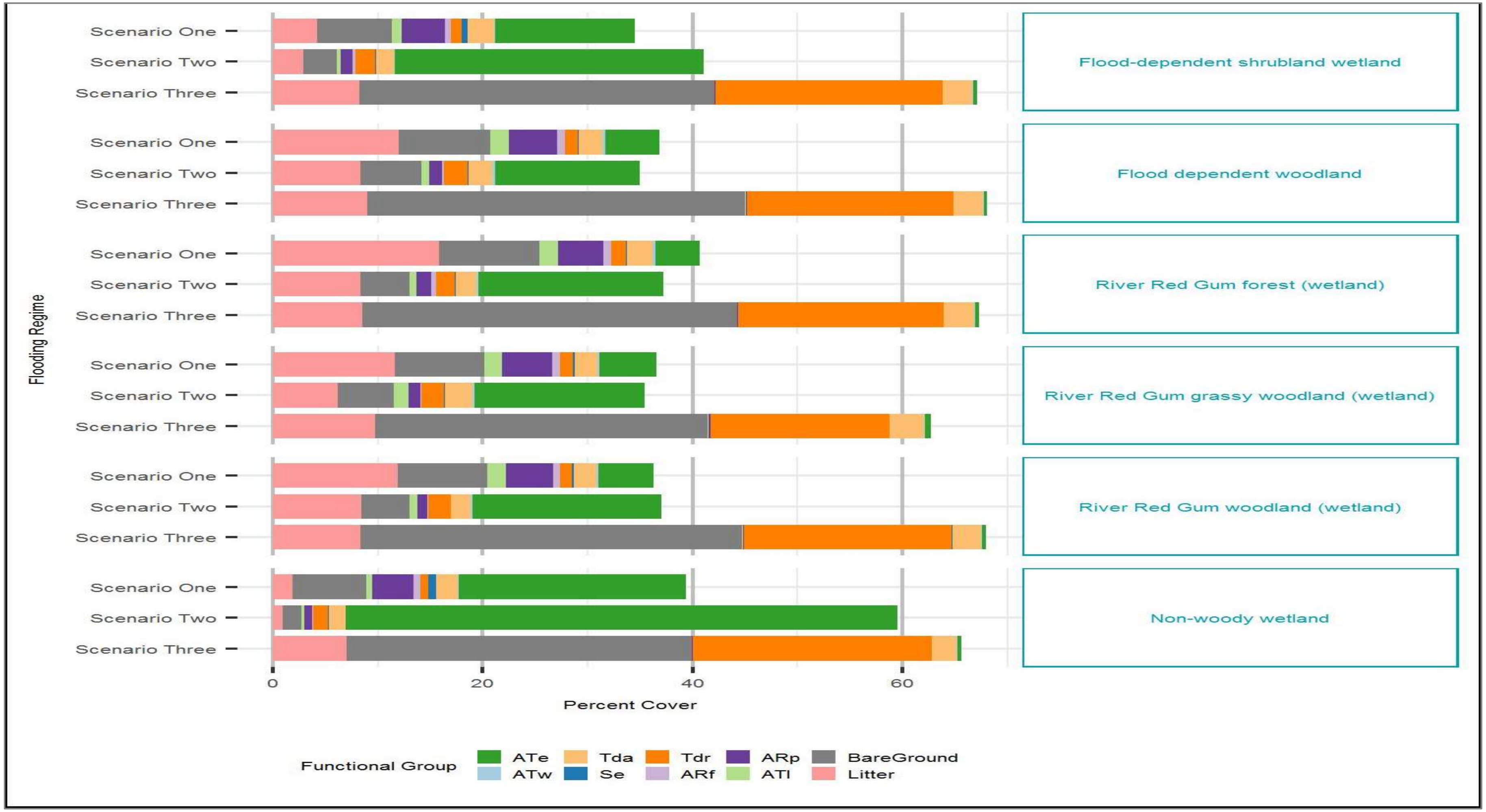


Figure 22 Response variable composition profiles for the lower stratum by wetland type

2.4.4.2 Middle stratum

Figure **23** is a plot of the mean percentage cover of species in summed for each of the WPFGs, using data from the middle stratum, with sites combined by wetland type, in each inundation scenario (1-4) (see Table 4). Scenario Four is the same as Scenario Two but with high grazing pressure and maximum time since last flood (see Table 4).

In the middle stratum, the percentage cover of species in the Amphibious WPFGs (ATe, ATw and Se) was highest in the longer duration inundation regimes (Scenarios One and Two). In all wetland types the percentage cover of Tdr and Tda species were higher in sites that received the minimum inundation regime (Scenario Three), than in the other scenarios. Interestingly the percentage cover of all other indicators in Scenario Four was not significantly different when compared to the same inundation scenario with low grazing pressure (Scenario Three) (Figure 23).

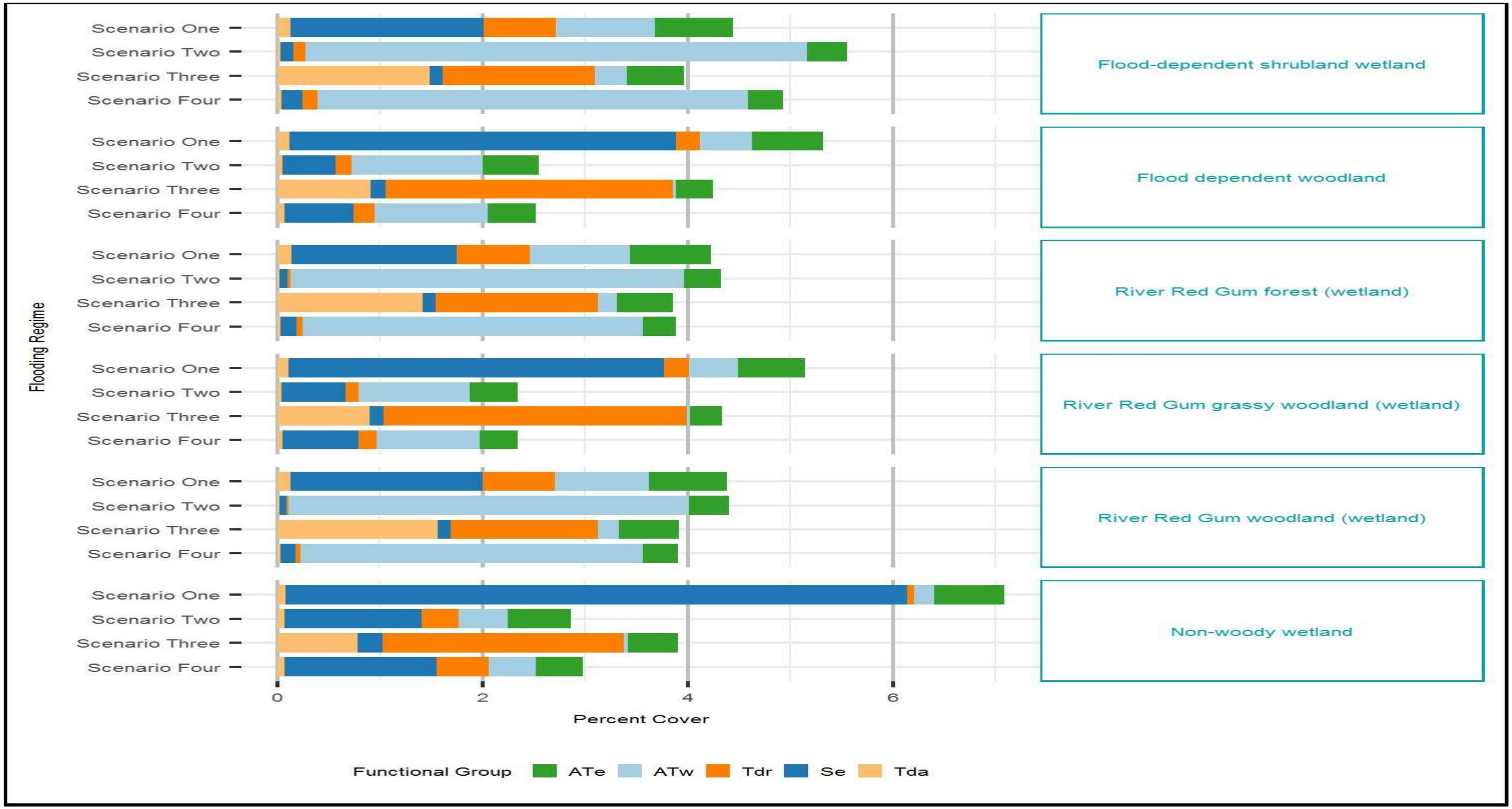


Figure 23 Community composition profiles for the for the middle stratum by wetland type

2.4.4.3 Tallest stratum

Figure 24 is a plot of the mean percentage cover of species in WPFG ATw, using data from the tallest stratum with sites combined by wetland type, in both possible inundation scenarios (1 and 2) (see Table 4). The percentage cover of the one ATw species, river red gum, in the tallest strata is highest under the maximum flooding regime (Scenario 1) (Figure 24).

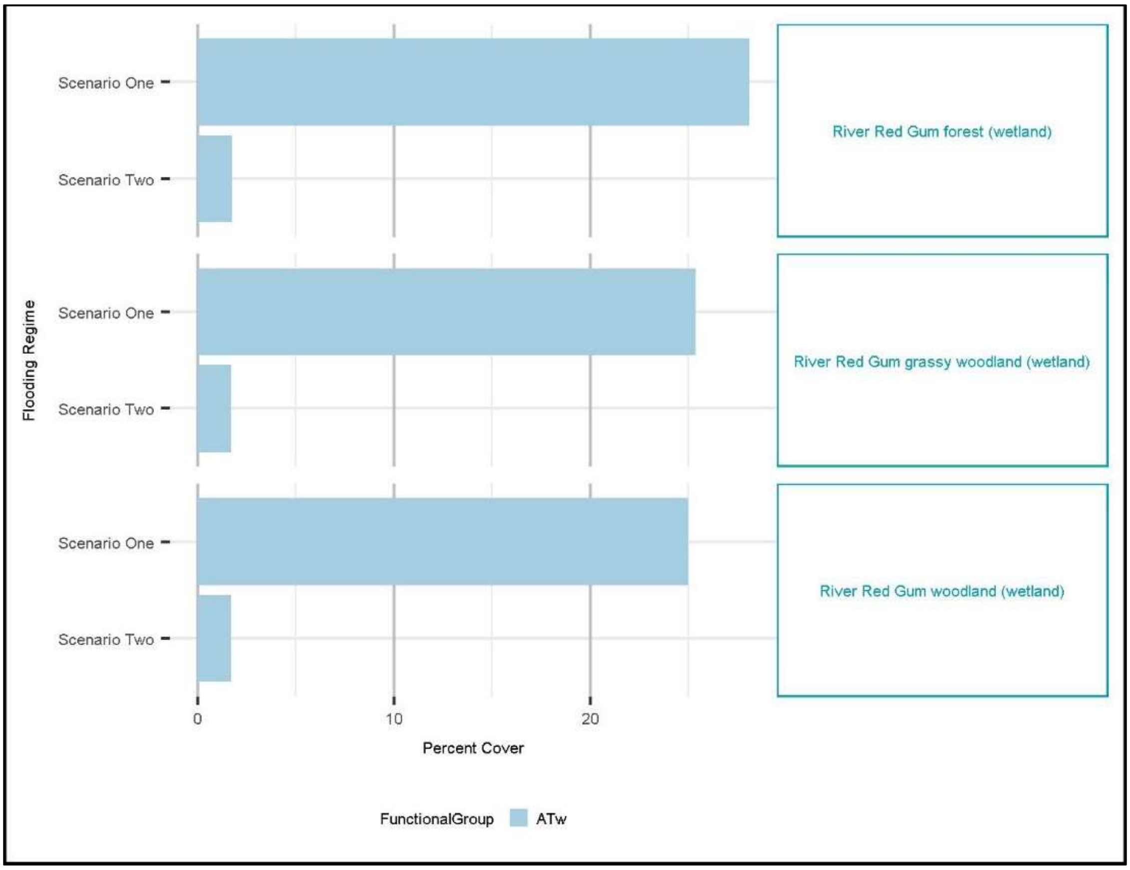


Figure 24 Management summary profiles for the tallest stratum

2.4.5 Inundation variable importance for tree stand condition

Figure 25 is a series of plots of the inundation variable importance measure (y axis) against scores for: percentage dead canopy, percentage dead limbs, Plant Area Index (PAI) and percentage live basal area (LBA) (x axis).

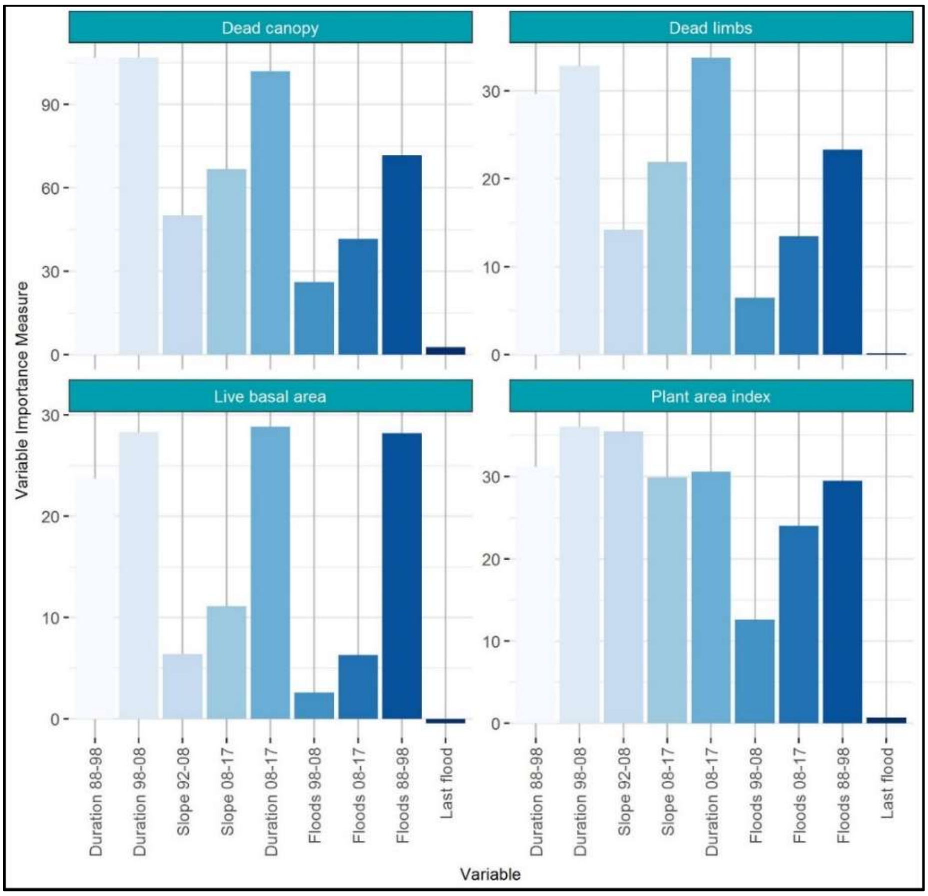


Figure 25 Variable importance measures for determining tree stand condition scores

Table 13 Rank scores for importance of predictor variables by response variables – tree condition variables

Tree condition variables (scores)	Duration 88-98	Duration 98-08	Duration 08-17	Slope 92-08	Slope 08-17	Time since last flood	Floods 88-98	Floods 98-08	Floods 08-17
% Dead canopy	8	9	7	4	5	1	6	2	3
% Dead limbs	7	8	9	4	5	1	6	2	3
Live Basal Area	6	8	9	4	5	1	7	2	3
Plant Area Index	7	9	6	8	5	1	4	2	3
Total	28	34	31	20	20	4	23	8	12

The rank scores for each of the nine predictor variables (ranked 9–0), by response variable are in Table 13. The mean number of days of inundation during the post-MD period (Duration 08-17) was the most important variable for percentage dead limbs and LBA, however inundation duration in the MD period (Duration 98-08), was the most important for percentage dead canopy and PAI. The rate of inundation change in the MD period (Slope 92-08) was also an important predictor variable for PAI. Time since last flood was the least important predictor variable for all response variables (Figure 25, Table 13).

2.4.6 Tree stand conditon site clustering profiles

The top row of Figure 26 shows inundation characteristics (*flooding environment*) of each derived cluster. The plots are ordered by decreasing mean days flooded during the MD period (1998/99 – 2007/08) (left to right). The most important variable for predicting the percentage cover of the tallest stratum (a surrogate for tree stand condition), was the mean days flooded in the pre-MD period (*Duration 88-98*) (see Section 2.4.3.3; Figure 25).

Figure 26 (middle row) is the tree stand condition variable score profile of each of the clusters of sites by tree stand condition individual variable scores (calculated from raw data), for PAI, percentage dead canopy, percentage live basal area and percentage dead limbs. The x-axis represents the tree stand condition variable scores modeled in the MRF. Note: scores range from 0-8 for percentage dead canopy, and 0-4 for all other variables (See Section 3.2.2.1). The midline of each boxplot is the mean score, box edges are the 1st and 3rd quantiles, and the whiskers represent 1.5 times the interquartile range. The site clusters are ordered by mean days flooded during the MD period in decreasing order (left to right).

The scores for all tree stand condition variables were highest in the clusters that had the longest inundation duration (clusters 4,2,3) during the MD period. In clusters where the inundation duration is highest there appeared to be less variability in the tree stand condition metric scores (Figure 26).

The bottom row of Figure 26 is a management summary of the cluster analysis for each tree stand conditon variable. Points are mean (±1 SE) tree stand condition score from each site in the cluster. Note: scores range from 0–8 for percentage dead canopy, and 0–4 for all other variables. The x-axis represents three *inundation duration classes*. To derive these classes, the ordered nine clusters were aggregated into thirds. Class 1 represents the three site clusters where mean days flooded (average duration) was greatest, with Class 2 representing those clusters of sites with moderate and and Class 3 those site cluster with lowest mean number days flooded per year. The score for each of the variables was highest in sites in clusters with the highest mean duration in the MD period (Class 1), except percentage dead canopy which was very slightly higher in Class 2.

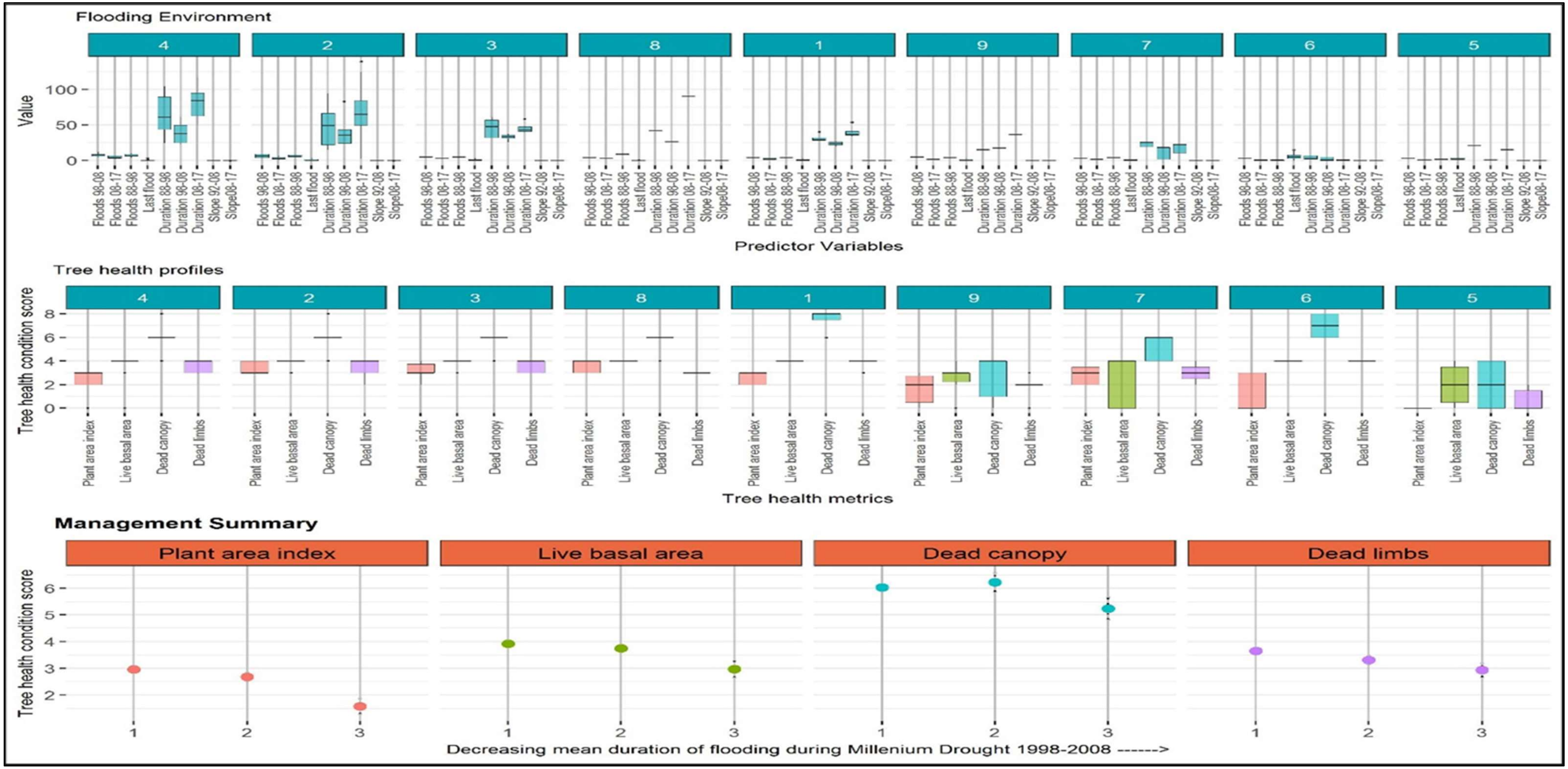


Figure 26 Site clustering profiles for tree stand condition

Figure 27 shows the mean score for each tree stand condition variable within each river red gum wetland type, for sites in each inundation duration cluster, ordered by decreasing duration of flooding in the MD period (1998/99 –2008/09). In river red gum woodland and river red gum grassy woodland, tree stand condition variable scores were lower in clusters with lowest mean days flooded during the MD.

In river red gum woodland, the decrease in condition score for each tree stand condition variable occurs in clusters with a moderate flooding duration. Flood-dependent grassy woodland and river red gum forest have a limited number of sites making it difficult to determine trends with the available data.

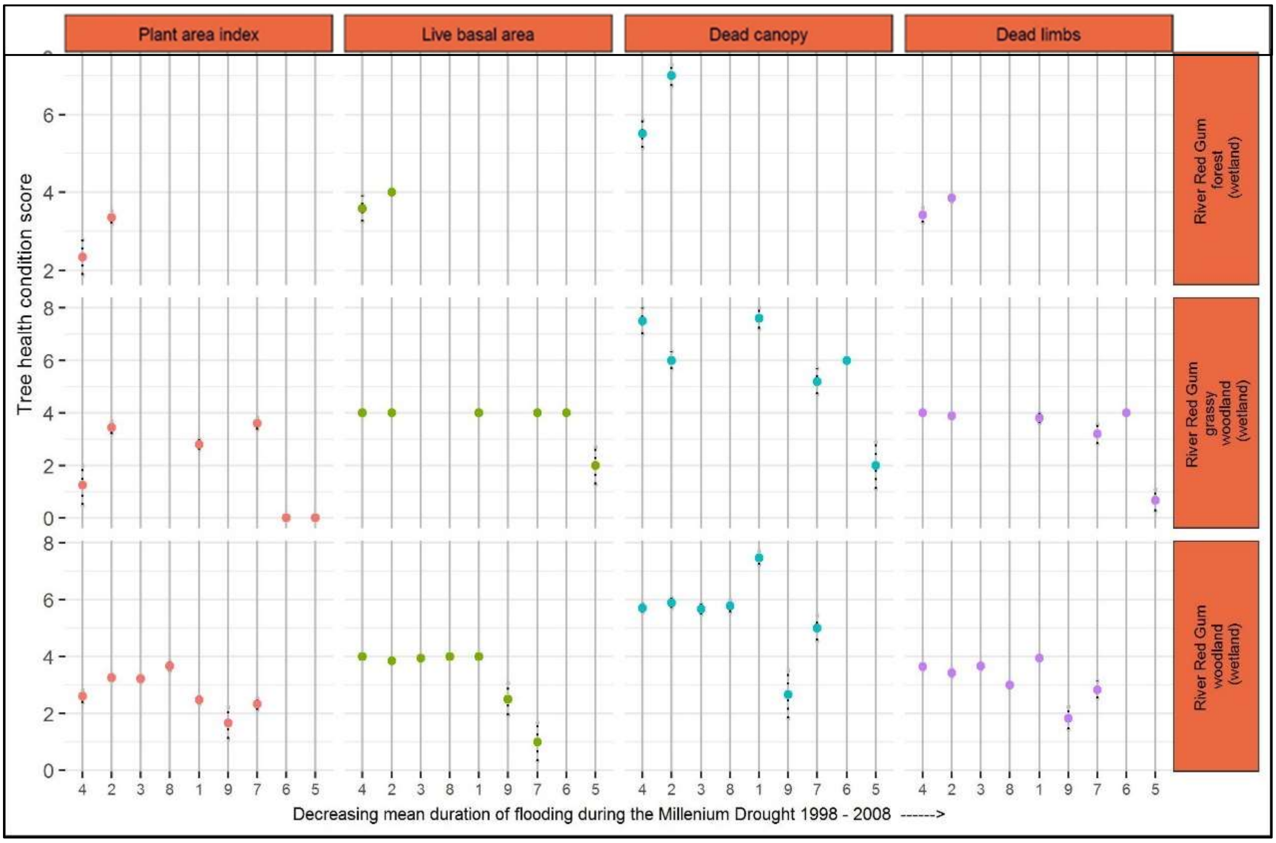


Figure 27 Management summary for tree stand condition based on wetland type

The MRF models provide a value that quantifies the variance explained in the statistical model, which can be viewed as a pseudo r squared. This value is calculated as the mean square error divided by the variance of the response subtracted from one (Pang et al. 2006). This value indicates how well the predictor variables explain the variation in the percent cover of the response variable (Table 14). The wetland woodlands model achieved a lower overall error rate than the wetland forests but also had a significantly higher sample size (Table 15).

Table 14 Tree stand condition variance

Response variable	Percentage of variance explained
PAI Score	52.65
LBA Score	43.87
DC Score	59.56
DL Score	67.19

Table 15: Error rate and sample size for the tree stand condition class validation model

Model	Wetland types	Sample size	Overall error rate
Wetland forest	River red gum forest	26	30.77
Wetland woodlands	River red gum woodland, River red gum grassy woodland, flood dependent woodland	143	21.68

The wetland forests model prediction error for the poor condition classes was high but these were also under sampled sites. The intermediate condition class was predicted more accurately, but more wetland forest sites would yield a meaningful MRF analysis. In the wetland woodlands model, the better condition classes, good and intermediate, were predicted from the tree health data with a reasonably high level of accuracy (Table 16, Table

17). The models are constrained by the limited number of sites across the range of condition classes however in those classes with numerous sites, prediction accuracy was typically high.

Table 16 Confusion matrix for the tree stand condition class validation model for wetland forests.

Observed/predicted	Excellent	Good	Intermediate	Intermediate / poor	Poor	Very poor	Class error
Excellent	4	0	0	0	0	0	0.00
Good	1	3	2	0	0	0	0.50
Intermediate	1	0	11	0	0	0	0.08
Intermediate/poor	0	0	2	0	0	0	1.00
Poor	0	0	1	0	0	0	1.00
Very poor	0	0	0	1	0	0	1.00

Table 17: Confusion matrix for the tree stand condition class validation model all woodland wetlands.

Observed/predicted	Excellent	Good	Intermediate	Intermediate /poor	Poor	Very poor	Class error
Excellent	0	0	0	0	0	0	NA
Good	0	33	6	0	0	0	0.15
Intermediate	0	7	62	3	0	0	0.14
Intermediate/poor	0	1	6	10	1	0	0.44
Poor	0	0	0	3	0	2	1.00
Very poor	0	0	0	1	1	7	0.22

Figure 28 shows the error rates and variable importance for determining condition classes for both wetland types. In both cases, for wetland woodlands and wetland forests the most important variables for determining condition score were the percentage of dead canopy and percentage foliage cover (PAI). In the woodland sites considered in very poor condition, the percentage of dead limbs was most influential. The percentage of live basal area had little impact in determination of tree stand condition in the current data set.

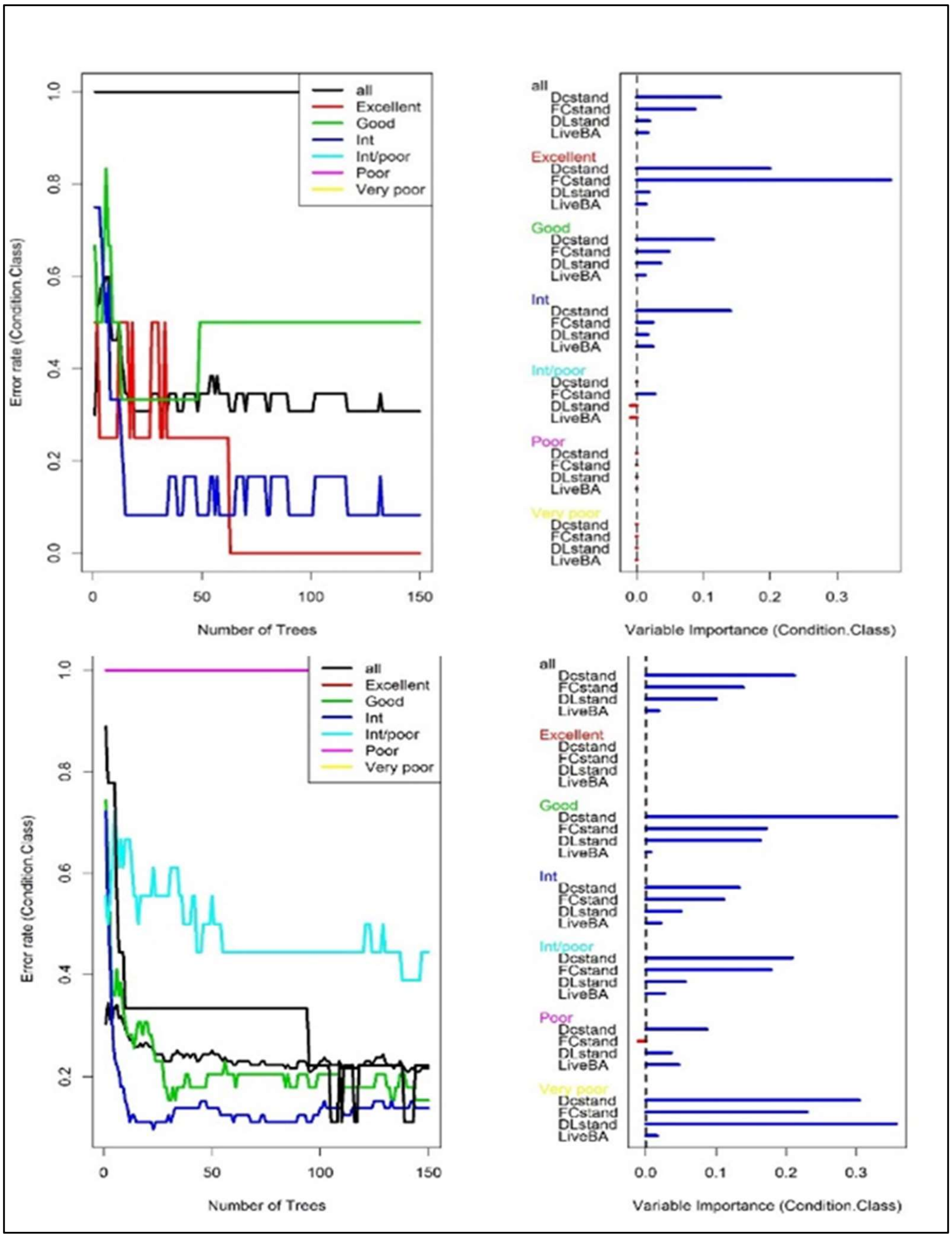


Figure 28 Out of bag error rate and variable importance for the forest wetland type (top row) and woodland wetlands types (bottom row).

2.4.7 Modelling tree stand condition variable ranges under different inundation regimes

Figure 29 is a plot of the mean score for each of the tree stand condition response variables (PAI, percentage dead canopy, percentage live basal area and percentage dead limbs), with sites combined by wetland type, in each inundation scenario (1 and 2). Under Scenario One, (Maximum inundation regime) sites received the maximum inundation frequency and duration recorded from sites that had a tallest stratum, during the Pre-MD and MD periods (1988–2008), and sites continued to receive regular inundation (at least once per year) in the post-MD period.

Under Scenario Two, sites received the Minimum inundation regime with no inundation during the MD and little recovery in inundation post 2008 (Table 4). For all wetland types all tree stand condition variable scores were higher in Scenario One, the maximum inundation regime. While all tree health scores are higher in Scenario One than Scenario Two, this was most apparent for the PAI score. This supports the findings in the community condition analysis (see Figure 24) where percentage cover of ATw species (i.e. river red gum), was highest in the maximum inundation scenario.

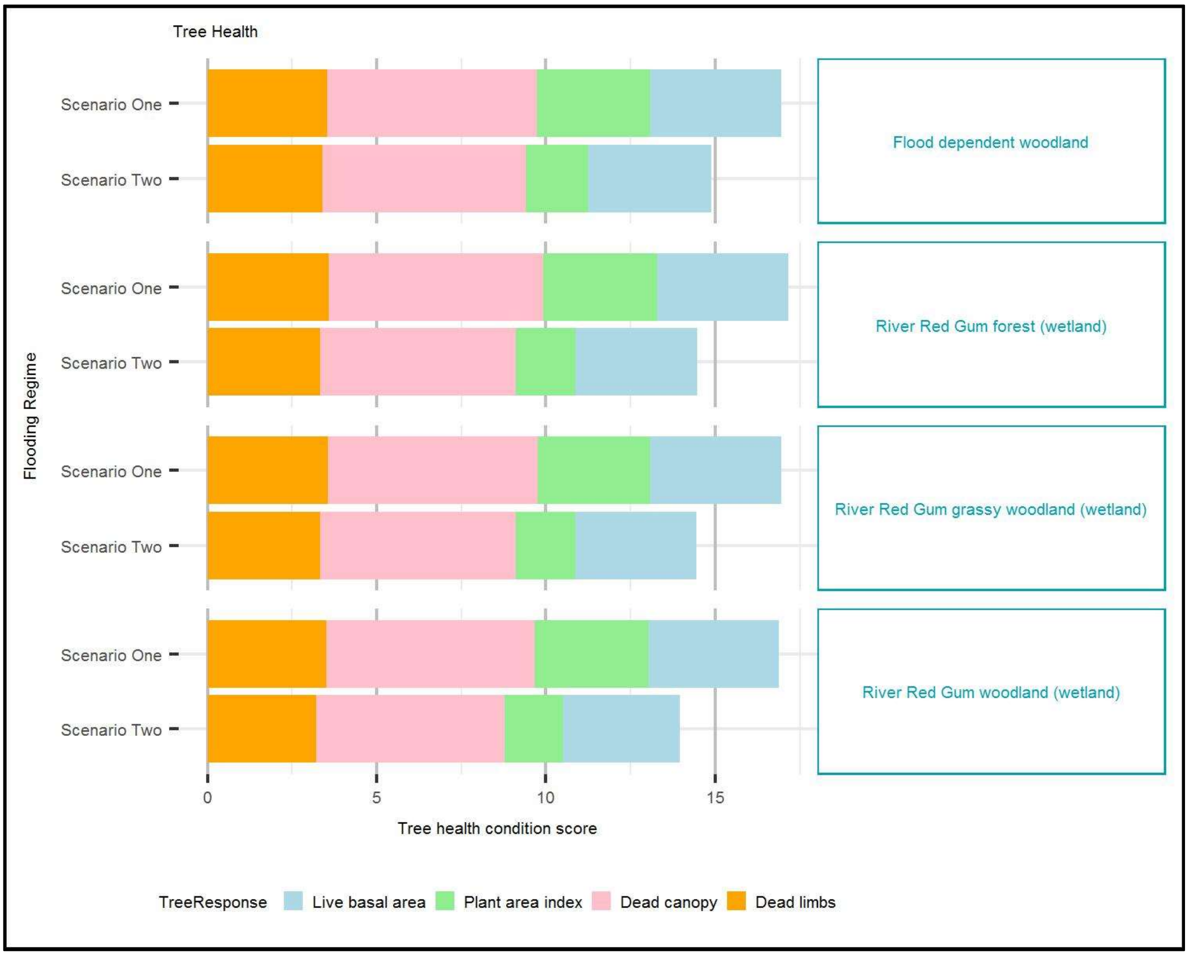


Figure 29 Tree stand condition score predictions for inundations scenarios across wetland types

2.5 Discussion

2.5.1 Floristic community condition response variable trends in relation to predictor variables

In this study several underlying hypotheses regarding inland floodplain wetland plant community dynamics in relation to inundation regimes were tested. These hypotheses were mostly supported by the results of the MRF analysis.

2.5.1.1 Hypothesis 1

Hypothesis 1: *Inland wetland plant communities possess key diagnostic indicator species and other species from amphibious, semi-aquatic and aquatic 'Water Plant Functional Groups' (WPFGs), and these respond to identifiable inundation regimes.*

Lower Stratum

For species in the lower stratum variable importance analysis showed that mean days flooded (inundation duration) during the post-MD period, the mean days flooded in the MD period and the number of years since last flood were the key drivers of change for percentage cover of the majority of WPFGs. The time since last flood was the most important predictor variable for Tdr species.

Middle Stratum

The number of floods in the pre-MD period and the rate of inundation duration change in the 1992-2008 period, was the key driver of percentage cover for middle stratum species. Unlike the lower stratum species, there was very little effect of the variable 'years since flood'. This indicates that the short-term availability of water plays less of a role in the response of species in the middle stratum than the mean value of days inundated over ten-year time scales.

Middle stratum species are often woody shrubs such as lignum or immature tree species, or persistent vegetatively regenerative species such as common reed, sedges and rushes. The percentage cover of Amphibious Tolerators-woody (ATw) species were highest in the moderate innundation regime while the percentage cover of Se species where higher in the maximum inundation regime. This suggests that semi-aquatic species in the group Se such as Phragmites spp. and Typha spp., require longer average annual inundation than amphibious woody species like rver red gum.

Tallest Stratum

For species in the tallest stratum, inundation duration in the pre-MD period was the most important variable and the rate of change in the 'number of floods in 5 years' since

1992 (the rate of regime shift), was also significant both when the data was pooled and when it was analysed by wetland type. The percentage cover of river red gums was generally lower in sites that experienced the greatest decrease in flood duration in the pre-MD, in all red gum wetland types.

2.5.1.2 Hypothesis 2

Hypothesis 2: *The percentage cover of species in the Amphibious and Submerged (semi-aquatic and aquatic) WPFGs will be higher in inundation regimes with longer duration and/or frequency of inundation.*

Lower Stratum

i) All sites

As hypothesised, in the lower stratum the highest total percentage cover of most species in the amphibious and submerged WPFGs are in sites in the longest duration regime class (ARf, ATe and ATl), or moderate inundation regime class (ARp, ATw and Se), and lowest in the lowest duration regime class. This was particularly the case for lower stratum data from flood-dependent shrubland wetland, and non-woody wetland.

When the lower stratum data was pooled for analysis (i.e. not by wetland type), the percentage cover of species in the amphibious functional groups ATe, ATl and ARf, was higher in sites with the longest duration in the post-MD period. These groups were represented mostly by the genera *Cyperus*, *Eleocharis*, *Persicaria* and *Juncus* (ATe), *Limnosella* and *Triglochin* (ATl), and *Azolla* and *Lemna* (ARf). The percentage cover of ARp species was almost constant across inundation duration classes in the lower stratum. The dominant ARp species recorded were *Marselia drummondii*, *Ludwigia peploides* and *Myriophyllum papilosum*. These are species that respond quickly to changes in water depth, but can tolerate fluctuations in water availability and are tolerant of dry periods (Roberts and Marston 2000). Warick and Brock (2003) found that amphibious fluctuation responder species the most likely to grow and reproduce in all the water regime treatment tested.

The percentage cover of ATw species was almost constant in all three inundation classes in the lower stratum. These were mostly juvenile stages of woody species; *Eucalyptus camaldulensis*, *Acacia stenophylla* and *Duma florulenta,* which are only resident in the lower stratum during the establishment phase of their life cycle. The percentage cover of Se species, mostly *Bolboschoenus*, *Phragmites*, *Triglochin* and *Typha* spp. was highest in the moderate inundation duration class. Similarly all these species (except *Triglochin* spp.) are only resident in the lower stratum during the establishment phase of their life cycle.

ii) By wetland type

In the lower stratum the highest total percentage cover of most species in the amphibious and submerged WPFGs are in sites in the longest duration regime class (ARf, ATe and ATl), or moderate inundation regime class (ARp, ATw and Se), and lowest in the lowest duration regime class. This was particularly the case for lower stratum data from flood-dependent shrubland wetland, and non-woody wetland.

Middle Stratum

i) All sites

When the middle stratum data was pooled for analysis, the percentage cover of species in the Submerged group (Se) and the amphibious group ATe (rushes and sedges e.g. *Juncus* ssp, and the grass *Phragmites*), was higher in those sites with longer mean inundation duration during all time periods (Pre, during and Post MD). As Amphibious Tolerator species are not able to respond morphologically to inundation, the depth of inundation tolerated by each species is a direct function of the final height of the plants following establishment (Warwick and Brock 2003). This restricts these species to shallow water inundation.

The percentage cover of species in the ATw group, usually immature river red gum (*E. camaldulensis*) trees, or lignum (*D. florulenta*), was higher in sites that had received moderate flooding duration during the three time periods in the middle stratum. In the middle stratum the percentage cover of species in the amphibious WPFGs (ATe and, ATw), and the Terrestrial dry group (Tdr) were highest, in sites in the moderate inundation regime class with a moderate rate of change in inundation frequency, and lowest in the lowest duration regime class in the MD period. The percentage cover of Se species is highest in the longest duration inundation regime class with a low rate of change in inundation frequency.

ii) By wetland type

The middle stratum data is mostly from woody vegetation types such as flood-dependent woodlands and forests. When the middle stratum data was analysed separately for wetland type, the percentage cover of species in the Amphibious WPFGs (ATe, ATw) and Se was highest in the longer duration inundation regimes in all wetland types. In river red gum forest, woodland, and flood-dependent woodland, there was an increase in the percent cover of species in the ATw group in the middle stratum (usually lignum or eucalypt species), in sites that received the maximum inundation regime, in comparison with sites in other scenarios, indicating longer average duration inundation favours the survivorship of juvenile trees. The percentage cover of Se species (*Phragmites* and *Typha* species), was highest in sites that received the maximum inundation regime in all wetland types, but particularly in non-woody wetland, flood dependent woodland and river-red gum grassy woodland. This may be due to the inclusion of lagoon sites in the flood dependent and grassy woodland data. More of these sites are required to allow the analysis of these sites as a separate wetland type.

Tallest Stratum

In the tallest stratum there was only one (ATw) species (river red gum) modelled. The percentage cover of this species is different in the different wetland types. However, within each of the wetland types the percentage cover of the ATw species was higher in the moderate inundation regime in the river red gum woodland type, and higher in the highest inundation regime in the river red gum forest.

In the tallest stratum, river red gum forest sites received a more moderate change in inundation events in the MD period (1998-2008) than river red gum grassy woodland sites, while river red gum woodland wetland sites received a more varied range of change in inundation in the MD period. This suggests that river red gum woodland wetland occurs in more hydrologically dynamic sites in the landscape, i.e. those that dry out and re-wet quickly, than red gum forest or grassy woodland sites, and are able to respond to changes in water availability quickly by shedding or growing new foliage.

2.5.1.3 Hypothesis 3

Hypothesis 3: *The percentage cover of species in the Terrestrial dry and Terrestrial damp WPFGs, including exotic species, will be lower in inundation regimes with longer duration and/or frequency of inundation*.

Lower Stratum

i) All sites

There were thirty-two Tdr and Tda exotic species mostly in the genera *Xanthium, Heliotropium* and *Rorippa*. Greet et al. (2013) found more exotic taxa, in particular, greater numbers of short-lived exotic terrestrial taxa and fewer native woody taxa, were associated with increasing level of drying of sites due to river regulationTerrestrial damp species occur across all wetland types and inundation regime classes. The percentage over of Tda species is slightly higher in sites with the lowest duration inundation class. Most were in the genera *Brachyscome*, *Centipeda, Alternanthera* and *Rumex.*

Middle Stratum

In the middle stratum percentage cover of species in the groups Tda and Tdr were generally highest in those sites with the lowest mean inundation. These were mostly species in the genera *Sclerolaena*, *Maireana* and *Acacia* or juvenile *E. coolabah*. In the middle straum the percentage cover of species in the terrestrial group Tda, were highest in the sites with the greatest rate of change in inundation frequency in the MD period and in sites that had fewer inundation events during the pre-MD period indicating that these species like tall grasses and coolibah, prefer a drier regime

ii) By wetland type

In the lower stratum, the percentage cover of Terestrial damp (Tda) and Terrestrial dry species (Tdr) was higher in sites with the shorter mean duration of inundation during the Post-MD period. This is most evident in flood-dependent shrubland wetland, non-woody wetland, flood-dependent woodland and flood-dependent grassy woodland. Barrett et al. (2010) found that terrestrial dry species dominanted in the wetlands that had the dryest water regime when compared with wetlands with 'wetter' water regimes.

2.5.1.4 Hypothesis 4

Hypothesis 4: *Increased cover of bare ground and or litter indicates that the inland floodplain wetland plant community is receiving a sub-optimum inundation regime*.

Bare ground

The percentage cover of bare ground was higher in sites with shorter mean duration of inundation, during the post-MD study period when the data was combined. When the data were analysed seperately for wetland type this trend was most evident for all types except grassy woodland.

Litter

The percentage cover of litter was constant across inundation regime classes when the data was combined. Litter is defined as dried plant matter and coarse woody debris of a cross sectional diameter of less than 10 cm. The type of litter present is different between wetland types. In non-woody wetlands litter is usually non-woody remnants of plants that cannot be identified to genus level. In woody plant communities (flood-dependent woodlands and forests) litter is usually woody material and fallen leaf matter. Therefore, in woody plant communities increased litter may be due to leaf and branch fall which may be seasonal and/or a delayed reaction to changed water availability levels. It is considered that litter does not constitute a reliable condition variable.

2.5.2 Tree stand condition response variable trends in relation to predictor variables

In this study several underlying hypotheses regarding inland floodplain wetland tree stand condition response in response to inundation regimes were tested. These hypotheses were supported by the results of the MRF analysis. Tree numbers sampled was insufficient to allow the use of raw tree variable response data in the MRF model, so tree stand condition variable scores derived from the raw data for PAI, percentage live basal area, percentage dead canopy and percentage dead limbs, and were used as the response variables.

2.5.2.1 Hypothesis 1

Hypothesis 1. *Less of the total potential canopy will be dead (i.e. lower percentage dead canopy), in sites where most trees' water requirements are met in a five-year period*

i) All sites

When data was pooled regardless of wetland type, the score for percentage dead canopy, was very slightly higher in the site clusters with moderate duration than the highest duration during the MD period and lowest in the site clusters with the lowest mean duration in the MD period.

ii) By wetland type

In river red gum woodland the percentage dead canopy score tended to be lower (i.e. the percentage dead canopy was higher), in site clusters with lower mean duration. In sites of river red gum grassy woodland this trend was less evident, but the score for percentage dead canopy was highest in the clusters with the longest mean average inundation in the MD period.

Of the two clusters in which river red gum forest sites occurred. the two with the longest duration inundation in the MD period, the percentage dead canopy score was higher in the cluster with lower mean duration. However there were a limited number of river red gum forest sites. This is likely due to the different physiology of forest trees from grassy woodland trees. The water requirements of the forest trees are likely to be greater than grassy woodland trees and thus, they shed their canopy more readily in low water availability scenarios. More grassy woodland data is also required.

2.5.2.2 Hypotheses 2, 3 and 4

Hypothesis 2. *In sites where their water requirements are met in a five-year period, larger canopy trees and/or more trees will be supported per ha/ tree canopies will be denser (i.e. higher Plant Area index (PAI)),*

Hypothesis 3. *In sites where their water requirements are met in a five-year period, less trees will die; therefore, the stand will have a higher ratio of live trees to dead trees by total basal area (i.e. higher percentage live basal area),*

Hypothesis 4. *In sites where their water requirements are met in a five-year period, trees will retain more of their large limbs: main structural elements arising from the trunk, (i.e. lower percentage dead limbs).*

i) All sites

All hypotheses were supported by the the data when data was pooled regardless of wetland type. The scores for the tree stand condition variables Plant Area Index (PAI), percentage live basal area and percentage dead limbs were highest in the site clusters that had the longest inundation duration during the MD period and lowest in sites with the lowest duration during the MD period

ii) By wetland type

When data was analysed separately for wetland type, the scores for percentage live basal area and percentage dead limbs were higher in the site clusters that had the longer inundation duration during the MD period for river red gum woodland and grassy woodland. The trends for PAI were less clear, however it was generally lower in clusters of sites with shorter duration during the MD period for river red gum woodland and river red gum grassy woodland. In river red gum forest the results were the same as for percentage dead canopy with the slightly lower duration sites of the two clusters having the higher score for PAI.

2.5.3 Key drivers of tree stand condition and tree wetland type distribution

i) All sites

When data was pooled regardless of wetland type, the average duration of inundation in the pre-MD period and the slope of the trend of change in inundation rate for the 5-year moving average, were the most important predictor variables for the percentage cover of river red gum in the tallest stratum (analogous to PAI). Catelotti et al. (2015) identified that river red gum tree condition declined with reduced flooding, and that the probability of inundation in the previous five years had the strongest explanatory power, with strong increasing threshold responses of persistence and recovery associated with probabilities of flooding exceeding 5 years in the previous ten years. The results of this study support the findings of Catelotti et al. (2015).

When the response variables were analysed against the inundation predictor variables for pooled data, inundation duration in the MD period was the most important variable for driving the scores for percentage dead canopy and for PAI, while duration during the Post-MD period was more important for percentage dead limbs and percentage live basal area.

For combined wetland type data, the tree stand condition scores were higher in the most frequent and longest inundation duration scenario during the MD period, except percentage dead canopy (see above). This was most apparent for the PAI score. The rate of inundation change in the MD period is important to predicting PAI.

ii) By wetland type

When the data were analysed separately for wetland type, river red gum forest sites only occurred in the clusters that had the longest mean duration during the MD period and the rate of change in flooding frequency between the pre-MD and MD was less (i.e. the number of floods did not change much).

River red gum woodland sites did not occur in the two clusters that had the driest flooding environment, (i.e. those that had the shortest mean duration during the MD period and the greater rate of change in flooding frequency between the pre-MD and MD periods.

River red gum grassy woodland sites occurred in all clusters except those in the moderate range. This may be because some grassy woodland sites are located on lagoons and may have a different hydrology to floodplain sites. These sites may need to be analysed as a separate category. There were also only a limited numbers of forest and grassy woodland sites in comparison to woodland sites. More sites in forest and grassy woodland sites would assist with this analysis.

2.5.4 Effect of grazing pressure

Robinson and Rowling (2000) found no change in plant species richness, but a significant change in plant community composition, less fine woody debris and greater percentage bare ground in sites with grazing stock access, compared to un-grazed sites.

In this study, modelling of the data found that there was a decrease in percent cover of ATe and ATw species in the mid stratum of sites that received the mean (moderate) inundation regime but also had heavy grazing pressure in comparison to the same inundation regime with low grazing pressure. Conversely, percent cover of Se species was higher in the sites with high grazing pressure in all wetland types. These Se species, such as *Typha*, have rhizomes and can quickly re-sprout after grazing due to the below ground carbohydrate stores provided by the rhizomes and are generally not palatable to stock or native herbivores except when very young plants (Cunningham et al. 1992).

The percent cover of Tda and Tdr species were marginally higher in the mean inundation regimes with heavy grazing pressure, in comparison low grazing pressure sites, but still less than in the Minimum inundation regime. These were primarily species of native grass that are not removed by grazing and may even be advantaged by grazing, as they outcompete annual species (Cunningham et al. 1997; Robertson and Rowling 2000; Wilson et al. 2008; DECCW 2010c).

2.5.5 Drought management and building resilience

The results strongly suggest that delivering environmental water to sites in drought times, does influence inland floodplain wetland plant community condition.

Lower Stratum

The percent cover of amphibious and semi-aquatic wetland plant functional species was higher, and the percent cover of terrestrial species and bare ground was lower, in sites that had received even moderate numbers of inundation events in the MD period compared than those that did not. Although the duration of inundation events in the post-MD period was the key driver of change in percent cover of aquatic and semi-aquatic WPFGs, bare ground and litter for the lower stratum, the mean inundation during the MD period was the second most important predictor for all WPFGs in the lower stratum. The variable ‘years since flood’ was also generally very important for predicting percent cover in lower stratum species regardless of the inundation during the MD.

Middle stratum

The number of floods in the pre-MD period and the rate of inundation duration change in the 1992-2008 period, were the key driver of percentage cover for middle stratum species. Unlike the lower stratum species, there was very little effect of the variable ‘years since flood’. This indicates that the short-term availability of water plays less of a role in the response of species in the middle stratum than the mean value of days inundated over ten-year time scales.

Middle stratum species are often woody shrubs such as lignum or immature tree species, or persistent vegetatively regenerative species such as common reed, sedges and rushes. The percentage cover of Amphibious Tolerators-woody (ATw) species were highest in the moderate innundation regime while the percentage cover of Se species where higher in the maximum inundation regime. This suggests that semi-aquatic species in the group Se such as *Phragmites* spp. and *Typha* spp*.,* require longer average annual inundation than amphibious woody species like rver red gum. The percentage cover of species in the terrestrial group Tda, were highest in the sites with the greatest rate of change in inundation frequency in the MD period and in sites that had fewer inundation events during the pre-MD period indicating that these species like tall grasses and coolibah, prefer a drier regime.

Tree stand condition

Similarly, tree stand condition variables; PAI and percentage dead limbs, were most influenced by mean days flooded during the MD period. The rate of inundation change in the MD period (Slope 92-08) was also an important predictor variable for PAI.

Chapter 3 Defining condition classes for key inland floodplain wetland plant community types in relation to inundation regimes

3.1 Introduction

The condition of inland floodplain wetland plant communities at any point in time must be quantifiable in order to define management targets, and to quantify any change in response to management interventions. In Chapter 2, the key indicators of floristic and tree stand condition were identified and hypotheses regarding their response to inundation predictor variables were examined using Multiple Regression Forest (MRF) analysis of floristic and tree stand condition data collected in the Marshes in the Post Millennium Drought period (2008/09-2016/17).

The percentage cover of flood-dependent species in the amphibious, semi-aquatic and aquatic Water Plant Functional Groups (WPFGs), were higher in sites with inundation regimes of longer duration and/or greater frequency of inundation events, while the percentage cover of species in the terrestrial dry and terrestrial damp WPFGs (including most exotic species) were lower, and cover of bare ground was higher in sites with shorter duration and/or less frequent inundation regimes. The most important inundation predictor variables were identified and models of response of wetland types to these inundation predictors were generated.

The current chapter outlines the application of these results of the MRF analysis to develop and tree stand condition classes and floristic condition classes and scoring schemas, specific to each of eight key inland floodplain wetland NSW Plant Community Types (PCTs) in the Marshes; river red gum (*Eucalyptus camaldulensis*) forest (PCT36), woodland (PCT

36A), and grassy woodland (PCT 454), Coolibah (*Eucalyptus. coolabah*) woodland (PCT 40), lignum (*Duma florulenta*) shrubland (PCT 247), water couch (*Paspalum distichum*) marsh grassland (PCT 204), mixed marsh (*Eleocharis* spp.) sedgeland (PCT 53), and floodplain grassland (PCT 214). These schemas were then validated using data collected in the Marshes in the period 2008/09 to 2016/17

3.2 Methods

3.2.1 Quantifying benchmarks, condition classes and scoring ranges for floristic community condition

The key response variables (indicators) of floristic condition identified in Chapter 2 were; Percentage Foliage Cover (%FC) of the PCT's diagnostic indicator species, sum of %FC of species in the aquatic and amphibious WPFGs; ATe, ATw, ARf, ATl, ARp, Se, Sr and Sk, %FC of exotic species and percentage cover of bare ground. Percentage cover of litter was not included as a response variable as it did not substantially contribute to the model (see Section 2.5.1). Percentage Foliage Cover (%FC), is defined in the NSW BVC as '*the percentage of the sample site occupied by the vertical projection of foliage and branches (if woody) from Walker and Hopkins (1990)* (OEH 2018b).

The floristic community condition 'excellent' or benchmark %FC of each water-dependent indicator species for each PCT represents the characteristic range that would occur if the water requirements of each were met at the regime scale. Floristic community condition benchmarks were developed using the figures derived from the floristic composition and structure cited as diagnostic for each of the PCTs contained in the NSW BioNet Vegetation Classification (NSW BVC) (OEH 2018b; OEH 2019). These are in turn derived from the structural diagnostic for the community type (e.g. Walker and Hopkins 1990).

To track progress and/or set graduated targets (e.g. for restoration), a range of sub-optimal condition classes are required when undertaking restoration activities in addition to the benchmark state (Hobbs and Harris 2001; Seddon et al. 2011; Brudvig et al. 2014). Therefore, in addition to the excellent / benchmark, four '*sub-optimal'* condition classes were derived for each PCT; '*Good'* '*Intermediate*', '*Intermediate/Poor*' and '*Poor.* These represent other scenarios including; i) where the water requirements of the response variable indicators are being met, but less often than that required to meet the excellent benchmark (good and intermediate), ii) the water requirements of the indicator species were not often being met (Intermediate/poor) and iii) where the water-dependent species have been partly or totally replaced by terrestrial species, and the community is no longer functioning effectively as a wetland (Poor and Very Poor).

In the condition class schema for each PCT, the floristic response variables measured were given a separate range and score. The PCT indicator species were weighted more heavily than other response variables if the indicator species was expected to cover more than 50 %t of the total percentage foliage cover of a plot. The final condition score is the sum of the scores for each of the indicators. Benchmark / Excellent condition is given the highest score of 20 out of 20.

The schemas including benchmarks, condition class ranges and scoring system are presented for each of the eight key inland floodplain wetland (PCTs is presented in the following sections.

3.3.1.1 Benchmarks and condition class ranges for water couch marsh grassland, PCT 204

PCT 204; Water couch marsh grassland, has the grass *P. distichum* (water couch) as a diagnostic indicator species in a '*grassland of up to 0.5 m in height'* with a diagnostic %FC of 30 to 70 % in the lower stratum (OEH 2018b). The NSW PCT 204 benchmark for %FC of '*grasses and grass like plants'*, is 40 % FC (OEH 2018b). The community structure of PCT

204 is an almost mono-specific grassland in the Marshes (Bowen et al 2014), and the Gwydir floodplain in northern New South Wales (Bowen et al. 2015), and on coastal floodplains such as on the Clarence River (Roberts and Marston 2011).

P. distichum requires frequent inundation (estimated every 1-2 years or 85% of years) to complete its life history (Bennett and Green 1994; Wilson et al. 2009; Roberts and Marston 2011). In the Gwydir floodplain, in the absence of large-scale flooding, the grassland area shrinks, and species composition begins to switch towards more terrestrial species (Wilson et al. 2009; Bowen and Simpson 2010b).

However, the grasslands can re-establish with flooding, even after several dry years. On the Gwydir floodplain, a site that had 60 to 80 %FC in wet years, had only 20 %FC or less in a very dry phase, but recovered to 80 %FC following reflooding (Wilson et al. 2009). This trend was observed in the Marshes where 12,006 ha of water couch marsh grassland mapped in 1991 had been replaced by invasive chenopod shrubland by the end of the Millennium drought in 2008 (Bowen and Simpson 2009; Bowen and Simpson 2010a; DECCW 2010a). However, when the same areas were remapped in 2013 after 3 wet years, 4,290.5 ha of that shrubland had regenerated to water couch marsh grassland (Bowen et al. 2015).

The benchmark %FC for *P. distichum* was set at 80% in the condition class schema. The percentage cover of the PCT diagnostic indicator species is weighted more highly (8 points as opposed to 4) than the other condition indicators, as water couch is the key indicator of both the type and the structure of this community (Table 18).

Increase in bare ground can be in response to excessively wet or dry conditions in water couch marsh grasslands. Therefore, in the sub-optimal condition categories;

intermediate /poor and poor, there is an increase in the %FC of native invasive chenopod species, bare ground and exotic species with a concomitant decrease in condition score (Table 18). A visual example of the various condition classes for water couch marsh grassland is shown in Figure 30 (Images by Sharon Bowen).

Table 18 Schema of community condition response variables, ranges and scores for PCT 204 - Water couch marsh grassland

Indicator	Description	Excellent/ Benchmark [#]	% cover Intermediate	% cover Intermediate/ Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate/ Poor	Score Poor
% Indicator species	% FC of *Paspalum distichum*	≥80	<80 - 40	<40 - 10	<10	8	6	4	0
% Bare ground	% Cover Bare Ground	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Exotic species	% FC Exotic Species	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Invasive native terrestrial species	% FC native invasive chenopods	≤10	>10 - 40	>40 - 80	>80	4	3	2	0
Score						20	15	10	0

[#] All conditions must be met to achieve Excellent/benchmark condition (i.e.; score = 20)

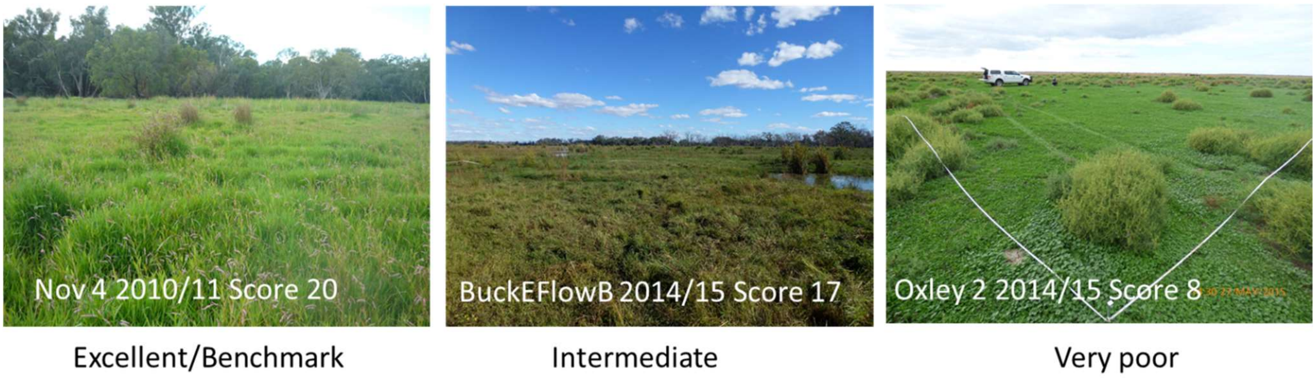


Figure 30 Floristic community condition classes - water couch marsh grassland

3.3.1.2 Benchmarks and condition class ranges for mixed marsh sedgeland, PCT 53

Mixed marsh sedgeland was first mapped in the Marshes by Paijmans (1981), who described it as '*an intricate mixture of herbaceous communities'* in which the sedge

Eleocharis plana and the rush *Juncus aridicola* were '*among the most prominent amphibious plants*.' It is analogous to PCT 53; Shallow freshwater wetland sedgeland in depressions on inland alluvial plains and floodplains. In the NSW BVC, PCT 53 is described as low to mid-high sedgeland/grassland dominated by '*spike rushes*' (i.e. sedges in the family Cyperaceae) including *Eleocharis pallens*, *Eleocharis acuta*, *Eleocharis plana* and *Cyperus* spp. It is a sedgeland/grassland of up to 0.5 m and has a diagnostic % FC of 30 to 70% (OEH 2018b).

Vegetation types dominated by species in the family Cyperaceae are rhizotomous and can form dense, stable, mono-specific or almost mono-specific stands (Roberts and Marsden 2011; Reid and Quinn 2004). In PCT 53, several species can fulfil the function of the diagnostic PCT indicator species thus, the indicator 'species' for PCT 53 is the sum of the %FC of all native species in the amphibious, semi-aquatic and aquatic WPFGs. This was set at 80% as the benchmark. The PCT diagnostic indicator; '% FC native wetland functional group species', are weighted more highly than the other condition indicators (8 points as opposed to 4), as these species are the key indicator of both the type and the structure of this PCT.

As in PCT 204, the sub-optimal condition categories intermediate/poor and poor, an increase in the %FC of native invasive chenopod species, bare ground and exotic species means a decrease in condition score (Table 19). A visual example of condition classes is shown in Figure 31 (Images by Sharon Bowen).

Table 19 Schema of community condition response variables, ranges and scores for PCT 53 – Mixed marsh sedgeland

Indicator	Description	Excellent/ Benchmark[#]	% cover Intermediate	% cover Intermediate/ Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate/ Poor	Score Poor
% Indicator species	% FC Native *WPF species*	≥80	<80 - 40	<40 - 10	<10	8	6	4	0
% Bare ground	% cover Bare Ground	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Exotic species	% FC exotic Species	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Invasive native terrestrial species	% FC native invasive chenopods	≤10	>10 - 50	>50 - 80	>80	4	3	2	0
Score						20	15	10	0

[#] All conditions must be met to achieve Excellent/benchmark condition (i.e.; score = 20)

Figure 31 Floristic community condition classes – mixed marsh sedgeland

3.3.1.3 Benchmarks and condition class ranges for floodplain grassland, PCT 214

Floodplain grassland communities sampled in the Marshes are identified as; PCT 214 '*Native Millet - Cup Grass grassland of the Darling Riverine Plains Bioregion'* and is described as; '*mid-high or tall grassland dominated by native millet* (Panicum decompositum) *and cup grass* (Eriochloa crebra*).* Diagnostic %FC is 30-70% (OEH 2018b). In the schema for the condition classes, ranges and scores I have set the excellent/Benchmark %FC≥ 40% (Table 20).

Table 20 Schema of community condition response variables, ranges and scores for PCT 214 – floodplain grassland

Indicator	Description	Excellent/ Benchmark#	% cover Intermediate	% cover Intermediate / Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate / Poor	Score Poor
Indicator species	% FC of *Native grasses*	≥40	<40 - 20	<20 - 10	<10	4	3	2	0
% Indicator species	% FC of *Wetland functional species*	≥30	<30 - 20	<20 - 10	<10	4	3	2	0
% Bare ground	% Cover Bare Ground	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Exotic species	% FC Exotic Species	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Invasive native terrestrial species	% FC native invasive chenopods	≤10	>10 - 50	>50 - 80	>80	4	3	2	0
Score						20	15	10	0

All conditions must be met to achieve Excellent/benchmark condition (i.e.; score = 20)

Figure 32 Floristic community condition classes – floodplain grassland

The NSW OEH benchmark is 27 %FC, so the range for intermediate to benchmark is 20 to 40 %FC. Floodplain grassland is intermittently flooded and supports wetland functional species in the wet phase, so %FC of wetland plant functional species (WPFGs) is set at 30 for the Excellent/Benchmark. In the sub-optimal condition categories; intermediate/poor and poor, there is an increase in the %FC of native invasive chenopod species, bare ground and exotic species with a decrease in condition score (Table 20). A visual example of condition classes is shown in Figure 32 (Images by Sharon Bowen).

3.3.1.4 Benchmarks and condition class ranges for lignum shrubland, PCT 247

Lignum (*D. florulenta)* is the key diagnostic dominant species of PCT 247 - *Lignum shrubland wetland* in the NSW BVC (OEH 2018b). PCT 247 is described as; 't*all shrubland or open shrubland to 2 m high dominated by Lignum. The ground cover may be dense after rains or inundation but very sparse during drought'* (OEH 2018b). Diagnostic %FC range is 10 to 70% (OEH 2018b).

The key PCT diagnostic indicator species %FC for lignum was set at 40% as the benchmark. The secondary diagnostic indicator; %FC native wetland functional group species, was set also set at 40%. As lignum shrubland communities contain many other amphibious, semi aquatic and aquatic wetland species, and the structure of lignum can vary from 10 to 70 %FC, the weighting of scores was set at the same level for the key and secondary indicator species (Table 21).

In the sub-optimal condition categories; intermediate/poor and poor, there is an increase in the %FC of native invasive chenopod species, bare ground and exotic species with a decrease in condition score. A visual example of condition classes is at Figure 33 (Images by Sharon Bowen).

Lignum plant size is equivalent to net growth and is a direct consequence of flooding history (Craig et al. 1991; Thoms 2007). However, lignum shrubs can remain in a dormant state for an extended period as the rootstock is at least 2 to 3 m deep, allowing the plant to survive prolonged dry periods (Craig et al. 1991; Roberts and Marsden 2011). Leaves are shed in response to drying (Capon et al. 2009).

Table 21 Schema of community condition response variables, ranges and scores for PCT 247 - lignum shrubland wetland

Indicator	Description	Excellent/ Benchmark#	% cover Intermediate	% cover Intermediate/ Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate/ Poor	Score Poor
% Indicator species	%FC *Lignum*	≥40	<40 - 20	<20 - 10	<10	4	3	2	0
% Indicator species	%FC Native *WFP species*	≥40	<40 - 15	<15 - 10	<10	4	3	2	0
% Bare ground	% cover Bare Ground	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Exotic species	%FC Exotic Species	≤10	>10 - <50	50 - 80	>80	4	3	2	0
% Invasive native terrestrial species	%FC native invasive chenopods	≤10	>10 - 50	>50 - 80	>80	4	3	2	0
Score						20	15	10	0

All conditions must be met to achieve Excellent/benchmark condition (i.e.; score = 20)

Thus, the % FC of the shrubs themselves is not a complete indicator of site condition.

Excellent/Benchmark　　Intermediate　　Intermediate

Figure 33 Floristic community condition classes – lignum shrubland

Other condition assessment methods for lignum include ‘*physiological*’ (vegetative) and ‘*phenological*’ (reproductive) characteristics (e.g. Henderson et al. 2011). Therefore, the following additional condition response indicators were included in the condition schema:

- Percentage of points sampled with live foliage > 80% = +1point
- Percentage of points sampled with live foliage < 50% = -1point
- Percentage of points sampled > 1 m in height >50% = +0.5 point
- Percentage of points sampled where plants are flowering - < 50% plants in an active reproductive state (flowers (recording if male or female), buds or fruit) = -0.5 point

- Percentage points sampled where plants flowering > 50% plants in an active reproductive state (had flowers, buds or fruit) = +0.5 point

Thus, a site can theoretically score more than 20 however a score of 20 is recorded.

3.3.1.5 Benchmarks and condition class ranges for river red gum forest and woodland, PCT 36 and PCT 36A

The NSW BVC describes PCT 36 as; '*very tall or tall open forest or woodland up to 30 m high lining major watercourses dominated by river red gum* (Eucalyptus camaldulensis subsp. camaldulensis)*….The ground cover may be dense after rain or flooding* (OEH 2018b). The diagnostic % FC for the tree canopy in forest communities is 30 to 70% and in woodland communities is 10 to 30% (OEH 2018b). The benchmark for trees is 38 %FC, however it is unclear whether this benchmark is applicable to woodland communities (OEH 2018b).

Table 22 Schema of community condition response variables, ranges and scores for PCT 36/36A – river red gum forest/river red gum woodland

Indicator	Description	Excellent/ Benchmark[#]	% cover Intermediate	% cover Intermediate / Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate / Poor	Score Poor
% Indicator Species (Forest)	%FC River red gum - tallest stratum	≥30[*]	<30 - 10	<10 - 1	<1	3	2.5	1.5	0
% Indicator Species (woodland)	%FC River red gum - tallest stratum	≥10[**]	3	1	0	3	2.5	1.5	0
% Indicator Species	%FC River red gum - middle	≥5	<5 - 0.5	<0.5 - >0	0	1.5	1	0.5	0
% Indicator Species	%FC River red gum - lower stratum	≥1	>1- 0.5	<0.5 - >0	0	1.5	1	0.5	0
% Indicator species	% FC native WFG species	≥40	<40 - 15	<15 - 10	<10	4	3	2.5	0
% Bare ground	% cover Bare Ground	≤30	<30 - 50	50 - 80	>80	2	1.5	1	0
% Exotic species	%FC Exotic Species	≤10	>10 - 50	>50 - 80	>80	4	3	2	0
% Invasive native terrestrial species	%FC native invasive chenopods	≤10	>10 - 40	>40 - 80	>80	4	3	2	0
Score						20	15	10	0

[#] All conditions must be met to achieve Excellent/benchmark condition (i.e. score = 20), [*]Forest sites only. [**]Woodland sites only

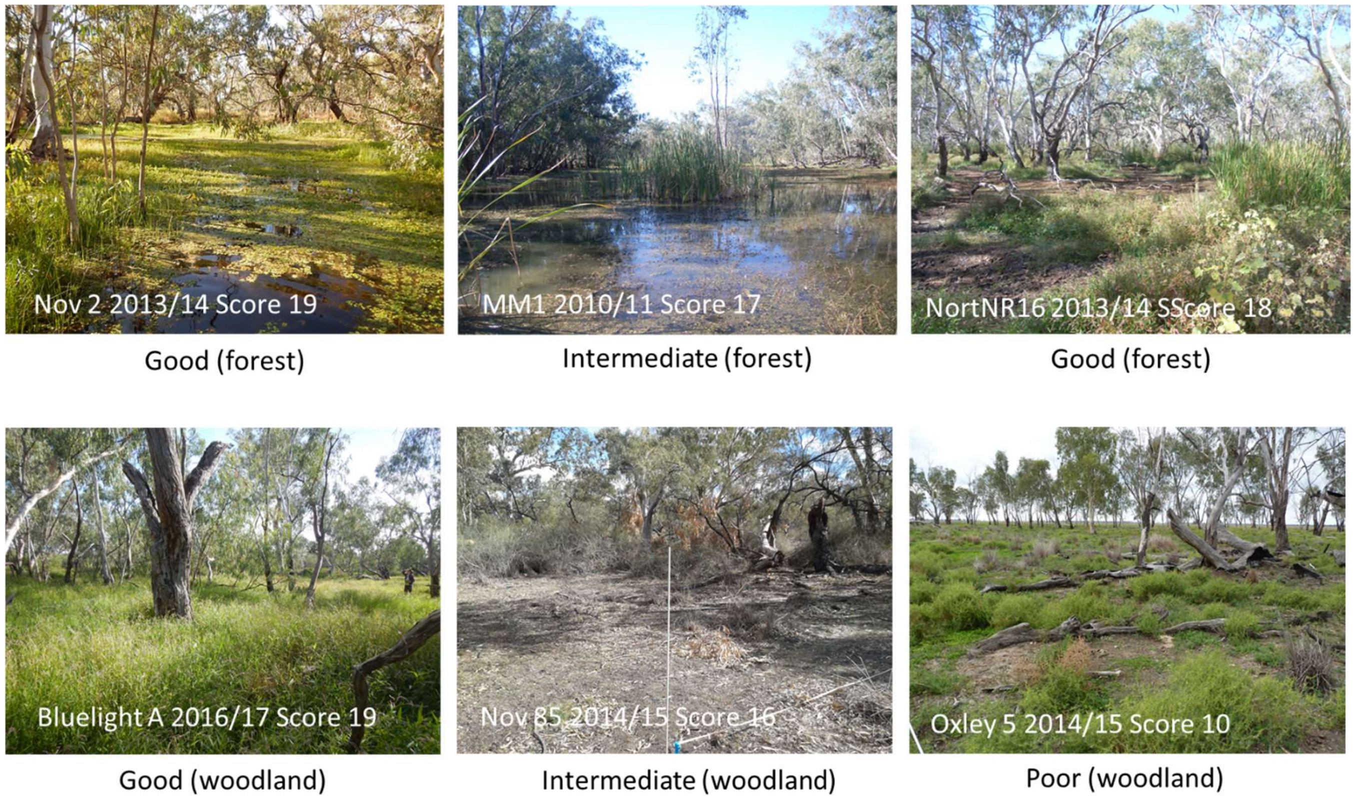


Figure 34 Floristic community condition classes – river red gum forest and woodland

In the schema for PCT 36/36A the range for excellent/benchmark is ≥30 % FC for forest and ≥10 % FC for woodland communities (Table 22). This follows the structural classification of Australian vegetation that defines structural forms of vegetation in terms of the dominant plant form and the percentage of foliage cover of the tallest plant layer, in which woodland has a %FC of 10-30 % and forest has a 5FC of >30 % (Specht 1970; Australian Government 2003; ANBG 2012).

The use of foliage cover rather than canopy cover takes special account of the open nature of eucalypt crowns. In sub-optimal condition categories; intermediate/poor and poor, there is an increase in the % FC of native invasive chenopod species, bare ground and exotic species with a decrease in condition score (Table 22). A visual example of condition classes is shown in Figure 34 (Images by Sharon Bowen).

3.3.1.6 Benchmarks and condition class ranges for river red gum grassy woodland, PCT 454

The NSW BVC describes PCT 454 '*River red gum grassy woodland*' as; '*tall to mid-high (3-10 m tall), open woodland or woodland dominated by river red gum* (Eucalyptus camaldulensis subsp. camaldulensis), *sometimes with Eucalyptus coolabah subsp. coolabah. Shrubs are absent or very sparse and include short chenopods….the ground cover varies from dense after rain or inundation to very sparse during drought'* (OEH 2018b). The diagnostic %FC is 10–30% and the NSW OEH benchmark for the tallest stratum is 35 %FC (OEH 2018b).

In the schema for PCT 454 the range for excellent/benchmark is ≥10 %FC. PCT 454 has non-flood-dependent native grass species as a component of their diagnostic community composition therefore, there is '*%FC of native grass species'* as a condition scoring response variable. In sub-optimal condition categories; intermediate/poor and poor, there is an increase in the %FC of native invasive chenopod species, bare ground and exotic species with a decrease in condition score (Table 23).

A visual example of condition classes is shown in Figure 35 (Images by Sharon Bowen).

Table 23 Schema of community condition response variables, ranges and scores for PCT 454 – river red gum grassy woodland

Indicator	Description	Excellent/ Benchmark[#]	% cover Intermediate	% cover Intermediate / Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate / Poor	Score Poor
% Indicator Species	%FC River red gum – tallest stratum	≥10	<10 - 3	<3 - 1	<1	3	2.5	2	0
% Indicator Species	%FC River red gum – middle stratum	≥5	<5 - 0.5	<0.5 - >0	0	1.5	1	0.5	0
% Indicator Species	%FC River red gum – lower stratum	≥1	0.5	<0.5 - >0	0	1.5	1	0.5	0
% Indicator species	%FC Native grasses	≥40	<40 - 10	<10 - 5	<5	3	2.5	2	0
% Indicator species	%FC native WPF species	≥30	<30 - 10	<10 - 5	<5	3	2	1	0
% Bare ground	% cover Bare Ground	≤40	<40 - 60	60 - 80	>80	2	1	0.5	0
% Exotic species	%FC Exotic Species	≤10	>10 - 40	>40 - 80	>80	3	2.5	1.75	0
% Invasive native terrestrial species	%FC native invasive chenopods	≤10	>10 - 40	>40 - 80	>80	3	2.5	1.75	0
Score						20	15	10	0

[#] All conditions must be met to achieve Excellent/benchmark condition (i.e.; score = 20)

Figure 35 Floristic community condition classes – river red gum grassy woodland

3.3.1.7 Benchmarks and condition class ranges for coolibah grassy woodland (PCT 40)

In the NSW BVC, PCT 40, 'Coolabah *open woodland wetland with chenopod/grassy ground cover on grey and brown clay floodplains'* is described as; '*mid-high'* (6 to 10 m tall) *'open woodland dominated by* Coolabah (Eucalyptus coolabah subsp. coolabah or subsp. excerata) *often with* Black Box (E. largiflorens) *or* Poplar Box (E. populnea subsp. bimbil). *The ground cover is dominated by chenopods and grasses…..* Lignum (Duma florulenta), *sedges including* Eleocharis *and* Carex spp*. and the fern* Nardoo (Marsilea spp.) *occur in low lying areas'* (OEH 2018b). Diagnostic %FC for PCT 40 is <10%) (OEH 2018b).

Coolibah requires intermittent flooding to regenerate (Roberts 1993), and for ephemeral ground species to complete their lifecycle although soils retain moisture for long periods (OEH 2018b; Maher 1995).

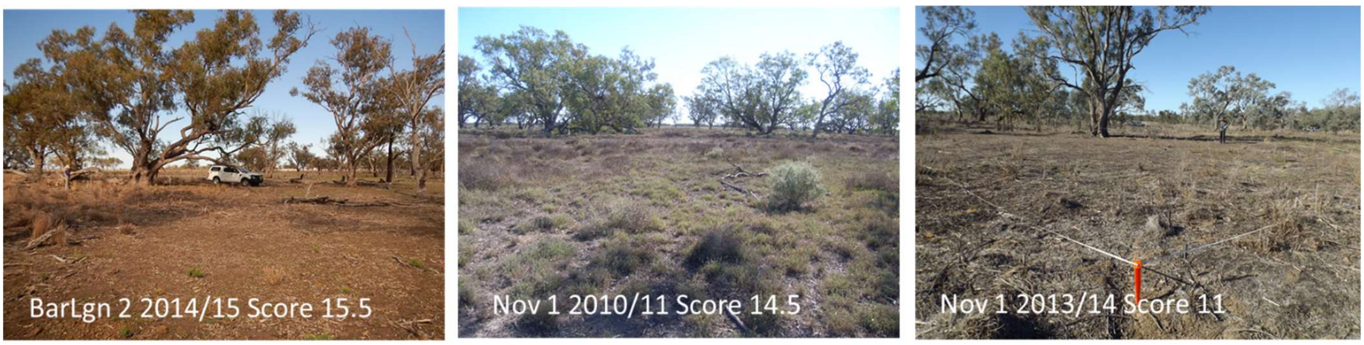
The condition class schema for PCT 40 the benchmark for Coolibah in the tallest stratum is set at ≥ 10 %FC, PCT 40 has non-flood-dependent native grass species as a component of their diagnostic community composition therefore, there is '*%FC of native grass species'* as a condition scoring response variable.

In sub-optimal condition categories; intermediate/poor and poor, there is an increase in the %FC of native invasive chenopod species, bare ground and exotic species with a decrease in condition score (Table 24). A visual example of condition classes is shown in (Figure 36) (Images by Sharon Bowen).

Table 24 Schema of community condition response variables, ranges and scores for PCT 40 coolibah woodland

Indicator	Description	Excellent/ Benchmark [#]	% cover Intermediate	% cover Intermediate / Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate / Poor	Score Poor
% Indicator Species	%FC Coolibah - tallest stratum	≥10	<10 - 3	<3 - 1	<1	3	2.5	2	0
% Indicator Species	%FC Coolibah - middle stratum	≥5	<5 - 0.5	<0.5 - >0	0	1.5	1	0.5	0
% Indicator Species	%FC Coolibah - lower stratum	≥1	0.5	<0.5 - >0	0	1.5	1	0.5	0
% Indicator species	%FC Native grasses	≥40	<40 - 10	<10 - 5	<5	3	2.5	2	0
% Indicator species	%FC Native WPF species	≥30	<30 - 10	<10 - 5	<5	3	2	1	0
% Bare ground	% cover Bare Ground	≤50	<50 - 60	60 - 80	>80	2	1	0.5	0
% Exotic species	%FC Exotic Species	≤10	>10 - 50	>50 - 80	>80	3	2.5	1.75	0
% Invasive native terrestrial species	%FC native invasive chenopods	≤10	>10 - 50	>50 - 80	>80	3	2.5	1.75	0
Score						20	15	10	0

[#] All conditions must be met to achieve Excellent/benchmark condition (i.e.; score = 20)



Intermediate | Intermediate | Intermediate/poor

Figure 36 Floristic community condition classes – coolibah grassy woodland

3.2.2 Quantifying benchmarks, condition classes and scoring ranges for tree stand condition

The key tree stand condition response variables were derived from the work of Cunningham et al. (2007). They are; PAI / Percentage Foliage Cover (%FC), percentage dead canopy, percentage live basal area and percentage dead limbs (see Section 2.2.3).

A condition class schema, including benchmark and tree stand condition class cover ranges and scores, was developed for all tree dominated wetland types/PCTs sampled in the Marshes; river red gum forest (PCT 36), river red gum woodland (PCT 36A), river red gum forest grassy woodland (PCT 454) and coolibah woodland (PCT 40). Unlike the floristic community condition, tree stand condition response variables are the same regardless of PCTs in this study. For the variable PAI / %FC there were separate benchmarks and scoring ranges for forest and woodland.

A tree dominated community is defined structurally as woodland or a forest by structure and percentage foliage cover of the tallest stratum (Specht 1970; Australian Government 2003; ANBG 2012). The PAI /%FC scores were derived from the diagnostic %FC ranges that define the community as a forest and woodland (Specht 1970; Walker and Hopkins 1990; Australian Government 2003; Hnatiuk et al. 2009; Sivertsen 2009; ANBG 2012). In a 0.1 ha plot PAI is analogous to %FC (PAI =% FC /100), (see Appendix 3). Having separate scoring ranges for PAI/%FC for reflects the difference between woodland and forest %FC/PAI ranges. This allows the same overall condition classes to be compared across both woodland and forest PCTs without artificially low scores being assigned to woodland sites due to naturally occurring low %FC/PAI.

The 'Excellent/benchmark' for each of the condition metrics represents the values typical of a stand of trees (forest or woodland) that has had its water requirements met in the last 5 years (Table 25). This benchmark condition was given the highest possible score of 20 out of 20.

In addition to the benchmark, three 'sub-optimal' condition classes and scoring ranges were also derived for a stand: '*Intermediate*', '*Intermediate/Poor*' and '*Poor* '. These represent the change in range of the condition indicators in situations where the water requirements of the trees are not being met to achieve the benchmark condition, and range through to situations where the trees are showing signs of severe water stress (high percentage of dead canopy and dead limbs or even tree death), and considered to be in '*Poor*' condition.

3.2.2.1 Tree stand condition classes, benchmarks and scoring system

In the schema for tree stand condition classes, ranges and scores, the variable 'percentage dead canopy' was weighted higher than the other condition variables (8 points as opposed to 4) (Table 25). This was because percentage dead canopy is the indicator that shows the most immediate response to water stress in most tree species (Cunningham et al. 2007), whereas the other three indicators are more indicative of longer term water stress. Interestingly variable importance analysis in MRF found that the mean number of days of inundation during the post-MD period 2008/09 – 2016/17, was the most important variable for percentage dead limbs and LBA, and the inundation duration in the MD period (1998/99-2007/08), was the most important predictor for percentage dead canopy and PAI. The rate of inundation change in the MD period (Slope 92-08) was also an important predictor variable for PAI (Chapter 2, Section 2.4.5).

All tree stand condition response variables are usually correlated, (i.e. an increase in percentage dead limbs can be correlated with an increase in percentage dead canopy, and a decrease in percentage live basal area in the 0.1 ha plot. However, this is not always the case and is dependent on the recovery or decline phase that a specific stand is in (Roberts et al. 2017b; Overton et al. 2014). A visual example of condition classes is shown in Figure 37 (Images by Sharon Bowen).

Table 25 Schema of tree stand condition response variables, ranges and scores for tree dominated PCTs

Indicator	Description	Excellent / benchmark#	% cover Intermediate	% cover Intermediate / Poor	% cover Poor	Score Good	Score Intermediate	Score Intermediate / Poor	Score Poor
% Dead canopy	Percent of total canopy that is dead	≤10	>10 - 40	>40 - 80	>80	8	6	4	0
% Live Basal Area	Percent of live trees	≥80	<80 - 60	<60 - 40	<40	4	3	2	0
% Dead Limbs	Percent of total limbs alive	≤10	>10 - 40	>40 - 80	>80	4	3	2	0
PAI## / (%FC) Forest	Plant Area Index/ %FC Forest/	≥0.7 (70)	<0.7 - 0.5	<0.5 - 0.3	<0.3	4	3	2	0
PAI/(%FC) Woodland	Plant Area Index/ %FC Woodland	≥0.3 (30)	<0.3 - 0.1	<0.1 - 0.05	<0.05	4	3	2	0
Score						20	15	10	0

All conditions must be met to achieve Excellent/benchmark condition (score of 20), ## Index not % cover

Good Intermediate Poor

Figure 37 Tree stand condition - river red gum

3.2.3.1 Floristic condition data collection

Site selection and survey methods for community condition and tree stand condition were described in Sections 2.2.6. Full data collection methods for both community condition and tree stand condition are outlined in Appendix 3.

Floristic condition variable data were collected from 74 plots in the Marshes from 2007/07 to 2016/17 (see Section 2.2.6). Tree stand condition data was collected from 40 of those sites from 2010/11 to 2016/17 (see Section 2.2.6). Survey sites were stratified on: i) historic PCT and ii) end of Millennium Drought condition as mapped in 2008 (Bowen and Simpson 2009) (see Section 2.2.6).

For each PCT, the community condition response variable data; %FC of the key diagnostic indicator species, %FC species summed by Water Plant Functional Groups (WPFG), %FC of exotic species for each stratum, and %cover of bare ground, were collated for each year sampled in the post-MD period; 2008/09 to 2016/17.

3.2.3 Testing condition class schemas –trends in the condition response variables of PCTs in response to inundation regimes

For each PCT, pre-classified site clusters and inundation duration classes generated by the MRF analysis of the site data (see Chapter 2), were interrogated for trends in their response variable data in relation to the most important predictor variables contained within their 'flooding environment' i.e.; the suite of average inundation frequencies and inundation duration metrics of each cluster identified in the MRF analysis. The relative distributions of these response variables and condition scores within the predictor variable classes were then examined for each inundation regime. To test the hypotheses underpinning the condition classes and scoring range schemas developed for each PCT, data pre-clustered floristic and tree stand condition variable data generated by the MRF analysis of the site data (see Chapter 2, Section 2.3.5), were interrogated for trends in response to the identified important predictor variables.

3.2.3.2 Tree stand condition data collection

For each tree dominated PCT (36, 36A, 454 and 40), the stand condition response variable data; Plant Area Index (PAI), (derived from percentage foliage cover (%FC)), percentage dead canopy, percentage live basal area and percentage dead limbs were collated from each site sampled in the years 2011/12 to 2016/17.

3.2.3.3 Assigning floristic community condition scores to sites

To generate floristic community condition scores for each site for each sampling year, a set of functions were written into a *Microsoft Excel* macro-enabled workbook to automate the calculation of floristic community condition scores using the condition class rules.

The program collated the percentages of the condition response variables %FC of indicator species, WPFGs and exotic species by stratum, percent bare ground. for each site and then assigned the final condition score for each variable for each site by PCT depending on which scoring range they fell within. Condition class ranges and scores are presented in Appendix 6.

3.2.3.4 Assigning tree stand condition scores to sites

Similarly, to generate condition scores for each site for each sampling year, a set of functions were written into a *Microsoft Excel* macro-enabled workbook to automate the calculation of tree stand condition scores using the condition class rules.

The raw data from each survey site for each year was transformed into tree stand condition indicator data; PAI, percentage dead canopy, percentage live basal area and percentage dead limbs. The program then collated the percentages of the condition response variables for each site and then assigned the final condition score for each variable for each site by PCT depending on which scoring range they fell within.

3.2.3.5 Assigning final condition scores to sites

For reporting purposes, the final floristic and tree stand condition scores for each site was assigned into a condition class that was independent of PCT or tree community structure, to allow comparison across all PCTs (Table 26).

Table 26 Final condition classes and score ranges

Score range	Condition Class
0 - 8.9	Very Poor
9 - 11.9	Poor
12 - 14.9	Intermediate/poor
15 - 17.9	Intermediate
18 - 19.9	Good
20	Excellent/benchmark

In a system that is strongly influenced by human induced factors, scores of 20 are rare. However, it is very important to define what those benchmark metrics are to set sub-optimum classes to track progress and to set targets for restoration (Brudvig et al. 2014). In flood-dependent vegetation communities the attaining of intermediate and good condition is a worthwhile management target as they are states in which community resilience likely to be maintained.

3.2.3.6 Annual inundation data, inundation predictor variables and inundation predictor variable importance

As outlined in Section 2.3.1.1, to derive annual duration (i.e. days flooded per year), for each site for the years 2008/09 to 2016/17, point data of location of survey sites (AMG grid co-ordinates) were overlain using a GIS package (ArcGIS 10.3) on event inundation duration mapping (Thomas and Heath 2017; Thomas et al. in prep). Average annual inundation for the three hydrologic time periods between 1988/89 and 2016/17; the Pre-Millennium Drought (Pre-MD) (1988/89 to 19997/98), Millennium Drought (MD) (1998/99 to 2007/08) and Post-Millennium Drought (Post-MD) (2008/09 to 2016/17) periods were derived for each site (see 2.3.1.1).

3.2.3.7 Deriving inundation duration regime classes for floristic condition data

All sites in all PCTs were classified into clusters based on their floristic condition response variable similarity using a proximity matrix and clustering analysis in the MRF analysis (see Section 2.4.3). For each PCT, clusters were then ordered according to the inundation variables that were the most important drivers of floristic community condition response variables in the MRF analysis; the mean number of days of inundation during the Post-MD period, and the years since last flood (see Section 2.4.2).

To derive the inundation duration regimes for for floristic condition in each PCT, the inundation data from each site was aggregated into three regime classes: *Class 1* is data from the clusters1 to 3, that represent those sites where average annual duration in the Post-MD period was longest; *Class 2* is data from the sites from the 4th to 6th clusters, that represent the moderate average annual duration in the Post-MD period and *Class 3* is data from sites in the 7th to 9th clusters, that represent those sites with the lowest average annual duration in the Post-MD period (See Section 2.4.3).

A summary of the inundation response variable data for each inundation duration class in each time period are presented. The summary is a useful measure of data spread. A corresponding box-and-whisker plot was constructed for the inundation regime variables in each inundation class present in the PCT to visually present the data from the three time periods.

3.2.3.8 Deriving inundation duration regime classes for tree stand condition data

All sites in tree dominated PCTs (36, 36A, 454 and 40), were classified into clusters based on their tree stand condition variable similarity using a proximity matrix and clustering analysis in the MRF analysis (see Section 2.4.6). For each PCT, clusters had been ordered according to the inundation variables that were the most important drivers of tree stand condition response variables in the MRF analysis; the mean number of days of inundation during the MD period, and the rate of change in inundation frequency in the MD period (Slope 92-08) (see Section 2.4.5).

To derive the inundation duration regimes for for tree stand condition condition in each tree dominated PCT, the inundation data from each of the pre-ordered site clusters were aggregated into three inundation regime classes: *Class 1* is data from the three site clusters where average annual duration was longest in the MD-period; *Class 2* is data from the three site clusters with moderate average annual duration in the MD-period and *Class 3* is data from the three site clusters with lowest average annual duration in the MD period.

A five-number summary of the inundation response variable data was performed for each inundation duration class for each time period. A corresponding box-and-whisker was constructed for each inundation regime class for each tree dominated PCT.

3.2.3.9 Assigning long-term inundation regime classes to PCTs

For the data in each inundation regime class, long-term regimes are defined by the average annual duration in the three-time periods using the mean, into a number of regime categories to enable direct comparison Table 27.

Table 27 Inundation regime categories

Average annual inundation duration (days)	Regime category
0 –10	Very Dry
>10–30	Dry
>30–60	Moderate
>60–90	Moderate/wet
>90–120	Wet
>120	Very Wet

3.2.4 Data analysis

To derive the data ranges for floristic community condition response variables and floristic community condition scores for sites in each PCT, the floristic condition response data and the condition scores from the three inundation regime classes were summarised . A corresponding box-and-whisker plot was constructed for the community condition response variables and condition scores. Similarly, to derive the ranges for tree stand condition response variables and condition scores for sites in each tree dominated PCT, the tree stand condition response data and the condition scores from the three inundation regime classes were summarised . A corresponding box and whisker plot was constructed for each inundation class for each PCT.

For each of the PCTs as appropriate, inundation duration, floristic condtition and tree stand condition variable and score data from each inundation class was transformed for normality if required and tested for homoscedasticity (equality of variance) using Levenes test. If the data was homoscedastic, differences between the means of the data from each inundation classes was tested using a one-way ANOVA. If there were more than two inundation classes the differences between groups were determined by post-hoc testing using Tukeys pairwise comparisons test.

If the data was heteroscedastic, even after transformation for normality , the differences between class medians were examined for significance using a Kruskal-Wallis test on the untransformed data. The Kruskal-Wallis test is a nonparametric test that compares the medians of populations and can be used when the values are scores (Townsend 2003). If the test was significant and there were more than two inundation classes, the test was re-run on the data in a pairwise fashion by inundation class to find which class medians were significantly different. Annual inundation duration data was also compared between the three time periods (Pre-MD, MD and Post-MD) for each inundation classes for each PCT. Tests were carried out in Minitab 18.1.

3.3 Results

3.3.1 Testing of floristic community condition schemas

Full results of statistical analyses are contained in Appendices 7 to 17.

3.3.1.1 Water couch marsh grassland, PCT 204

Sites of water couch marsh grassland were sampled in two starting inundation regimes, and three MRF classes: Class 1; Moderate – Moderate (mapped as Intermediate in 2008), Class 2; Moderate/Wet – Moderate (mapped as Intermediate/poor in 2008) and Class 3; Dry –Very Dry (mapped as Very Poor in 2008) (see Table 27). There was no significant difference between the mean average inundation duration of the classes in the Pre-MD period. During the MD period there was a significant difference between the sites in Class 3 and sites in Classes 1 and 2 (*P <0.05, F=8.2, DF=2*). Sites in Class 3 were much drier than sites in the other classes in the MD period, but there was no difference between sites in Class 1 and 2 (Table 28, Figure 38a, Appendix 7a).

Table 28 Summary of average annual inundation duration (days), PCT 204, Pre-MD, MD and Post-MD periods

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought (days)	Class 1	5	56.6	10.6	23.6	33.2	35.5	57.9	77	92.8
	Class 2	4	71	18.6	37.3	37.1	42.5	61.4	109.1	124.1
	Class 3	3	27.23	4.17	7.21	20.3	20.3	26.7	34.7	34.7
Millennium Drought (days)	Class 1	5	51.1	9.21	20.6	33.8	34.65	41.7	72.25	81.5
	Class 2	4	39.42	8.2	16.41	19.6	23.6	39.55	55.13	59
	Class 3	3	$2.13^{\#}$	2.13	3.7	0	0	0	6.4	6.4
Post-Millennium Drought (days)	Class 1	5	$113.2^{\#\#}$	10.6	23.8	75.8	90.1	123.3	131.2	135
	Class 2	4	$63.83^{\#}$	5.78	11.56	49.78	52.97	63.78	74.75	78
	Class 3	3	$9.04^{\#}$	6.89	11.93	0	0	4.56	22.56	22.56
Years since last flood Post-MD (years)	Class 1	37	0.12	0.09	0.557	0	0	$0^{\#\#}$	0	3
	Class 2	28	0.68	0.19	0.98	0	0	$0^{\#\#}$	1	3
	Class 3	15	9.33	2.45	9.49	0	1	$4^{\#\#}$	20	23

$^{\#}$ P<0.05, $^{\#\#}$ P<0.001

In the Post-MD period there was a significant difference in the mean average annual inundation duration between all Classes (*P<0.001, F=31.51, DF=2*). Average mean inundation of sites in Class 1 had doubled from the Pre-MD period. Sites in Class 2 had almost returned to Pre-MD duration in the Post-MD period whereas sites in Class 3 had very short average annual inundation during the Post-MD period. The median years since flood were significantly different between sites in all three classes (P<0.001, H=22.85), (with sites in Class three having the longest median years since flood (Table 29, Figure 38a and Appendix 7a).

Table 29 Summary of response variables and floristic condition scores for Water couch marsh grassland - PCT 204, 2008/09 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
% FC Water couch	Class 1	37	52.54	4.97	30.2	0.1	31.05	58	78.25	96
	Class 2	28	53.31	6.52	34.49	0.00	25.00	52.50	88.75	99
	Class 3	15	0.00	0.00	0.00	0.00	0.00	0.00##	0.00	0
% cover Bare ground	Class 1	37	8.12	3.18	19.33	0.00	0.10	0.60	2.70	84
	Class 2	28	13.97	4.37	23.14	0.00	0.10	4.40	16.35	82.7
	Class 3	15	20.49	7.26	28.11	0.10	1.00	8.00#	41.00	83
% FC Exotic species	Class 1	37	8.24	2.16	13.13	0.00	0.05	1.00	14.00	43
	Class 2	28	8.46	3.45	18.24	0.00	0.23	1.45	4.49	82.4
	Class 3	15	18.37	5.81	22.48	0.10	0.80	8.10	28.00	69.2
% FC Invasive native chenopods	Class 1	37	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.1
	Class 2	28	6.28	2.62	13.84	0.00	0.00	0.20	4.97	60.6
	Class 3	15	15.14	5.49	21.25	0.00	0.90	4.10##	25.10	61
Floristic condition score	Class 1	37	16.78	0.49	2.98	8.00	15.00	17.00	18.50	20
	Class 2	28	16.25	0.74	3.91	8.00	14.25	17.50	20.00	20
	Class 3	15	10.20	0.30	1.15	7.00	10.00	10.00##	11.00	12

# P<0.05, ## P<0.001

The median %FC of *P. distichum,* (water couch) was in the PCT diagnostic range of 30 to 70 %FC in sites in Classes 1 and 2 (medians 58% and 52.5%). There was no significant difference between sites in Classes 1 and 2 but there was a significant difference between those sites and sites in Class 3 (*P <0.001, H=33.92*).

The median % cover of bare ground was significantly higher ($P < 0.05$, $H=6.43$) in the sites in the driest inundation class (Class 3) compared to the wettest class (Class 1).

The median %FC of invasive native chenopods was significantly higher in Class 3 (*$P < 0.001$, $H=36.37$*) than the other two classes. There was no difference in the median of % FC of exotic species between the classes (Appendix 7b, Table 29and Figure 38b).

The lowest median condition scores were at sites in Class 3 (*$P < 0.001$, $H=24.39$*) (10: Poor category; see Table 26). The median condition scores were not significantly different between sites in classes 1 and 2 (Table 29, Figure 38c and Appendix 7c).

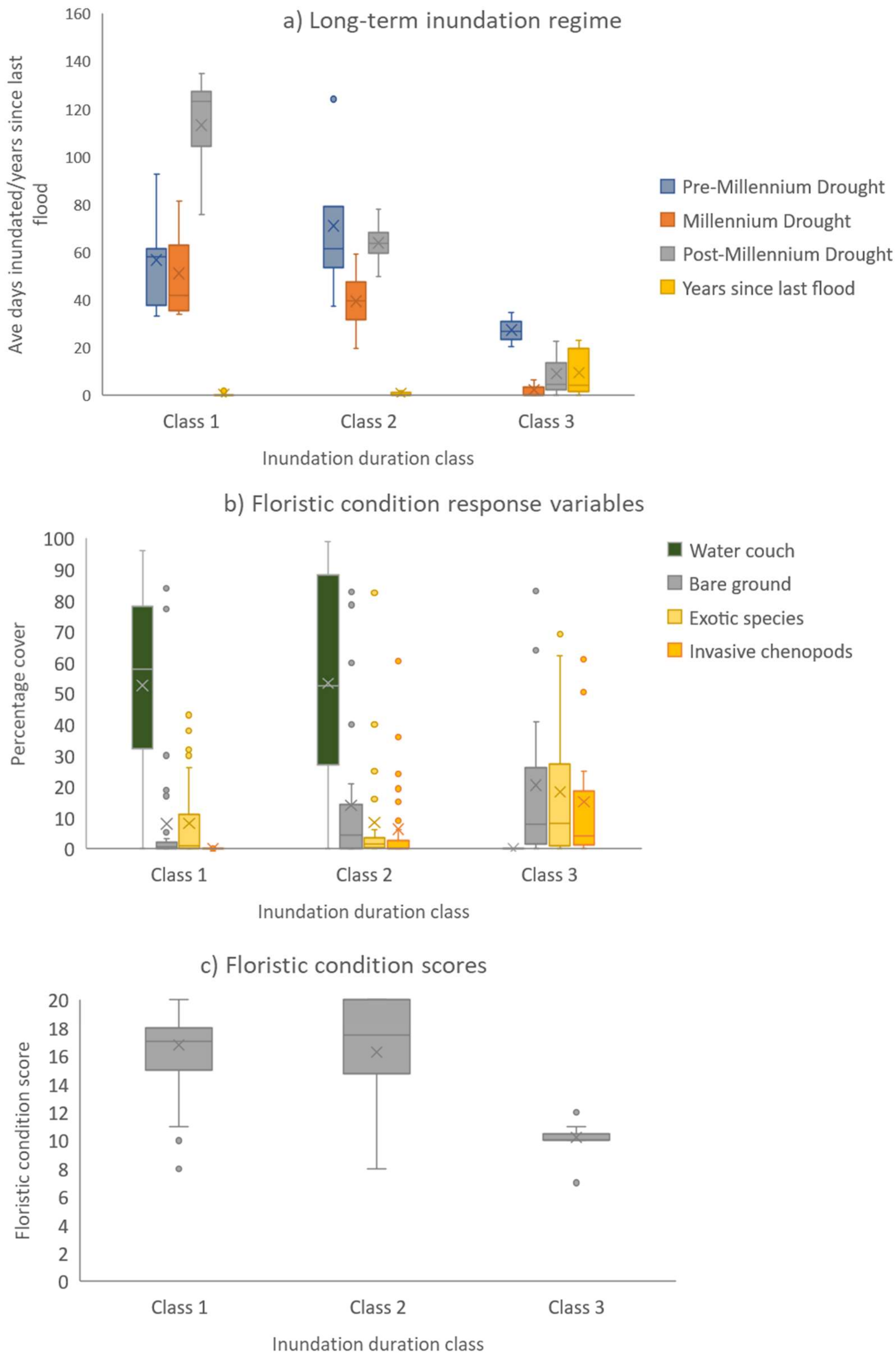


Figure 38 Distribution of inundation predictor variables, community condition response variables and condition scores – PCT 204

3.3.1.2 Mixed marsh sedgeland, PCT 53

Sites of mixed marsh sedgeland were sampled in two stating inundation regimes and three MRF classes: Class 1; Moderate/wet – Moderate, (mapped as Intermediate in 2008), Class 2; Dry – Dry, (mapped as Intermediate/poor in 2008) and Class 3; Dry – Dry (mapped as Poor – Very Poor in 2008) (see Table 27). This in the Pre-MD period there was a significant difference in the mean average annual duration between all Classes ($P<0.01$, $F=18.91$, $DF=2$). Sites in Class 1 had the longest average duration (85.5±12 days), and was significantly different to sites in Class 2 ($P<0.01$, $T=-5.45$), and 3($P<0.01$, $T=-0.61$).

In the MD period the mean annual inundation duration was significantly different ($P < 0.05$, $T=-2.97$), between the sites in Class 1 and the sites in Class 3, but not between sites in Class 1 and Class 2 or Class 2 and 3 (Table 30, Figure 39a and Appendix 8a).

Table 30 Summary of average annual inundation duration (days), PCT 53, Pre-MD, MD and Post-MD periods

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought (days)	Class 1	3	85.5$^{\#\#}$	12	20.8	66.7	66.7	82	107.8	107.8
	Class 2	5	26.4$^{\#\#}$	6.5	14.54	13.2	14.75	21.2	40.65	48.9
	Class 3	3	19.83$^{\#\#}$	3.09	5.36	16.3	16.3	17.2	26	26
Millennium Drought (days)	Class 1	3	46.6$^{\#}$	9.87	17.1	33	33	41	65.8	65.8
	Class 2	5	20.12	6.85	15.32	6.6	6.95	19.6	33.55	44.3
	Class 3	3	10.33	6.67	11.55	0	0	8.2	22.8	22.8
Post-Millennium Drought (days)	Class 1	3	118.5$^{\#\#\#}$	4.21	7.28	113	113	115.67	126.74	126.74
	Class 2	5	36.4	10.8	24.1	8.2	13.3	41.2	57	69.9
	Class 3	3	5.93$^{\#}$	3.53	6.12	0	0	5.56	12.22	12.22
Years since last flood Post-MD (years)	Class 1	16	0	0	0	0	0	0$^{\#\#\#}$	0	0
	Class 2	27	1.185	0.346	1.798	0	0	0$^{\#\#\#}$	2	8
	Class 3	13	11.77	2.67	9.61	0	0.5	17$^{\#\#\#}$	20.5	23

$^{\#}$ P<0.05, $^{\#\#}$ P<0.01$^{\#\#\#}$ P<0.001

In the Post-MD period sites in Class 1 had the longest mean annual duration in the Post-MD period ($P < 0.001$, $DF=2$, $F=33.28$), (118.47±4.21 days), an increase of 70% on the Pre-MD median average inundation duration. Sites in Class 2 returned to slightly more than the annual inundation duration regime of the Pre-MD period in the Post-MD period and where significantly different to sites in Class 1 (*P < 0.01, T=-6.36*) and sites in Class 3 (*P < 0.001, T=-7.79*), that had a reduction in the mean annual inundation regime in the Post-MD period. Sites in both Class 1 and 2 had median of 0 years between floods (annual inundation) in the Post-MD period. However, there was a significant difference between sites in the three Classes in years between floods (*P<0.001, H=17.59*), with sites in Class 3 having a median of 17 ± 2.41 years (Table 30, Figure 39a and Appendix 8a).

The mean %FC wetland plant functional species (WPF) exceeded the PCT diagnostic range of 30 to 70 % FC in sites in Class 1 (79.31±7.19 %) and Class 2 (65.16±5.83 %). There was no significant difference between the means of sites in Class 1 and 2. However, there was a significant difference (*P <0.001, DF=2, F=14.15*) in the median %FC of WPF species between sites in Classes 1 and 2 and sites in Class 3 (Table 31, Figure 39b and Appendix 8b).

Table 31 Summary of response variables and floristic condition scores for Mixed marsh sedgeland - PCT 53, Post-MD period, 2008/09 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
% FC Wetland plant functional species	Class 1	16	79.31	7.19	28.77	0.55	75.48	87.85	99	100
	Class 2	27	65.16	5.83	30.32	6	37.8	74	90.3	99.4
	Class 3	13	22.83##	7.92	28.57	0.1	1	4.3	51	79.35
% cover Bare ground	Class 1	16	13.8	6.9	27.62	0	0.15	1	18	99.45
	Class 2	27	11.87	3.9	20.25	0	0.1	5	10	78.7
	Class 3	13	7.6	2.69	9.71	0	0.85	2.4	11.95	30.1
% FC Exotic species	Class 1	16	4.59	1.9	7.6	0	0.05	0.9	5.72	23.6
	Class 2	27	6.6	1.71	8.9	0	1.1	3.05	6	31.5
	Class 3	13	35.55	9.52	34.31	0.1	2.3	25#	73.75	90
% FC Invasive native chenopods	Class 1	16	0.006	0.006	0.025	0	0	0##	0	0.1
	Class 2	27	3.76	1.84	9.57	0	0	0.1##	1	41
	Class 3	13	18.25	6.1	21.98	0.1	0.7	3##	40.45	61.5
Floristic condition score	Class 1	16	17.5	0.79	3.16	8	16.25	18	20	20
	Class 2	27	17.33	0.54	2.82	10	16	17	20	20
	Class 3	13	12.23	1.06	3.83	8	9	10##	16.5	18

# P<0.05, ## P<0.001, ### P<0.001

The median %FC of exotic species was higher in sites in Class 3 than sites in the other Class 1(*P < 0.05, H=5.2*) and Class 2 (*P< 0.05, H=8.13*).

The median % FC of invasive native chenopod species was higher in sites in Class 3 than sites in Class 1 (*$P = 0.001$, $H=20.4$*) and Class 2 (*$P < 0.001$, $H=10.46$*). There was no significant difference in the % cover of bare ground between the three classes (Table 31, Figure 39b and Appendix 8b).

Median floristic community condition scores were not significantly different between sites in Class 1 and 2 but were significantly different between sites in Classes 1 (*$P<0.001$, $H= 12.89$*) and 2 (*$P <0.001$, $H=9.79$*) in comparison to sites in Class 3 The median was in the Intermediate to Good range in sites in Class 1 (17.5±0.79) and Intermediate range in sites in Class 2 (17.33±0.59). In Class 3 the mean score was in the Poor to Intermediate/poor floristic community condition category (12.23±1.06) (Table 31, Figure 39c and Appendix 8c).

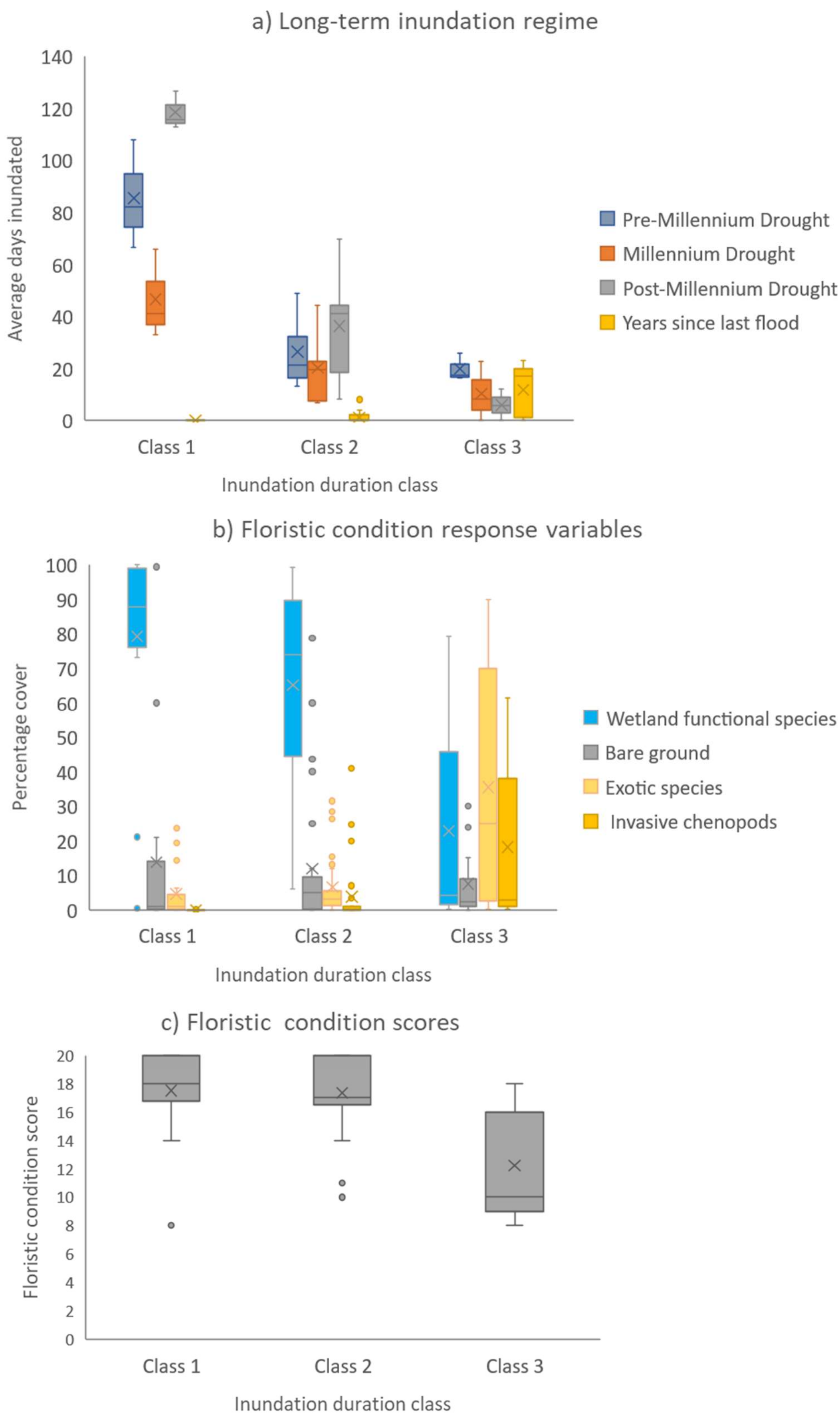


Figure 39 Distribution of inundation predictor variables, community condition response variables and condition scores – PCT 53

Although the floristic condition scores of sites in Classes 1 and 2 where not significantly different, the relative contribution of the WPF species *P. distichum* (water couch) were significantly different (*P<0.001, H=18.35*) and the key diagnostic species of PCT 53; *Eleocharis* spp, *Cyperus* spp and *Juncus* spp (sedges and rushes) were significantly different (*P<0.05, H=5.66*) (Table 32, Figure 40 and Appendix 8d).

In sites in Class 1, the median percentage of water couch was 35% and sedges and rushes comprised 3.4% of the total % FC of WPF species. In Class 2, the median percentage of sedges and rushes was 44.4% of the total %FC of WPFs and water couch was 0% (Table 32, Figure 40b, Appendix 8d). Sites in Class 3 had a median percentage of water couch of 0%FC and 0 %FC of sedges and rushes (Table 32, Figure 40c).

Table 32 Proportional distributions of key diagnostic wetland functional group species by inundation regime class – PCT 53, 2008/09 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max	% of total %FC of WPF species
%FC *Paspalum distichum*	Class 1	17	38.97	7.2	29.68	0	13.5	35##	62.5	88	43.05
	Class 2	30	3.7	2.86	15.64	0	0	0	0.18	85	0.00
	Class 3	14	0.02	0.02	0.07	0	0	0	0	0.25	0.00
% FC Sedges and Rushes	Class 1	17	8.1	3.72	15.34	0	0.2	3.4##	10.6	64	5.51
	Class 2	30	38.08	5.87	32.13	0	1.08	44.4##	62.4	97.9	71.96
	Class 3	14	0.08	0.077	0.27	0	0	0	0	1	0.00
%FC WPF species (Other)	Class 1	17	15.34	4.61	18.99	0	0.63	8.2	24.8	60.4	10.09
	Class 2	30	8.38	2.44	13.37	0	0.28	1.5	12.2	46.9	2.43
	Class 3	14	14.08	6.05	22.65	0	0.1	0.35	28.9	63.5	26.92
% FC All WPF species	Class 1	17	74.44	8.1	33.4	0.55	73.8	81.3	97.9	100	
	Class 2	30	54	6.1	33.44	0.1	18.8	61.7	82.7	99	
	Class 3	14	16.98	6.62	24.78	0.1	0.18	1.3	33.1	74.85	

# P<0.05, ## P<0.001

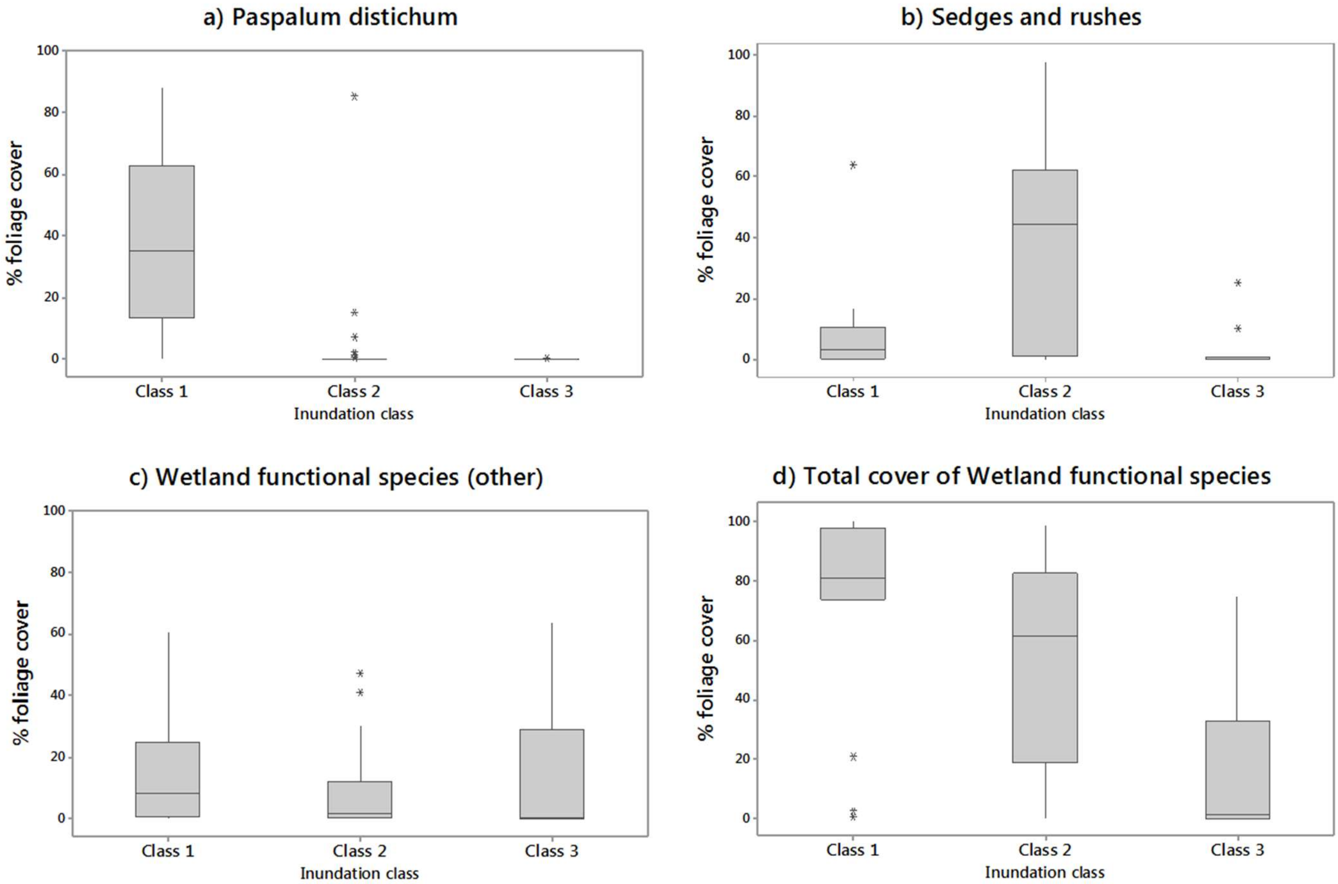


Figure 40 Proportional distributions of key diagnostic wetland plant functional group species by inundation regime class – PCT 53

3.3.1.3 Floodplain grassland, PCT 214

Sites supporting grassland were sampled in one inundation regime; Very Dry-Very Dry and two mapped starting conditions: Class 2; Poor in 2008 and Class 3; Very Poor in 2008 (see Table 27). Thus, there was no significant difference in the median average annual duration period between the sites in Class 2 and sites in Class 3 in either the Pre-MD period or the MD-period or the Post-MD. However, the median time between inundation events in sites in Class 3 was significantly longer than Class 2 ($P < 0.05, H=3.98$) (Appendix 9a, Table 33 and Figure 41a).

Table 33 Summary of average annual inundation duration (days), Floodplain grassland – PCT 214, Post-MD period, Pre-MD, MD and Post-MD periods

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought (days)	Class 2	2	0.2	0	0	0.2	*	0.2	*	0.2
	Class 3	2	4.25	4.05	5.73	0.2	*	4.25	*	8.3
Millennium Drought (days)	Class 2	2	0	0	0	0	*	0	*	0
	Class 3	2	0.4	0.4	0.566	0	*	0.4	*	0.8
Post-Millennium Drought (days)	Class 2	2	8.06	1.83	2.59	6.22	*	8.06	*	9.89
	Class 3	2	2.78	2.78	3.93	0	*	2.78	*	5.56
Years since last flood Post-MD (years)	Class 2	8	6.25	3.45	9.75	0	0.25	1.5	17	22
	Class 3	8	16.38	3.84	10.88	0	4.25	22[#]	24.75	27

[#] P<0.05

The mean %FC of native grasses was below the diagnostic range of 30 to 70 %FC in both inundation Classes 2 and 3. There was no significant difference between the inundation regime classes for % FC native grasses, % FC exotic species, % FC WFP species, % cover bare ground or % FC invasive native chenopods variables (Appendix 9b, Table 34 and Figure 41b).

Mean floristic community condition scores were in the Intermediate/poor range for sites in Class 2 (12.13±1.06) and Class 3 (12.13±1.08) and there was no significant difference between the classes (Appendix 9c, Table 34 and Figure 41c).

Table 34 Summary of response variables and floristic condition scores for Floodplain grassland - PCT 214, 2008/09 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
% FC Native grasses	Class 2	8	25.8	11.6	32.9	1	1.1	11.4	45	94.1
	Class 3	8	16.39	9.65	27.29	0.1	0.5	2.25	31.2	76.1
% FC Wetland functional species	Class 2	8	0.73	0.23	0.65	0	0.2	0.55	1.25	1.9
	Class 3	8	3.92	2.62	7.4	0	0.1	0.25	7.81	20
% cover Bare ground	Class 2	8	41.13	9.23	26.12	0	22.5	39	65	81
	Class 3	8	29.86	7.55	21.34	0	12.75	23.5	51.5	58.9
% FC Exotic species	Class 2	8	8.18	4.78	13.51	0.3	0.4	1.1	23	30.1
	Class 3	8	6.78	4.92	13.92	0.3	0.55	1.95	4.55	41
% FC Invasive native chenopods	Class 2	8	3.57	2.93	8.28	0	0.13	0.6	1.77	24
	Class 3	8	8.68	3.48	9.85	0.3	1.02	3.75	19.13	25
Floristic condition score	Class 2	8	12.13	1.06	3	8	9.25	12	15	16
	Class 3	8	12.13	1.08	3.04	9	9.25	12	13.75	18

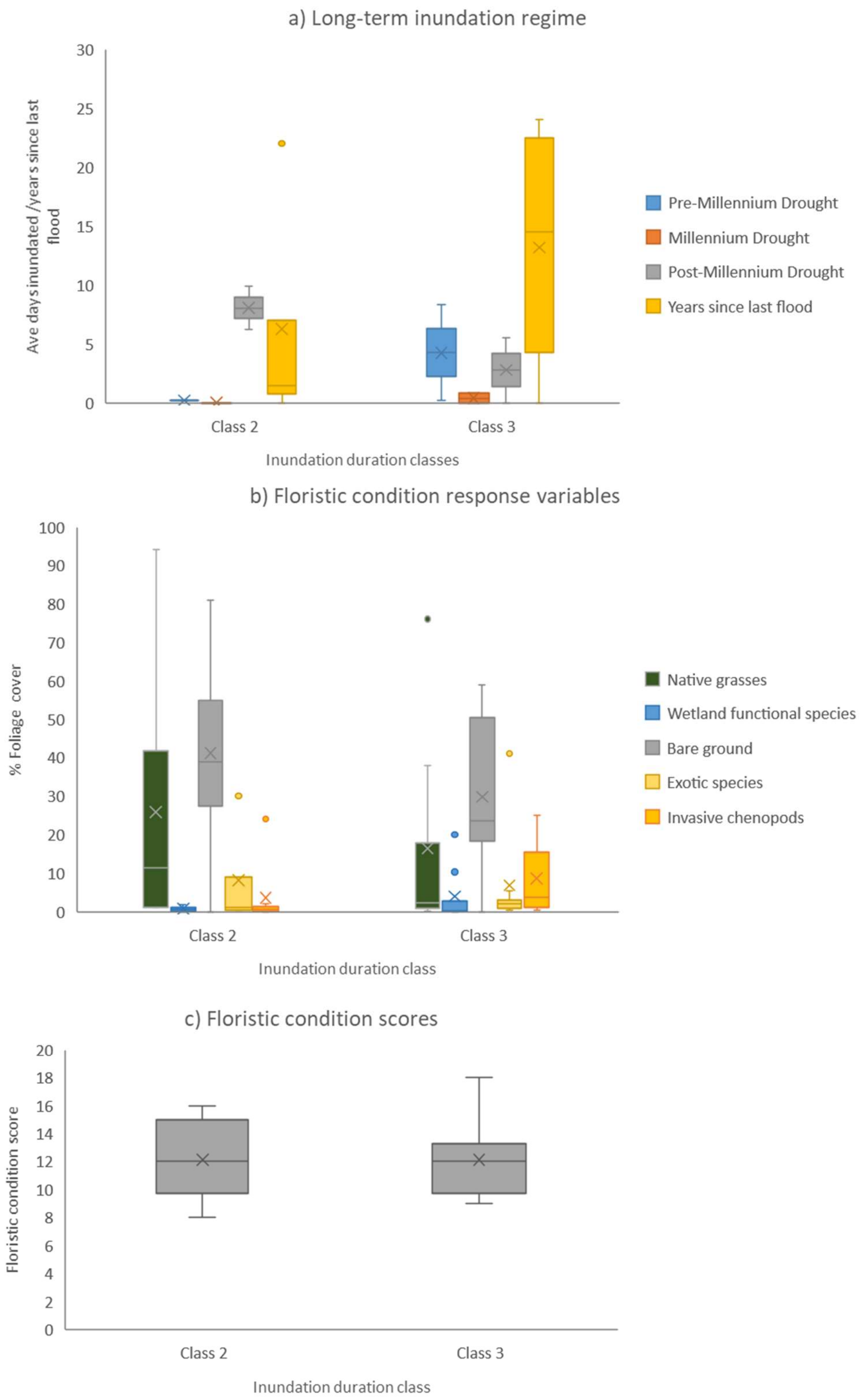


Figure 41 Distribution of inundation predictor variables, community condition response variables and condition scores – PCT 214

3.3.1.4 Lignum shrubland, PCT 247

Sites of lignum shrubland were sampled in two distinct inundation regimes: Class 1; Moderate/Wet – Moderate (mapped as Intermediate in 2008) and Class 2; Dry – Very Dry (mapped as Good in 2008) (see Table 27). As there were only two data points for inundation duration for sites in Class 2, the results are indicative only. Class 1 had the longest mean average duration in the Pre-MD period ($P < 0.05$, $DF=1$, $F=10.62$). In the MD period there was no significant difference in means for average annual inundation duration between the classes. Sites in both classes had a reduction in mean average annual inundation duration in the MD period in comparison to the Pre-MD (Appendix 10a, Table 35 and Figure 42a).

Table 35 Summary of average annual inundation duration (days), Lignum shrubland – PCT 247, Post-MD period, Pre-MD, MD and Post-MD periods

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought (days)	Class 1	4	81.3 #	10.8	21.6	59.1	61.1	81	101.7	103.9
	Class 2	2	27.15	6.05	8.56	21.1	*	27.15	*	33.2
Millennium Drought (days)	Class 1	4	36.52	8.96	17.92	24.7	24.9	29.3	55.37	62.8
	Class 2	2	7.35	0.05	0.07	7.3	*	7.35	*	7.4
Post-Millennium Drought (days)	Class 1	4	84.56 #	5.7	11.4	76.44	76.58	80.44	96.64	100.89
	Class 2	2	49.44	2	2.83	47.44	*	49.44	*	51.44
Years since last flood Post-MD (years)	Class 1	4	0.75	0.75	1.5	0	0	0	2.25	3
	Class 2	8	0.88	0.39	1.13	0	0	0.5	1.75	3

* Insufficient data, # $P<0.05$

In the Post-MD period there sites in Class 1 had longer mean annual average duration of inundation (84.56±5.7 days), than sites in Class 2 (49.44±2) ($P<0.05$, $DF=1$, $F=16.52$). Sites in both Classes had annual or near annual inundation in the Post-MD period (Appendix 10a, Table 35 and Figure 42a).

The mean % FC of lignum was in the diagnostic range of 10 to 70 %FC, in sites in Class 1 (31.37±3.52 % FC) and Class 2 (32.97±5.65 % FC). There was no significant difference in mean %FC lignum, % FC wetland functional species, % cover bare ground, %

FC exotic species or % FC invasive native chenopods between the two inundation regime classes (Appendix 11b, Table 3 and Figure 42b).

There was no significant difference between mean floristic community condition scores (18±1.34) in sites in Class 1 and (17.88±0.52) in Class 2 sites. Both classes were in the Intermediate to Good range (Appendix 10c, Table 36, and Figure 42c).

Table 36 Summary of response variables and floristic condition scores for Lignum shrubland - PCT 247, 2008/09 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
% FC Lignum	Class 1	4	31.37	3.52	7.05	25	25.62	29.74	38.75	41
	Class 2	8	32.97	5.65	15.98	20	21.91	27.09	38.03	69
% FC Wetland functional species	Class 1	4	32.5	15.6	31.2	0	4	29.3	64	71.2
	Class 2	8	46.06	9.7	27.42	14.2	19.45	45.95	69.42	83.2
% cover Bare ground	Class 1	4	11.36	6.58	13.16	0	0.07	9.97	24.04	25.5
	Class 2	8	8.77	3.63	10.26	0	0	6.63	15.23	28
% FC Exotic species	Class 1	4	10.98	5.44	10.88	0	0.82	11.47	20.66	21
	Class 2	8	7.1	3.79	10.72	0	0.4	4.33	7.58	32.6
% FC Invasive native chenopods	Class 1	4	0.45	0.45	0.89	0	0	0	1.339	1.79
	Class 2	8	1	1	2.83	0	0	0	0	8
Floristic condition score	Class 1	4	18.5	1.34	2.68	14.5	15.75	19.75	20	20
	Class 2	8	17.88	0.52	1.46	15	17	18.5	19	19

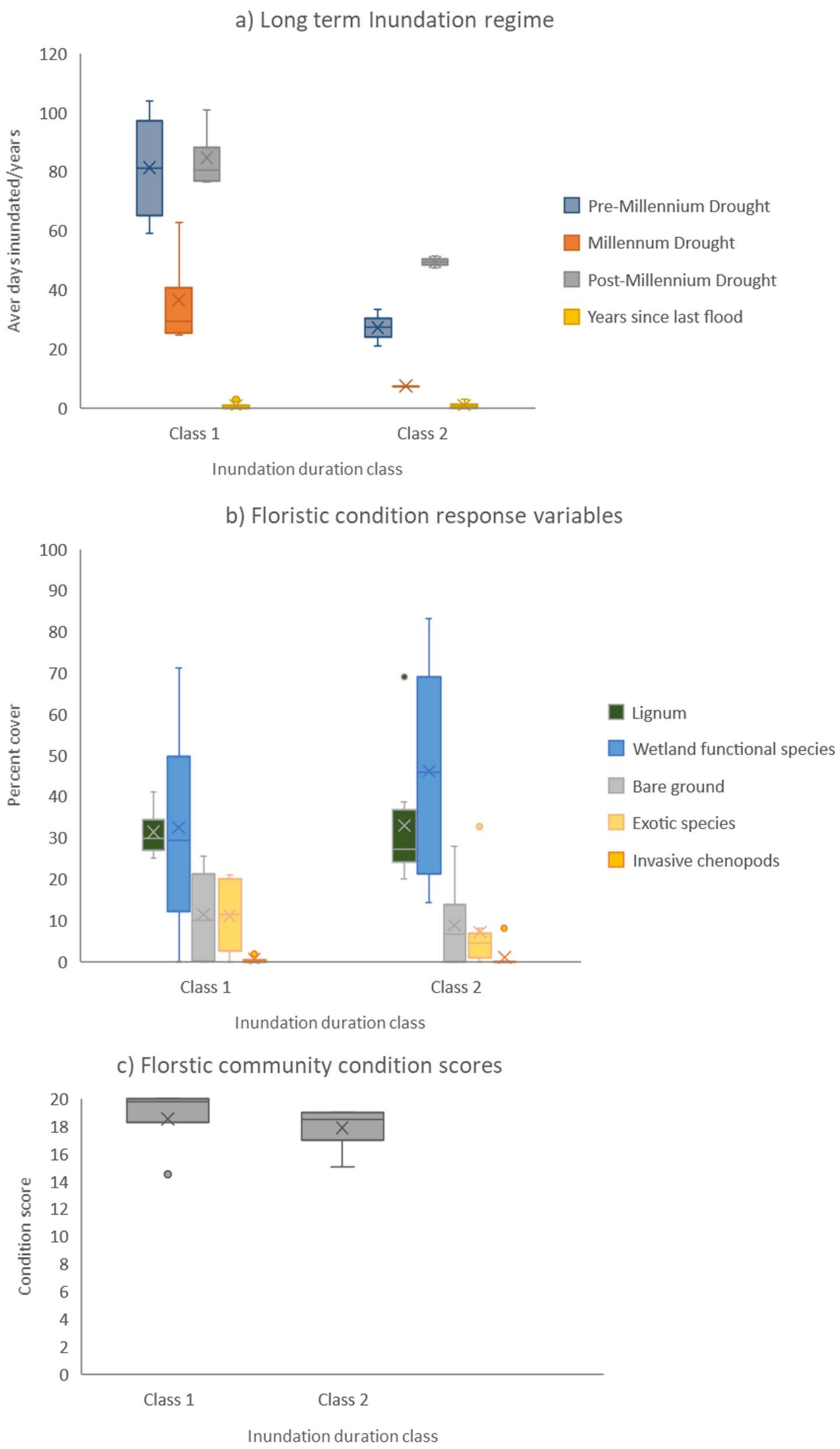


Figure 42 Distribution of inundation predictor variables, community condition response variables and condition scores – PCT 247

3.3.1.5 River red gum forest and woodland, PCT 36/36A

Sites of river red gum forest were sampled in only one starting inundation regime: Class 1; (Moderate/Wet – Moderate) and all sites were mapped as Good condition in 2008 (see Table 27). Sites of river red gum woodland were sampled in one starting inundation regime (Moderate – Moderate) and two conditions: Class 1; mapped as Intermediate in 2008 and Class 2; mapped as Intermediate to Poor in 2008. The mean average annual inundation of forest sites was higher than the woodland sites in Class 2 but not significantly different to Class 1 woodland sites in the Pre-MD period ($P<0.01, T=-3.32$), the MD period ($P < 0.01, T=-3.56$), and as expected the average annual inundation of Class 1 and 2 woodland sites was not significantly different. In the Post MD period there were significant differences between the Class 1 Woodland and Class 2 woodland sites ($P < 0.05, T=-2.57$).

Table 37 Summary of average annual inundation duration (days), River red gum forest and woodland – PCT 36/36A, Post-MD period, Pre-MD, MD and Post-MD periods,

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought	Class 1 (Forest)	4	$84.4^{\#\#}$	12.2	24.5	48.9	59.1	92.1	102	104.5
(days)	Class 1 (Woodland)	3	46.93	8.26	14.31	32.3	32.3	47.6	60.9	60.9
	Class 2 (Woodland)	19	48.72	4.56	19.87	15.5	29.2	49.5	66.4	82.3
Millennium Drought	Class 1 (Forest)	4	$59.38^{\#\#}$	8.69	17.38	43.4	45.02	55.55	77.55	83
(days)	Class 1 (Woodland)	3	42.03	9.7	16.8	31.4	31.4	33.3	61.4	61.4
	Class 2 (Woodland)	19	32.91	2.94	12.8	17.8	24.3	26.8	39.5	65.1
Post-Millennium Drought	Class 1 (Forest)	4	118.75	9.27	18.54	94.78	100.28	120.44	135.53	139.33
(days)	Class 1 (Woodland)	3	$75.9^{\#\#\#}$	18.1	31.4	41.1	41.1	84.6	102	102
	Class 2 (Woodland)	19	$58.78^{\#}$	4.35	18.95	22.56	41.22	62.67	75.22	90.56
Years since last flood Post-MD	Class 1 (Forest)	23	0.04	0.04	0.21	0	0	$0^{\#\#}$	0	1
	Class 1 (Woodland)	12	0.5	0.29	1	0	0	0	0.75	3
	Class 2 (woodland)	98	0.89	0.13	1.27	0	0	0	2	7

$^{\#}$ P<0.05, $^{\#\#}$ P<0.01 $^{\#\#\#}$ P<0.001

The forest sites had a reduction in average inundation duration during the MD period and an increase in average annual inundation duration in the Post-MD period in relation to the Pre-MD period (Appendix 11a, Table 37 and Figure 43a). In the Post-MD period there was a significant difference between the medians of years since last flood between forest sites and woodland sites in Class 2 (*P < 0.01, H=8.74*) but not between forest sites and woodland sites in class 1 and no difference in medians between Class 1 and Class 2 woodland sites.

Table 38 Summary of response variables and floristic condition scores for River red gum forest and woodland – PCT 36/36A, 2008/09 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
% FC RRG** – Tallest stratum	Class 1 (Forest)	23	54.52###	5.46	22.5	19.85	37.32	52.55	74.74	97.71
	Class 1 (Woodland)	12	19.74	5.29	14.97	4.43	9.16	15.48	32.25	47.87
	Class 2 (woodland)	98	19.86	1.73	15.73	1.75	9.83	15.75	22.52	80.77
% FC RRG – Middle stratum	Class 1 (Forest)	23	2.74	0.95	4.56	0	0	0.5#	4	20
	Class 1 (Woodland)	12	0.43	0.415	1.44	0	0	0	0.075	5
	Class 2 (woodland)	98	0.93	0.32	3.19	0	0	0	0.1	19.33
% FC RRG – Lower stratum	Class 1 (Forest)	23	0.30	0.11	0.53	0	0	0	0.5	2
	Class 1 (Woodland)	12	0.1	0.08	0.29	0	0	0	0.075	1
	Class 2 (woodland)	98	0.26	0.06	0.56	0	0	0.1	0.1	4
% FC Wetland functional species	Class 1 (Forest)	23	59.38	6.16	29.54	1.9	39.1	62.9#	85.9	99.7
	Class 1 (Woodland)	12	34.74	6.1	21.13	7.3	22.7	29.8	50.75	78.8
	Class 2 (woodland)	98	44.44	3.45	34.18	0.1	8.1	42.85	76.95	99.6
% cover Bare ground	Class 1 (Forest)	23	12.64	2.98	14.29	0	1	6	20	60
	Class 1 (Woodland)	12	32.67	5.38	18.63	6	16.25	33.5##	43.75	72
	Class 2 (woodland)	98	17.24	2.28	22.61	0	0.5	5	28	88
% FC Exotic species	Class 1 (Forest)	23	7.91	1.87	8.99	0.5	1.6	4.5	11.6	36
	Class 1 (Woodland)	12	5.32	1.29	4.48	0.3	2.47	4.05	9.07	15.2
	Class 2 (woodland)	98	9.84	1.65	16.34	0	0.6	2.1	12.65	86
% FC Invasive native chenopods	Class 1 (Forest)	23	0	0	0	0	0	0	0	0
	Class 1 (Woodland)	12	0.18	0.17	0.58	0	0	0	0	2
	Class 2 (woodland)	98	3.1	0.77	7.62	0	0	0.15##	1.15	42.01
Floristic condition score	Class 1 (Forest)	23	16.91	0.33	1.56	13	16	17.5##	18	19
	Class 1 (Woodland)	12	15.46	0.41	1.42	12	14.63	15.5	16.34	17.5
	Class 2 (woodland)	98	15.19	0.25	2	8	13.5	16	17	19

**%FC calculated from 0.1ha plot, # P<0.05, ## P<0.01 ### P<0.001

In the Post-MD period the mean of average annual duration of forest sites was 118.75±9.27 days (3-4 months) occurring annually, woodland sites in Class 1 had 58.78±4.35

days (2 months) and sites in Class 2 was 75.9±18.1 (3 months) every 0-2 years(Appendix 11a, Table 37 and Figure 43a)

As expected there was a significant difference between the mean %FC of RRG in the tallest stratum for forest sites in Class 1 (*P < 0.001, T=-4.8*) and woodland sites in Class 1 and 2 (*P < 0.001, T=-7.71*). However, there was no significant difference between the mean % FC of RRG in the tallest stratum between woodland sites in Class 1 and 2. The forest sites had a mean % FC of river red gum (RRG) in the tallest stratum of 54.54±5.46 %; this was within the diagnostic range for % FC for forest (30 to 70 % FC). The woodland sites in Class 1 had a mean of %FC in the tallest stratum of 19.74±5.29% and Class 2 sites had a % FC of RRG in the tallest stratum of 19.86±1.73 %. Both were within the diagnostic range for woodland (10 to 30 % FC) (Appendix 11b, Table 38 and Figure 43b).

Forest sites had higher median % FC of RRG in the middle stratum than the woodland sites in Class 1 (*P < 0.05, H=6.44*) and Class 2 (*P < 0.01, H=10.24*), but there was no difference between woodland sites. There was no difference in the median % FC of RRG, % FC of WFP species or % FC of exotic species in the Lower stratum between the forest sites and the woodland sites, or between the woodland sites (Appendix 11b, Table 38, Figure 43b).

Woodland sites in Class 1 had greater median % cover of bare ground than forest sites (*P < 0.01, H=10.22*) or woodland sites in Class 2 (*P <0.01, 8.58*). Woodland sites in Class 2 had greater median % FC of native invasive chenopods than woodland sites in Class 1 (*P < 0.01, H= 8.25*) or forest sites (*P<0.001, H=23.64*) (Appendix 11b, Table 38 and Figure 43b). All sites had median floristic condition scores in the Intermediate range and there was a significant difference between forest sites and woodland sites in Class 1 (*P < 0.01, H=6.88*) and Class 2 (*P <0.001, H=12.33*) but not woodland sites (Appendix 11c, Table 38 and Figure 43c).

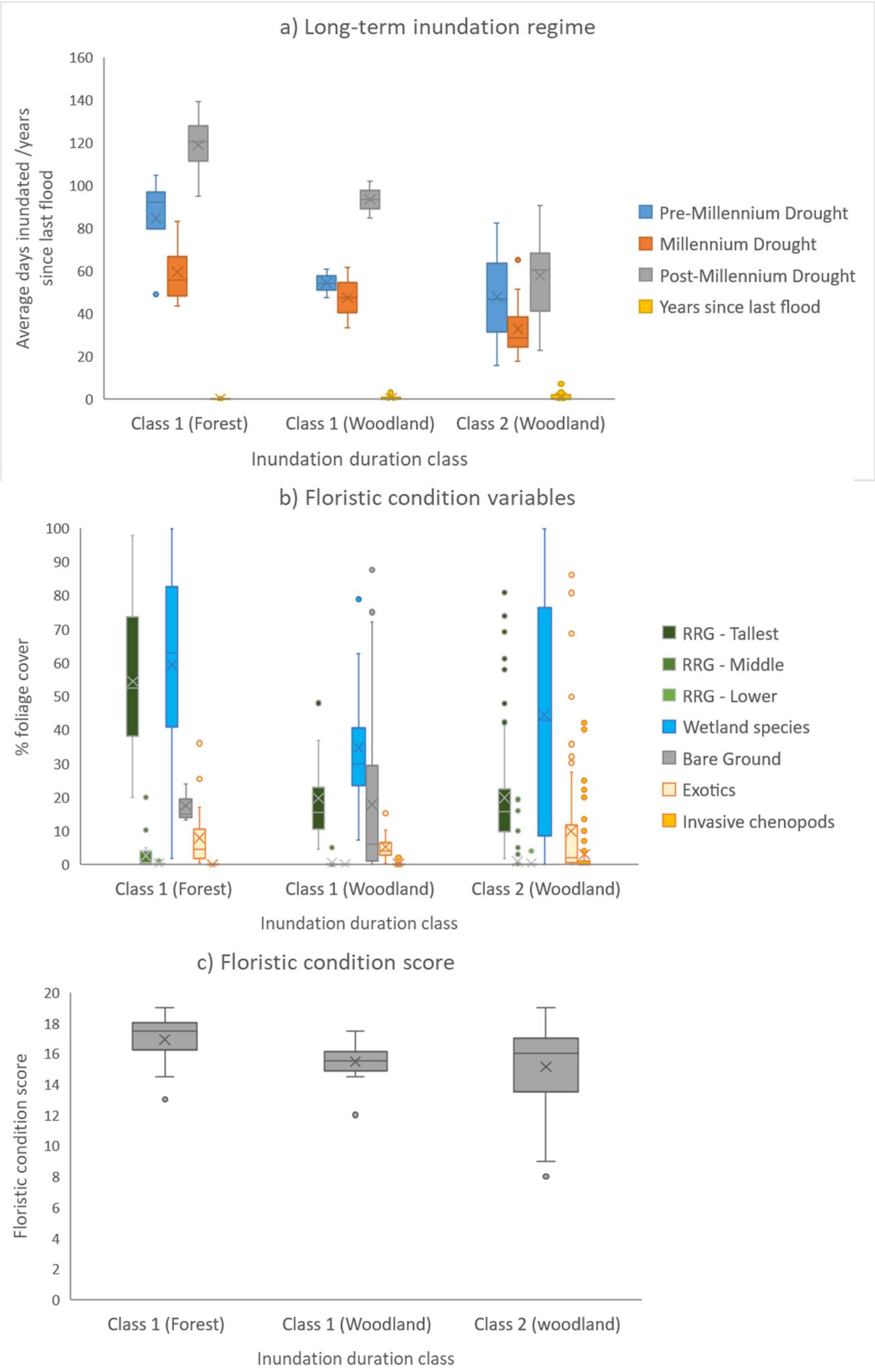


Figure 43 Distribution of inundation predictor variables, community condition response variables and condition scores – PCT 36/36A

3.3.1.6 River red gum grassy woodland, PCT 454

Sites of river red gum grassy woodland were sampled in two condition classes: Class 2; (Dry – Dry) and sites were mapped as Intermediate in 2008 and Class 3; (Dry –Very Dry) where sites were mapped as Poor in 2008 (see Table 27). There was no significant difference in the mean average annual inundation in the Pre-MD period between the sites in Class 2 and Class 3 (Appendix 12a, Table 39 and Figure 44a).

There was a significant difference between sites in Class 2 and 3 in mean annual inundation duration in the MD period ($P< 0.001, F=165.84$), when the sites in Class 3 received a tenth of the mean average annual inundation duration of the sites in Class 2. In the Post-MD period there was a significant difference between sites in Class 2 and 3 in mean annual inundation duration ($P < 0.01, F=25.05$), when the average annual inundation duration in sites in Class 2 doubled in relation to the Pre-MD period. There was no significant difference in the medians of the classes for years since last flood. Sites in Class 3 experienced a large reduction in the average inundation duration during the MD period in relation to the Pre-MD period and did not return to their Pre-MD levels in the Post-MD period (Appendix 12a, Table 39 and Figure 44a).

Table 39 Summary of average annual inundation duration (days), River red gum grassy woodland – PCT 454, Post-MD period, Pre-MD, MD and Post-MD periods

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought	Class 2	2	26.45	1.85	2.62	24.6	*	26.45	*	28.3
(days)	Class 3	4	15.9	3.22	6.45	6.7	9.1	17.9	20.7	21.1
Millennium Drought	Class 2	2	24.65$^{###}$	1.85	2.62	22.8	*	24.65	*	26.5
(days)	Class 3	4	2.23	0.88	1.76	0.8	1	1.65	4.03	4.8
Post-Millennium Drought	Class 2	2	46.33$^{##}$	9.56	13.51	36.78	*	46.33	*	55.89
(days)	Class 3	4	7.47	3.4	6.8	0.89	1.36	6.83	14.22	15.33
Years since last flood Post-MD (years)	Class 2	9	1.33	0.40	1.23	0	0	1	2.5	3
	Class 3	24	2.54	0.49	2.39	0	0	2.5	4.75	7

* Insufficient data, $^{##}$ P<0.01,$^{###}$ P<0.001

The sites in Class 2 had a mean %FC of RRG in the tallest stratum of 13.51±4.15 % while sites in Class 3 had a mean of 23.01± 5.97%. Both were within the diagnostic range for % FC for woodland (10 to 30%) however, there was no significant difference found between the classes (Appendix 12b, Table 40 and Figure 44b).

Table 40 Summary of response variables and floristic condition scores for River red gum grassy woodland – PCT 454, 2008/09 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
% FC RRG** – Tallest stratum	Class 2	9	13.51	4.15	10.97	4.1	4.42	6.23	25	29.9
	Class 3	24	23.01	5.97	26.69	0	1.63	9.99	38.85	88.58
% FC RRG – Middle stratum	Class 2	9	0.06	0.02	0.07	0	0	0	0.1	0.2
	Class 3	24	0.08	0.04	0.22	0	0	0	0	1
% FC RRG – Lower stratum	Class 2	9	0.01	0.01	0.03	0	0	0	0	0.1
	Class 3	24	0.05	0.04	0.20	0	0	0	0	1
% FC Wetland functional species	Class 2	9	25.16	9.44	28.33	0.1	0.9	18.4	47.35	81.7
	Class 3	24	14.94	4.61	22.57	0	0.77	3.55	19.25	81.1
% FC Native grasses	Class 2	9	0.58	0.57	1.70	0	0	0	0.05	5.1
	Class 3	24	1.58	0.99	4.85	0	0	0.1	0.45	22.2
% cover Bare ground	Class 2	9	18.11	6.36	19.09	1	2.5	3	38.5	45
	Class 3	24	25.06	5.11	25.05	0	2.1	13.5	50	74
% FC Exotic species	Class 2	9	20.67	6.72	20.15	0.2	3.1	15.5	39.75	55.2
	Class 3	24	6.37	2	9.8	0	0.8	3.06	6.58	39.3
% FC Invasive native chenopods	Class 2	9	1.87	1.12	3.37	0	0.05	0.1	3.15	10
	Class 3	24	3.94	0.98	4.81	0.1	0.5	1.55	6.63	20
Floristic condition score	Class 2	9	12.14	0.61	1.84	9.75	10.25	12.5	13.25	15.5
	Class 3	24	11.5	0.36	1.76	8.5	10.5	11	13	16.5

** %FC calculated from 0.1ha plot

There was no significant difference between classes of the mean of % FC of RRG in the middle stratum, % FC of RRG in the lower stratum, % cover of bare ground, or the % FC of invasive native chenopods. There was no significant difference between the medians of % FC of exotic species, % FC of native grasses, or % FC of WPF species between the two classes, (Appendix 12b, Table 40 and Figure 44b), or between mean floristic condition scores (see Table 26), (Appendix 12c, Table 40 and Figure 44c).

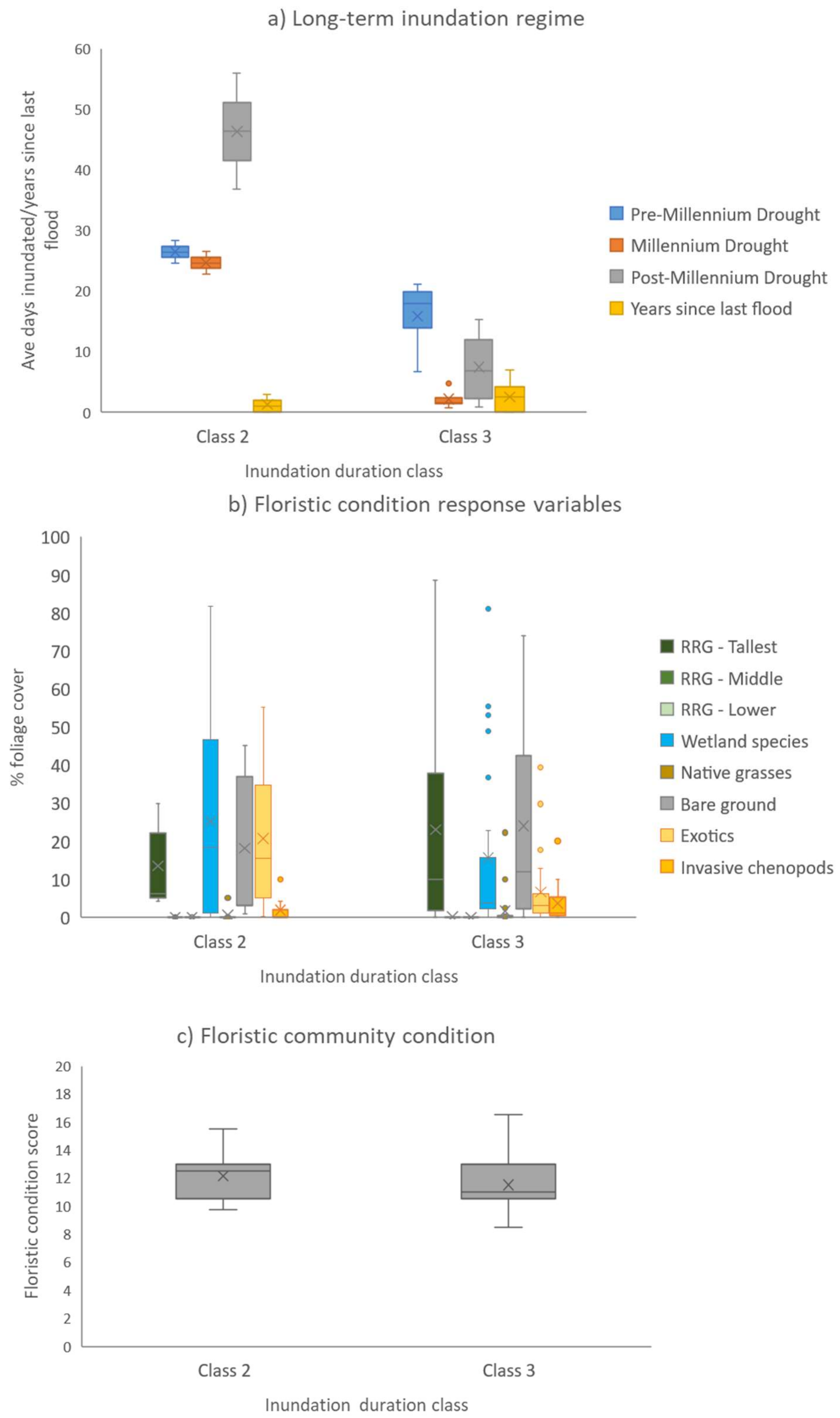


Figure 44 Distribution of inundation predictor variables, community condition response variables and condition scores – PCT 454

3.3.1.7 Coolibah grassy woodland, PCT 40

Sites of coolibah grassy woodland were sampled in two regimes: Class 2; Dry – Dry and Class 3; Very Dry-Very Dry. Sites in both classes were mapped as Intermediate in 2008 (see Table 27). Thus the sites in Class 2 had a longer mean of average annual inundation in the Pre-MD period than sites in Class 3 (*P < 0.05, DF=1, F=19.52*). There was no significant difference in the mean of average inundation duration between the sites in the two classes in the MD period, with both classes decreasing from the Pre-MD period (Appendix 13a, Table 41 and Figure 45a).

In the Post-MD period the mean average annual inundation duration doubled from the Pre-MD period mean in sites in Class 2 while sites in Class 3 did not return to their Pre-MD levels (*P < 0.01, DF=1, F=70.11*). Sites in Class 2 had much more frequent inundation events on average in the Post-MD period than sites in Class 3 (*P < 0.01, H=11.6*) (Appendix 13a, Table 41 and Figure 45a).

Table 41 Summary of average annual inundation duration (days), Coolibah woodland – PCT 40, Post-MD period, Pre-MD, MD and Post-MD periods,

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought (days)	Class 2	3	20.63#	3.22	5.57	14.8	14.8	21.2	25.9	25.9
	Class 3	2	2.25	0.35	0.49	1.9	*	2.25	*	2.6
Millennium Drought (days)	Class 2	3	13.6	5.4	9.35	8.2	8.2	8.2	24.4	24.4
	Class 3	2	0.4	0.4	0.56	0	*	0.4	*	0.8
Post-Millennium Drought (days)	Class 2	3	41.7#	3.81	6.6	36.89	36.89	39	49.22	49.22
	Class 3	2	0.44	0.44	0.63	0	*	0.44	*	0.89
Years since last flood Post-MD (years)	Class 2	12	1	0.35	1.21	0	0	0.5##	2	3
	Class 3	12	8.33	1.62	5.61	0	3.25	8##	13.75	16

* Insufficient data, # P<0.05, ## P<0.01

There was no significant difference in the mean % FC of coolabah in the tallest stratum between the classes; 29.44±9.17% (Class 2) and 11.1±3.01% (Class 3). Sites in both classes are within the range of the diagnostic for woodland of 10 – 30 % FC although the mean of sites in Class 2 is well above the diagnostic for PCT 40 of ≤10 % FC. There was no difference in the median of %FC of coolibah in the middle or lower strata between the classes. Sites in Class 2 had a greater median %FC of wetland species than Class 3 sites ($P < 0.01$, $H = 8.17$). Sites in Class 3 had a greater median %FC of native grasses ($P < 0.01$, $H = 8$) and a greater mean % cover bare ground ($P < 0.01$, $DF = 1$, $F = 9.23$) than sites in Class 2. There was no significant difference in % FC of exotic species or % FC invasive native chenopods between sites in the two classes (Appendix 13b, Table 42 and Figure 45b).

Mean floristic community condition scores were in the Intermediate/poor range (13.02±0.49 and 12.96±0.38) and there was no significant difference between the sites in Class 2 and 3 (Appendix 14c, Table 42 and Figure 45c).

Table 42 Five-number summary of response variables and community condition scores, Post-MD, coolibah woodland – PCT 40, Post-MD period

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
% FC Coolibah[#] – Tallest stratum	Class 2	12	29.44	9.17	25.94	9	9.75	13.05	58.23	68.75
	Class 3	12	11.1	3.01	8.5	0.75	4.43	9.31	18.15	24.38
% FC Coolibah – Middle stratum	Class 2	12	0.05	0.04	0.14	0	0	0	0	0.5
	Class 3	12	0.01	0.01	0.03	0	0	0	0	0.1
% FC Coolibah – Lower stratum	Class 2	12	0.03	0.01	0.05	0	0	0	0.075	0.1
	Class 3	12	0.03	0.02	0.06	0	0	0	0	0.2
% FC Wetland functional species	Class 2	12	30.07	8.92	30.91	2.6	4.55	19.30[##]	55.63	95.9
	Class 3	12	5.83	2.69	9.32	0	0.13	0.65	10.97	24.8
% FC Native grasses	Class 2	12	8.68	5.01	17.35	0	0.60	1.55	7.53	61.4
	Class 3	12	23.82	5.64	19.54	1.9	7.35	22.50[##]	35.63	63.5
% cover Bare ground	Class 2	12	24.03	6.15	21.32	2	6.75	16.00	43.75	65
	Class 3	12	47.68	4.77	16.52	19	35.05	47.50[##]	59.88	74.8
% FC Exotic species	Class 2	12	8.27	4.97	17.22	0.2	0.60	2.20	2.38	58.3
	Class 3	12	1.18	0.60	2.08	0	0.03	0.55	1.45	7.5
% FC Invasive native chenopods	Class 2	12	1.43	0.67	2.31	0	0.03	0.40	2.38	6.1
	Class 3	12	3.83	1.91	6.63	0.1	0.10	0.60	4.30	20
Floristic condition score	Class 2	12	13.02	0.49	1.70	10.5	11.56	13.25	14.38	16
	Class 3	12	12.96	0.38	1.32	11	12.00	13.00	14.00	15

[**]%FC calculated from 0.1ha plot, [##] P<0.01

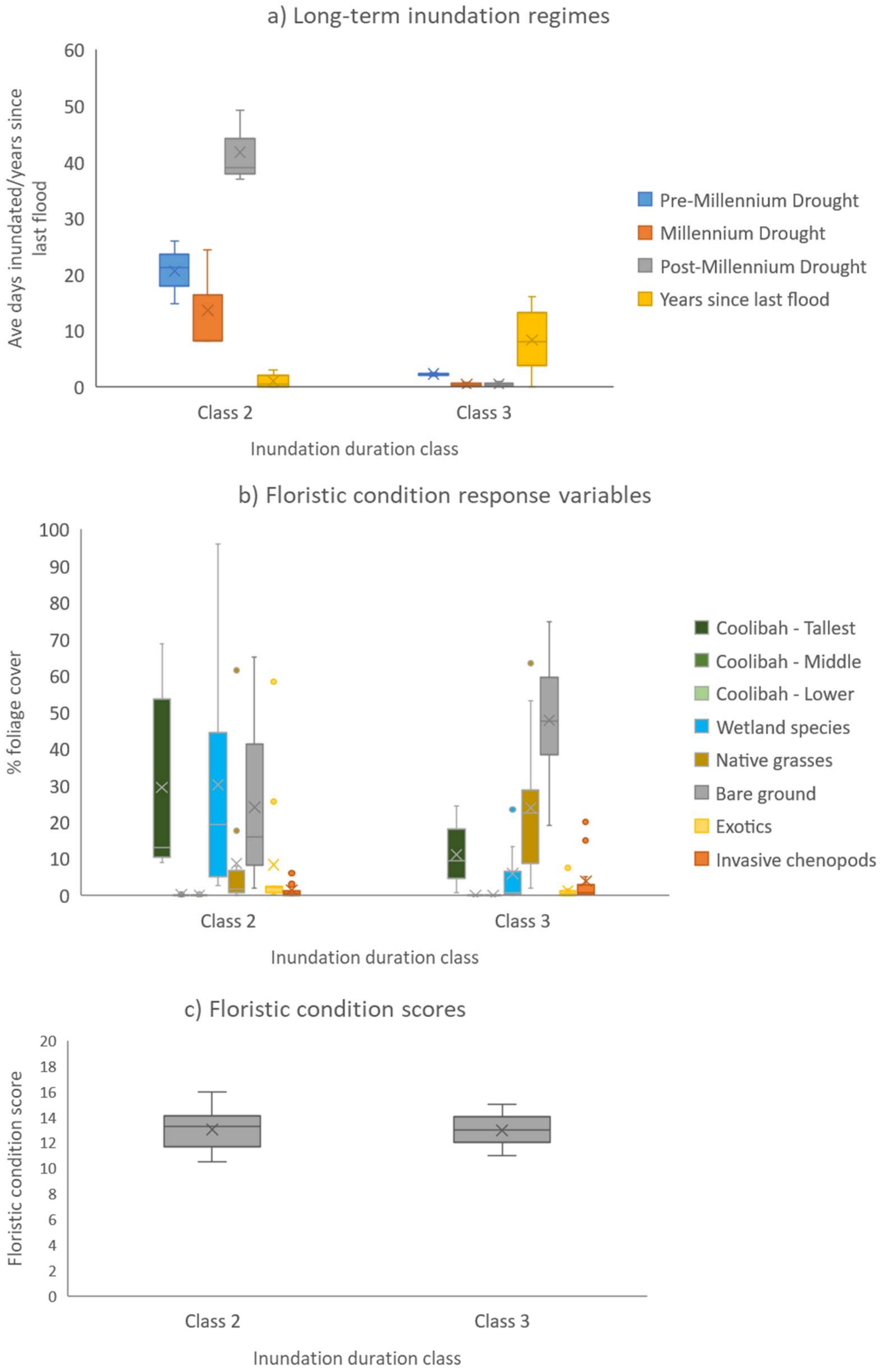


Figure 45 Distribution of inundation predictor variables, community condition response variables and condition scores – PCT 40

3.3.2 Testing of tree stand condition schemas

The inundation classes derived from the MRF analysis were slightly different used for floristic community condition analysis, as the clustering was performed on the tree stand condition variable data only and the clusters were ranked in order from longest to shortest average duration inundation in the MD-period instead of the Post-MD period. Long-term regimes were defined for the inundation classes by the mean of the average annual duration in the three-time periods (see Table 27).

3.3.2.1 River red gum forest and woodland, PCT 36/36A

For forest sites all inundation metrics are the same as for the floristic community clusters as the sites are the same and only one regime /inundation class was sampled. Sites of river red gum woodland were sampled in two regimes; Class 1; Moderate – Moderate (mapped as Intermediate in 2008) and Class 2; Moderate – Dry (mapped as Intermediate/ Poor in 2008) (see Table 27).

There was a significant difference between the mean average annual inundation duration in the forest sites and woodland sites in Class 1 ($P < 0.001, T = -3.33$) and Class 2 ($P < 0.001, T = -5.5$) and between the woodland sites ($P < 0.01, T = -3.3$) in the Pre-MD period. In the MD period there was a significant difference between the mean average annual inundation duration in the forest sites and woodland sites in Class 1 ($P < 0.05, T = -3.25$) and Class 2 ($P < 0.001, T = -5.88$) and between the woodland sites ($P < 0.01, T = -3.9$). In the Post-MD period there was a significant difference between the mean average annual inundation duration in the forest sites and woodland sites in Class 1 ($P < 0.001, T = -4.92$) and Class 2 ($P < 0.001, T = -6.37$) and a slight significant difference between the woodland sites ($P = 0.05, T = -2.52$) (Appendix 14a).

Table 43 Summary of average annual inundation duration (days), River red gum forest and woodland – PCT 36/36A, Pre-MD, MD and Post-MD periods

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought	Class 1 (Forest)	4	84.4###	12.2	24.5	48.9	59.1	92.1	102	104.5
(days)	Class 1 (Woodland)	13	54.57###	4.3	15.49	26	45.65	50.5	68.65	75.7
	Class 2 (Woodland)	7	30.29##	3.43	9.09	15.5	25.9	29.2	40.4	42
Millennium Drought	Class 1 (Forest)	4	59.38#	8.69	17.38	43.4	45.02	55.55	77.55	83
(days)	Class 1 (Woodland)	13	37.06###	3.07	11.08	24.3	28.3	35.7	44	61.4
	Class 2 (Woodland)	7	22.54##	1.45	3.85	17.8	18.7	22.8	26.1	26.8
Post-Millennium Drought	Class 1 (Forest)	4	118.75###	9.27	18.54	94.78	100.28	120.44	135.5	139.33
(days)	Class 1 (Woodland)	13	66.8###	4.53	16.32	41.11	54.83	64.33	79.56	102
	Class 2 (Woodland)	7	44.97#	8.36	22.13	22.56	34.11	36.78	53.67	90.56
Rate of change 1992 to 2008 (Index)	Class 1 (Forest)	4	-0.037	0.002	0.004	-0.043	-0.041	-0.036	-0.034	-0.034
	Class 1 (Woodland)	13	-0.053	0.004	0.016	-0.074	-0.070	-0.054#	-0.041	-0.027
	Class 2 (woodland)	7	-0.028	0.004	0.011	-0.042	-0.040	-0.025	-0.023	-0.012

# P<0.05, ## P<0.01, ### P<0.001

Forest sites had the longest mean average annual inundation duration in all three time periods overall. Woodland Sites in Class 1 had longer mean average annual inundation duration in all periods (54.57±4.3 days, 37.06±3.07 days and 66.8±4.53 days) than woodland sites in Class 2 (30.29±3.43 days, 22.54±1.45 days and 44.97±8.36 days). Both Class 1 and Class 2 woodland sites increased in median annual duration in the Post-MD period in relation to the Pre-MD period (Appendix 14a, Table 43 and Figure 46a).

There was a significant difference in the rate of change in inundation frequency in the MD period between woodland sites in Class 1 and sites in Class 2 ($P < 0.01, H = 9.31$), indicating that woodland sites in Class 1 had the most marked change in inundation frequency between the Pre-MD and MD periods (Appendix 14a, Table 43; Figure 46a).

As expected forest sites had a higher mean %FC (54.52±5.46%) and PAI (0.5452±0.0546), than woodland sites in Class 1 ($P < 0.001, T =-5.46$) and Class 2 ($P < 0.001, T = -7.78$) and was well within the diagnostic range for forest of 30 – 70 % FC (or

>0.3 - 0.7 PAI). Woodland sites in Class 1 had higher mean % FC (22.82±2.08 %) and PAI (0.2303±0.0208), than sites in Class 2 (14.88±2.5 %) and PAI (0.1488±0.025) ($P < 0.01$, $T = -3.67$). These were within the diagnostic range for woodland of 10 - 30 % FC (or 0.1 - 0.3 PAI). The medians for % DC, % LBA and % DL were not significantly different between the forest sites and the woodland sites, or between the woodland sites in either of the inundation regime classes (Appendix 14b, Table 44 and Figure 46b).

Table 44 Summary of tree stand condition response variables, River red gum forest and woodland – PCT 36/36A, 2010/11 – 2016/17

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Plant Area Index (PAI)	Class 1 (Forest)	17	0.55###	0.055	0.225	0.199	0.373	0.526	0.747	0.977
	Class 1 (Woodland)	57	0.23###	0.021	0.156	0.032	0.132	0.200	0.270	0.808
	Class 2 (Woodland)	34	0.15##	0.025	0.146	0.018	0.075	0.102	0.158	0.691
% Foliage Cover (FC)	Class 1 (Forest)	17	54.52###	5.46	22.5	19.85	37.32	52.55	74.74	97.71
	Class 1 (Woodland)	57	22.82###	2.08	15.53	3.15	12.45	19.96	26.78	80.77
	Class 2 (Woodland)	34	14.88##	2.5	14.59	1.75	7.54	10.23	15.77	69.05
% Live basal area (LBA)	Class 1 (Forest)	17	99.11	0.38	1.56	95.87	98.13	100	100	100
	Class 1 (Woodland)	57	94.41	1.16	8.73	63.64	91.09	100	100	100
	Class 2 (Woodland)	34	83.33	4.8	27.98	11.19	63.77	100	100	100
% Dead canopy (DC)	Class 1 (Forest)	17	18.79	2.84	11.71	1.82	9.94	16.09	25.89	44.57
	Class 1 (Woodland)	57	28.18	1.82	13.78	2.5	17.21	25.83	37.53	60
	Class 2 (Woodland)	34	29.3	4.76	27.74	0.15	5.55	14.44	44.92	88.89
% Dead limbs (DL)	Class 1 (Forest)	17	6.02	2.62	10.78	0	0	0	9.78	32.71
	Class 1 (Woodland)	57	10.23	1.61	12.17	0	0	6.25	17.88	50
	Class 2 (Woodland)	34	20.09	4.45	25.95	0	0	8.63	37.45	83.33
Condition Score	Class 1 (Forest)	17	17.18	0.52	2.13	13	16	17	19.5	20
	Class 1 (Woodland)	57	16.32	0.22	1.64	12	16	16	17	19
	Class 2 (Woodland)	34	14.97	0.77	4.47	3	11.75	17	18	19

P<0.01, ### P<0.001

Median condition score ranges were in the Intermediate category for forest and woodland sites in both classes. There was no significant difference in median tree stand condition scores between forest and woodland sites or between woodland sites in Class 1 and 2 (Appendix 14c, Table 44 and Figure 46c).

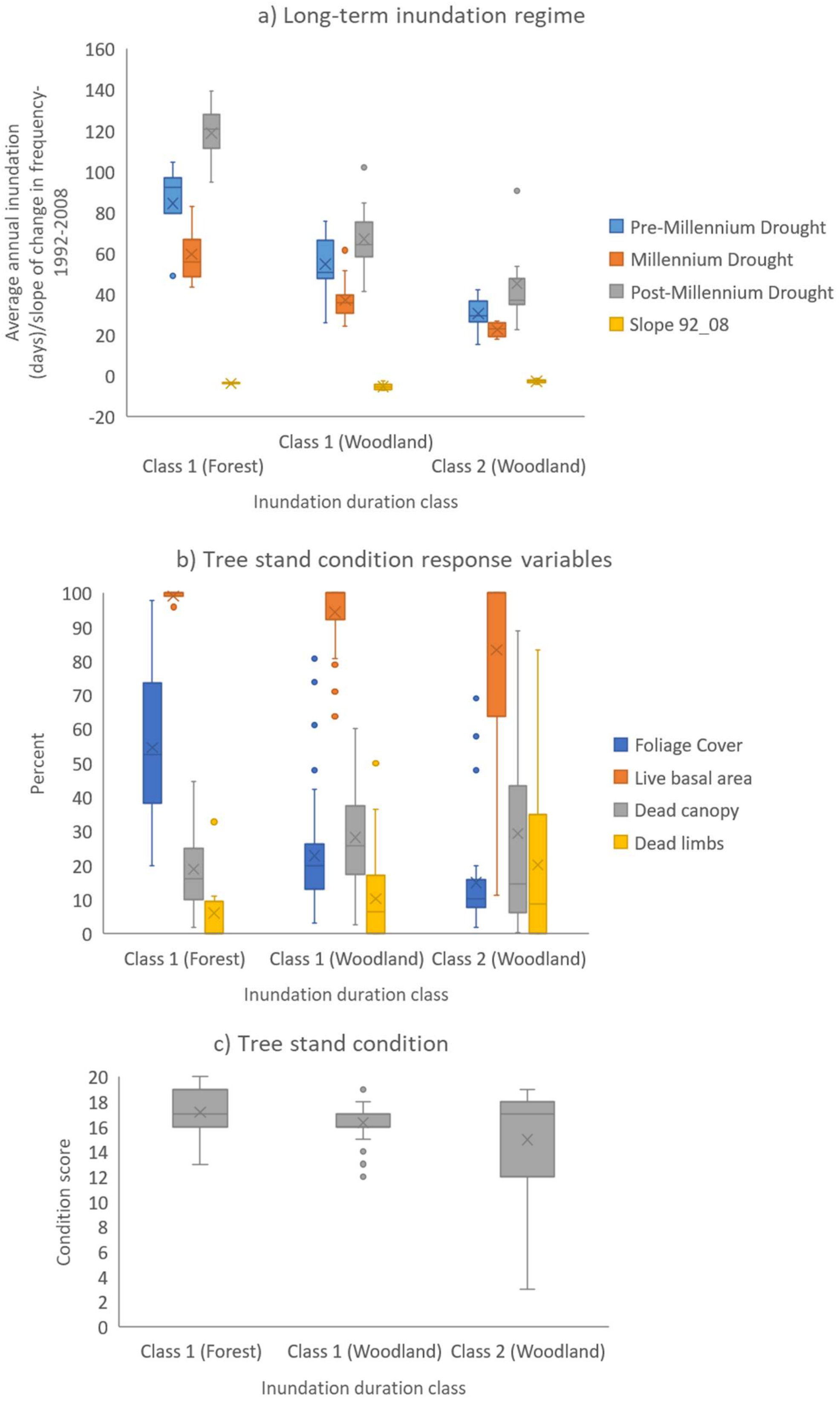


Figure 46 Distribution of inundation predictor variables, tree stand condition response variables and condition scores – PCT 36/36A

3.3.2.2 River red gum grassy woodland, PCT 454

Sites of river red gum grassy woodland were sampled in two starting inundation regimes; Class 1 and Class 2; Dry – Dry (mapped as Intermediate in 2008) and Class 3; Dry – Very Dry (mapped as Poor in 2008) (see Table 27). However, there was no significant difference between the means of average inundation duration, or rate of change in inundation frequency of sites in the three inundation classes in any of the time periods. There were very few sites sampled in this PCT and only one site sampled in Class 2 so results are indicative only. Sites in Class 3 received very little average annual inundation in any of the three time periods; 15.77±4.56 days, 2.40±1.22 days and 9.04±4.27 days respectively (Appendix 15a, Table 45 and Figure 47a).

Table 45 Summary of average annual inundation duration (days), River red gum grassy woodland – PCT 454, Post-MD period, Pre-MD, MD and Post-MD periods

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought	Class 1	2	20.45	4.15	5.87	16.30	*	20.45	*	24.60
(days)	Class 2	1	28.30	*	*	28.30	*	28.30	*	28.30
	Class 3	3	15.77	4.56	7.89	6.70	6.70	19.50	21.10	21.10
Millennium Drought	Class 1	2	12.30	10.50	14.90	1.70	*	12.30	*	22.80
(days)	Class 2	1	26.50	*	*	26.50	*	26.50	*	26.50
	Class 3	3	2.40	1.22	2.12	0.80	0.80	1.60	4.80	4.80
Post-Millennium Drought	Class 1	2	29.30	26.60	37.60	2.80	*	29.30	*	55.90
(days)	Class 2	1	36.78	*	*	36.78	*	36.78	*	36.78
	Class 3	3	9.04	4.27	7.40	0.89	0.89	10.89	15.33	15.33
Rate of change 1992 to 2008	Class 1	2	-0.033	0.007	0.010	-0.040	*	-0.033	*	-0.026
	Class 2	1	-0.025	*	*	-0.025	*	-0.025	*	-0.025
	Class 3	3	-0.008	0.004	0.007	-0.013	-0.013	-0.012	0.000	0.000

* Insufficient data

There was no significant difference between % FC and PAI between means of sites in Class 1, 2 or 3. The median values of % LBA were significantly lower for sites in Class 3 ($P < 0.01, H = 7.2$), compared to Class 1, but not significant different between sites in Classes 1 and 2 or Classes 2 and 3. Mean values for % DC were significantly higher for sites in Class 3

(*P = 0.001, T = 5.54*) than sites in Class 1, but not significantly different between sites in Classes 1 and 2 or 2 and 3. Sites in Class 1 had lower mean % DL (*P < 0.001, T = 5.31*) than Class 3 however, not between Classes 1 and 2 or Classes 2 and 3 (Appendix 15b, Table 46 and Figure 47b).

Table 46 Five-number summary of tree stand condition response variables, river red gum grassy woodland – PCT 454

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Plant Area Index (PAI)	Class 1	9	0.348	0.109	0.326	0.041	0.05	0.343	0.637	0.886
	Class 2	3	0.248	0.0304	0.0527	0.1937	0.1937	0.25	0.299	0.299
	Class 3	15	0.11	0.0376	0.1458	0	0.015	0.0304	0.2281	0.3939
% Foliage Cover (FC)	Class 1	9	34.8	10.9	32.6	4.1	5	34.3	63.7	88.6
	Class 2	3	24.76	3.04	5.27	19.38	19.38	25	29.9	29.9
	Class 3	15	11.15	3.76	14.58	0	1.5	3.04	22.81	39.39
% Live basal area (LBA)	Class 1	9	100	0	0	100	100	100	100	100
	Class 2	3	100	0	0	100	100	100	100	100
	Class 3	15	80.91	6.78	26.28	36.03	42.94	92.09##	100	100
% Dead canopy (DC)	Class 1	9	10.86	1.78	5.34	5	5.13	11.25	13.75	21.25
	Class 2	3	16.67	1.67	2.89	15	15	15	20	20
	Class 3	15	47.6###	7.47	28.93	11.7	22.86	41.87	80	93.33
% Dead limbs (DL)	Class 1	9	1.611	0.519	1.557	0	0	2.5	3	3.5
	Class 2	3	7.5	7.5	12.99	0	0	0	22.5	22.5
	Class 3	15	35.24###	9.09	35.2	0	0	36.05	83.33	83.33
Condition Score	Class 1	9	17.56	0.29	0.88	16	17	18	18	18
	Class 2	3	16.67	0.33	0.58	16	16	17	17	17
	Class 3	15	10.93#	1.48	5.74	0	4	14	14	18

# P<0.05, ## P<0.001, ### P<0.001,

The mean tree stand condition score was highest in the sites in Class 1 (17.56±0.29; Intermediate) and lowest in sites in Class 3 (10.93±1.48; Poor – Intermediate/poor), (*P < 0.05, T =-2.89*) there was no significant difference between mean tree stand condition scores between sites in Class 1 and Class 2 or between sites in Class 2 and Class 3 (Appendix 15c, Table 46 and Figure 47c).

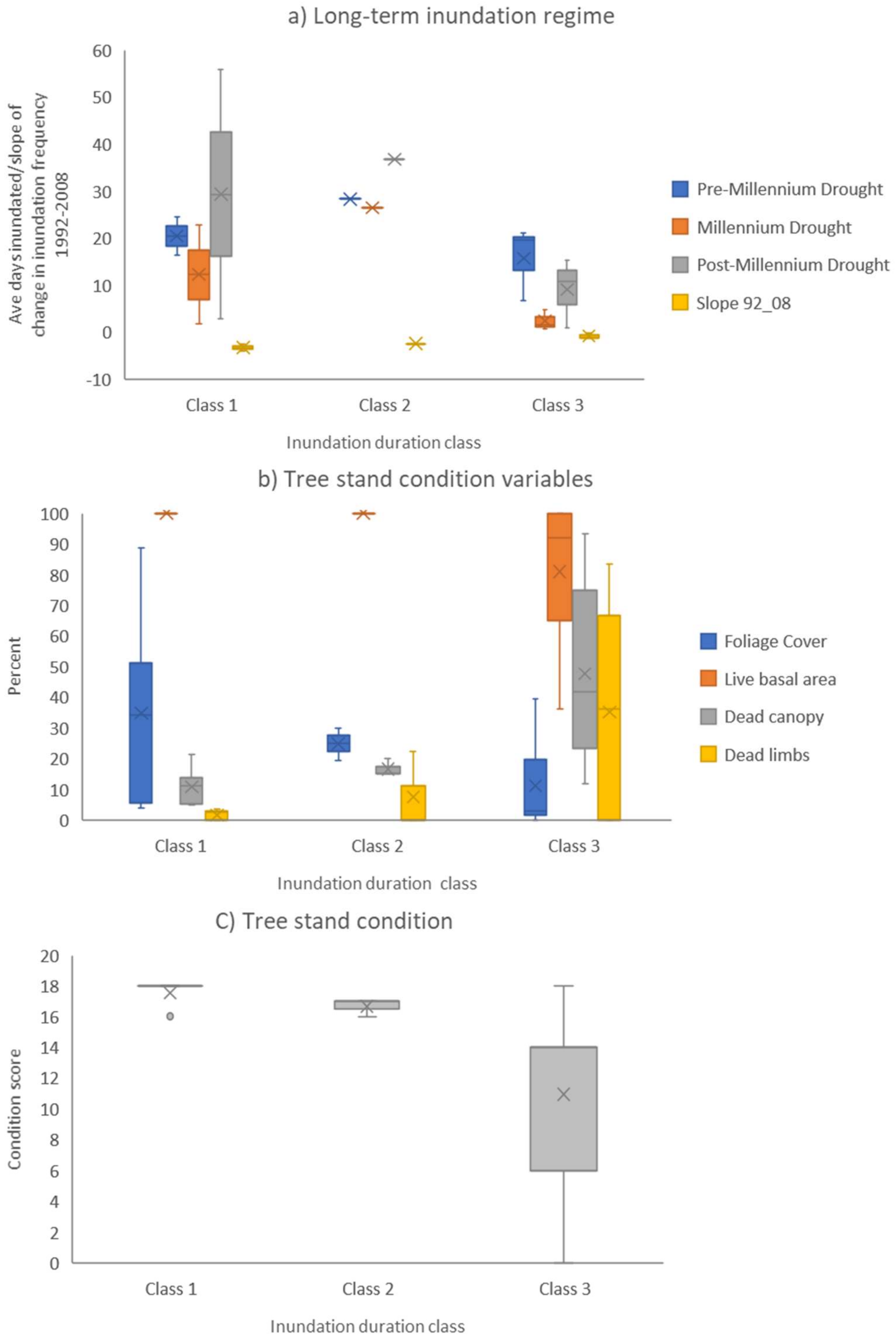


Figure 47 Distribution of inundation predictor variables, tree stand condition response variables and condition scores – PCT 454

3.3.2.3 Coolibah grassy woodland, PCT 40

Sites of coolibah grassy woodland were sampled in two inundation regimes; Class 2; Dry-Dry (mapped as Intermediate – Poor in 2008) and Class 3; Very Dry-Very Dry (mapped as Intermediate in 2008) (see Table 27 and Appendix 15). There were a very small number of sites sampled in this PCT (n=4) so the results are indicative only, There was no significant difference in the medians for annual average inundation between sites in the classes in any of the time periods. There was also no significant difference between the mean rate of change in inundation frequency between 1992 and 2008, however these results may be an artefact of the low value of n (Appendix 16a, Table 47 and Figure 48a).

Table 47 Five-number summary of tree stand condition predictor variables, coolibah grassy woodland – PCT 40

Time period	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Pre-Millennium Drought	Class 1	2	18.00	3.20	4.53	14.80	*	18.00	*	21.20
(days)	Class 3	2	2.25	0.35	0.50	1.90	*	2.25	*	2.60
Millennium Drought	Class 1	2	16.30	8.10	11.46	8.20	*	16.30	*	24.40
(days)	Class 3	2	0.40	0.40	0.57	0.00	*	0.40	*	0.80
Post-Millennium Drought	Class 1	2	43.06	6.17	8.72	36.89	*	43.06	*	49.22
(days)	Class 3	2	0.44	0.44	0.63	0.00	*	0.44	*	0.89
Rate of frequency change 1992 to 2008	Class 1	2	-0.015	0.003	0.004	-0.018	*	-0.015	*	-0.012
	Class 3	2	-0.009	0.004	0.005	-0.013	*	-0.009	*	-0.005

* Insufficient data

There was no significant difference between the means of % FC in sites in Class 1 and sites in Class 3. The means of %FC for both classes (30 ±12.5 and 12 .2 ±4.35 %) were within the diagnostic range for woodland (10 – 30% FC) but above the diagnostic range for PCT 40 (≤ 10 % FC) (see Section 3.3.1.7) (Table 47, Figure 48b).

There was no significant difference between the median value of %FC, % DC, %LBA or % DL between sites in Class 2 and Class 3 (Appendix 16b, Table 48, Figure 48b).

Not surprisingly given the above, there was no significant difference between the mean tree stand condition scores of sites in Classes 1 and 3. Both classes had mean scores in the Intermediate range; 17.6±0.6 and 17.4±0. 68 (see Table 26), (Appendix 16c, Table 48 and Figure 48c). Again results are influenced by the low value of *n*.

Table 48 Five-number summary of tree stand condition response variables, coolibah grassy woodland – PCT 40

Variable	Inundation Class	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Plant Area Index (PAI)	Class 2	5	0.3	0.125	0.281	0.09	0.098	0.105	0.599	0.687
	Class 3	5	0.122	0.0435	0.0972	0.0075	0.0258	0.1323	0.213	0.2438
% Foliage Cover (FC)	Class 2	5	30	12.5	28.1	9	9.8	10.5	59.9	68.8
	Class 3	5	12.2	4.35	9.72	0.75	2.58	13.23	21.3	24.38
% Live basal area (LBA)	Class 2	5	98.13	1.15	2.57	95.32	95.32	100	100	100
	Class 3	5	100	0	0	100	100	100	100	100
% Dead canopy (DC)	Class 2	5	17.2	6.89	15.42	0	2.5	15	33	34
	Class 3	5	9.2	2.68	5.99	3	3.83	10	14.17	18.33
% Dead limbs (DL)	Class 2	5	8	4.9	10.95	0	0	0	20	20
	Class 3	5	0	0	0	0	0	0	0	0
Condition Score	Class 2	5	17.6	0.6	1.34	16	16.5	17	19	19
	Class 3	5	17.4	0.68	1.52	16	16	17	19	19

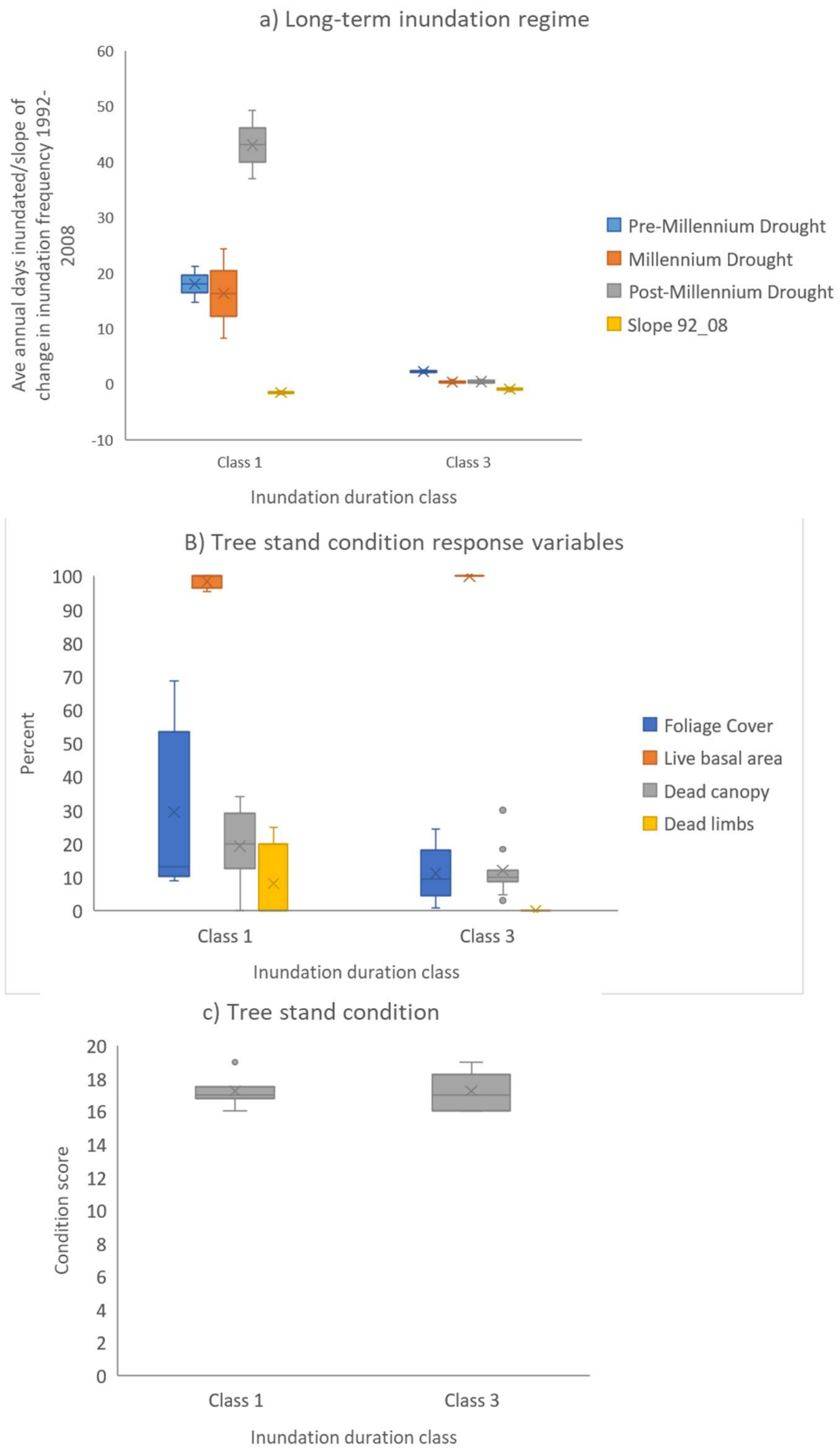


Figure 48 Distribution of inundation predictor variables, tree stand condition response variables and condition scores – PCT 40

3.4 Discussion

3.4.1 Performance of the floristic community condition schemas

3.4.1.1 Water couch marsh grassland floristic community condition

The dominant species of watercouch marsh grassland; *P. distichum* is an ATe species. In section 2.4.3.1, I discussed that the MRF analysis found that the mean % FC of ATe species was was lower in site clusters with shorter mean duration of inundation during the Post-MD period (see Sections 2.4.3.1). The modeling of the MRF outcomes showed that non-woody wetlands would have proportionally more cover of ATe species was highest in the moderate mean annual inundation regime (55.8 days) compared to the longest or shortest regimes (see Section 2.4.4.1.).

In the Post-MD period sites in the driest inundation class received an average of 9.33±2.45 days (≈1 to 2 weeks). This sites were in the Poor condition category, reflecting the expected score in response to sub optimal inundation regimes for this PCT, with lower median %FC of water couch (Poor scoring range - <10%) and higher median % cover of bare ground and median % FC of invasive native chenopods (though still within the benchmark range <10%). Sites in the inundation regime classes with the longer average annual inundation had median % FC of water couch in the Intermediate range (<10 – 10%), and were in the Intermediate condition category. These sites received on average 63.83±5.78 days (≈2 months) to 113.2±10.6 days (≈3 months). This is less than the recorded inundation requirements of 4 to 6 months (Casanova 2015), or 5 to 8 months (Roberts and Marston 2011). The conditon class schema was very able to distinguish between sites in different condition classes. The underlying hypotheses regarding the response variables within the condition class schema for PCT 204 were well demonstrated by the data.

3.4.1.2 Mixed marsh sedgeland floristic community condition

The dominant species of mixed marsh sedgeland; *Eleocharis* spp. *Cyperus* spp. and *Juncus* spp., are all ATe species and therefore they would be expected to respond to moderate inundation regimes as outlined in Sections 2.4.3.1 and 2.4.4.1.

The sites in the driest inundation class had a median floristic community condition score in the Poor category (10), reflecting the expected score in response to sub optimal inundation regimes for this PCT. The mean %FC of WPF species was in the Intermediate/poor range (<40 – 10%) in the sites in the lowest inundation duration class. Median % FC WPF species was in the Intermediate scoring range (<80 – 40%) in sites with longer average annual inndation (<80 – 40%). Sites in the driest class had median % FC of exotic species in the Intermediate range (>10 - <50), while sites with longer average annual inundation had median % FC of exotic species and invasive native chenopods in the benchmark range (<10%). The sites in the Intermediate condition category received on average 36.4±10.8 days (≈1 to 1.5 months) to 118.47±4.21 days (≈3 months) annual inundation and the sites in the Poor category received an average of 5.93±3.53 days (≈1 week).

Although the mean %FC of WPF species were not significantly different in sites in the two wettest inundation regime classes, the sites in the Class with the longest mean annual inundation duration in the Post-MD period (Class 1), were dominated by one species (40.05% of total % FC WPF species), water couch (*P. distichum*), rather than exhibiting the mix of species of sedges and rushes in the families Cyperace and Juncaceae that is diagnostic of PCT 53. These sites may be changing over time in the Post-MD period and it is possible that they may become more similar to water couch marsh grasslands (PCT 204) if the increase in the average annual inundation duration experienced in the Post-MD period continues. Therefore, an analysis of the dominant species comprising the % FC of WPF species should be undertaken when assessing condition for sites of this PCT. The the condition scoring schema needs to be changed to place more weight on the %FC of the diagnostic families for PCT 53; Cyperaceae and Juncaceae with a score afforded proportionally to the proportion of sedges and rushes in the total % FC of WPFspecies. An eample is: a site that consisted of 43% watercouch and 57% sedges and rushes (also with 0% bare ground; score = 4, 0% FC exotic species; score =4 and 0% invasive native chenopods; score=4) would score in the Good-to benchmark category for % FC of WPF species (i.e.100% FC WPF species = ≥80%= score of 8). So the score would be 8+4+4+4=20. However as the proportion of sedges and rushes is only 57% of the total % FC of WPF species the score is ammended to 6 (i.e <80 -40% = 6) and thus, the plot gets a final score of 6+4+4+4=18 (Good) instead of 20 (Excellent). This will allow the condition scoring schema to distinguish between sites where the vegetation is diagnostic of PCT 53 and sites where the vegetation is less diagnostic or even transitioning to another vegetation community.

Sedge species such as common spike rush (*Eleocharis acuta*) has been recorded as requiring annual flooding with duration of 3 to 10 months, while *Cyperus exaltatus* requires annual flooding with duration 135–200 days (8 months) (OEH 2012). Tall spikerush (*E. sphaceolata*) is recorded as requiring inundation annually for 6 to 8 months (Williams and Ridpath 1982). The results of this study indicate that while the published water requirements may be accurate for individual species of sedge, they are probably overestimates for PCT 53 as a whole. The condition schema score reflects the dominance of % cover of bare ground and the reduction in the indicator WPFG species in response to sub-optimal inundation regimes for this PCT. The scoring system was adequately able to reflect the condition of sites. However, sites that were in an inundation class that had parameters that fell between Classes 2 and 3 would further test the condition schema.

3.4.1.3 Floodplain grassland floristic community condition

Sites of floodplain grassland were sampled one inundation regime and there were very few sites sampled (*n*=8). This data limitation does not allow full testing of the condition class schema. However although the ranges hypothesised for floodplain grassland response variables were not fully tested due to lack of data, the condition schema adequately reflected the sub-optimal condition of the sites sampled. The median % FC of native grasses and % FC of WPF were in the Poor scoring range (<10%) and the % median cover of bare ground were in the Intermediate scoring range (>10 - <50). The mean floristic community condition scores for sites in both classes in the Intermediate/poor range. More sampling of this PCT in multiple inundation regimes would assist in further testing the schema.

3.4.1.4 Lignum shrubland floristic community condition

Lignum (*D. florulenta*) is an ATw species and is most commonly a middle stratum species as it is generally taller than 1 m. The results of the MRF analysis found that the percentage cover of species in the ATw group in the middle stratum was higher in clusters of sites that had received moderate flooding duration during the three time periods (Pre-MD, MD and Post-MD) (see Section 2.4.3.2). Modelling of the MRF results predicted that in the middle stratum, the percentage cover of ATw species was highest in the longest and moderate duration inundation regimes (see Section 2.4.4.2).

Sites of lignum shrubland were sampled in two inundation regimes. There were only a very small number of samples in each class (*n*=4 and *n*=8). This data limitation does not allow full testing of the condition class schema. However, although the ranges hypothesised for lignum shrubland response variables were not fully tested due to lack of data, the condition schema adequately reflected the condition of the sites sampled. The mean % FC of lignum was in the Intermediate scoring range (<40 – 20 %) and although data limitations only allow the results to be indicative all other response variables are within the good to intermediate scoring ranges of the condition class schema.

Sites in both classes were in the Intermediate to Good range for floristic community condition and had received a mean average inundation duration of 84.56±5.7 days (≈3 months), and Class 2 received a mean of 49.44±2 (≈ 1.5 months). Published sources record that lignum requires an average flood duration of 1 to 6 months every 1 in 3 years (Casanova 2015). More samples in each inundation class would assist with further testing the condition class schema for lignum shrubland.

3.4.1.5 River red gum forest floristic community condition

Three river red gum communities in the Marshes were sampled; river red gum forest with wetland plant understorey, river red gum woodland with a wetland plant understorey and grassy woodland. Inundation frequency has been found to determine the floristic composition of the understorey in river red gum communities, e.g. tall forest with mainly sedge understorey at Barmah Forest had a median flooding frequency of 55 to 73 per cent of years; while shorter forest with native grass understorey had a median flooding frequency of 36 % of years (Bren and Gibbs 1986).

In this study river red gum forest was only sampled in one starting inundation regime; Moderate/Wet –Moderate. In the Post-MD period the forest sites received 2.5 to 3 months mean annual inundation (Wet regime). The optimum water regime identified for river red gum forest with a sedge understorey in Victoria is a frequency of 7 years in 10, for a minimum of 4 to 7 months, with a maximum dry interval of 3 years (DSE 2008). Although the majority of ecological studies have been done in the southern part of the Murray–Darling

Basin and are strongly focused on floodplain forests, the findings are relevant throughout the Murray–Darling Basin, (Roberts and Marsden 2011). Roberts and Marsden (2011) propose that a suitable water regime for river red gum forest is inundation about every 1 to 3 years for about 5 to 7 months.

The forest sites had greater % FC of RRG in the tallest and middle strata than the woodland sites. % FC in the tallest stratum was within the benchmark range (≥ 30%) and the % FC RRG in the middle stratum was in the Intermediate range (<5 -0.5%) in the condition class schema for RRG forest. The % FC for RRG in the lower stratum was in the Intermediate/poor range (<0.5 - >0) so affected the final condition score. The %FC of WPF species was in the benchmark range (≥40%). The medians for % cover of bare ground, % FC of exotic species and %FC of invasive native chenopods were all within the benchmark ranges. The median floristic condition score is in the Good range (18). Thus the condition class schema performs according to the underlying hypotheses regarding the response variables. The inclusion of forest samples in other inundation regimes will be required for a definitive test. However, river red gum forest usually occurs near permanent watercourses in the Marshes and therefore the influence of in river flows on condition is a confounding factor in any experimental design.

3.4.1.6 River red gum woodland with wetland understorey floristic community condition

Sites of river red gum woodland were sampled one starting inundation regime (Moderate – Moderate) with two starting conditions; Class 1 mapped as Intermediate and Class 2 mapped as condition Intermediate to Poor. In the Post MD period sites in Class 1 received approximately 2 months of inundation annually (Moderate regime) while sites in Class 2 received an average of 3 months inundation every 0-2 years (Moderate/Wet regime). Roberts and Marsden (2011) record the flooding regime required for river red gum woodland sites as about every 2 to 4 years for about 2 to 4 months although this was derived from data from the southern MDB.

Sites in both classes had no difference in their means of % FC RRG in the tallest stratum and the mean was within the Intermediate range (<30 -10%) in the floristic condition class schema for PCT 36A. The median % FC of RRG in the middle strata and lower stratum was in the Intermediate/poor to poor ranges. This affected the median of the final floristic condition scores of sites in both classes.

Sites in both classes had median % FC of WPF species approximately in the intermediate score range (<40 – 15%) and median % FC of exotic species in the benchmark range (<10%), although the spread of this variable was very great in both classes. Sites in Class 1 had a greater median % cover of bare ground (<30 – 50% - Intermediate range) than sites in Class 2 (<10% – benchmark range) and this would affect the final condition scores. Sites in class 2 had a greater median % FC of invasive native chenopods than Class 1 however, the levels for sites in both classes were very low and within the benchmark range (<10%). Both sites in Class 1 and Class 2 had a median floristic community condition scores in the Intermediate range. Thus, the hypotheses contained within the floristic condition schema were reflected in the data analysis for these sites and the schema performed as expected. However, more sites in other regimes would help to test the schema more rigorously.

3.4.1.7 River red gum grassy woodland floristic community condition

The sites in both classes had mean %FC of RRG in the tallest stratum in the benchmark range (≥10%) in the floristic condition schema for PCT 454. Sites in both class had % FC of RRG in the middle and lower stratum in the Intermediate/poor range. The mean % FC for WPF species for sites in both classes was in the Intermediate range. Medians for %

FC native grasses was in the Poor category in both classes, means for % FC invasive native species were in the benchmark range and medians % FC exotic species varied from benchmark to Intermediate range.

In Victorian woodlands, river red gum woodland with a grass or shrub understorey was found to have an optimum water regime of inundation three to four times in 10 years, for up to 2 months, and a maximum dry interval of 5 to 7 years (DSE 2008). The river red gum grassy woodland sites sampled received two regimes classes in the Post-MD period; 7.47±3.4 days (1.5 weeks) and 46.33±9.56 days (1 to 2 months) mean average annual inundation in the Post-MD period The mean floristic condition scores were in the Poor to Intermediate/poor range (12.14±0.61 and 11.5±0.36). This indicates that most river red gum grassy woodland sites sampled in the Marshes in the Post-MD period were not receiving adequate inundation. The condition class schema reflects the underlying hypotheses regarding the response variables, however as there were very few sites sampled in either class (*n*=2) and (*n* = 6), it is likely that the analysis was constrained by lack of data and any differences between the classes could not be adequately assessed. Sampling additional grassy woodland sites in both inundation regimes is required to further test the condition schema.

3.4.1.8 Coolibah woodland floristic community condition

Sites of coolibah grassy woodland were sampled in two regimes; Moderate/Dry-Dry- and Very Dry-Very Dry). Sites in inundation Class 2 had a regime of inundation for 1 to 1.5 months every 1 to 2 years and sites in Class 2 had a regime of negligible inundation every 8 to 13 years (basically no inundation). Condition scores were similar for both Class 1 and 2 with condition scores in the Poor to Intermediate/poor range.

Coolibah trees are known to utilise groundwater (Payne et al. 2006; Forster 2015) and therefore can persist in floodplains were inundation frequency is very variable. However, the understorey wetland species require frequent inundation to be in good condition. The condition class schema adequately reflects the understorey condition however; more sampling in this PCT is required to test the schema. It is hypothesised that that two different PCTs have been sampled in the experimental design; PCT 40 and PCT 39. PCT 39 is usually characterised by the presence of lignum and river cooba in the middle stratum (OEH 2018b). While lignum and river cooba were absent from the sites surveyed in the Marshes, the presence of amphibious wetland species in the understorey and the difference in the frequency of inundation in the Pre-MD phase between the Class 2 and Class 3 sites indicate that the two classes may be indicative of two different PCTs with different understorey species assemblages, rather than the same PCT in two different classes. More sampling is required to test both this hypothesis and the condition schema.

3.4.2 Performance of the tree stand condition schemas

This MRF analysis found that the average duration of inundation during the MD period was the most important variable for predicting the percentage cover of the river red gum in the tallest stratum and that inundation duration during the MD period was the most important predictor variable for the tree stand condition response variables; PAI, %Dead canopy, % Dead limbs and %Live basal area (see Section 2.4.5 and 2.5.2). When modelled against inundation scenarios, all tree stand condition response variable scores were predicted to be higher under the wetter scenario (see Section 2.4.7) and this trend underpins the tree stand condition schema.

3.4.2.1 River red gum forest tree stand condition

The MRF predictor variable importance analysis found that inundation duration in the pre-MD period was the most important variable for predicting the % FC in the tallest stratum of ATw species such as river red gum (see Section 2.4.2.3). The MRF inundation predictor variable analysis found that mean number of days of inundation during the MD period was the most important variable, but duration in the Pre-MD and post-MD periods was also important for the tree stand condition response variables (see Section 2.4.5).

MRF clustering analysis by wetland type found that river red gum forest sites were in clusters that had the highest frequency of inundation in the pre-MD and second highest in the MD periods, compared to woodland sites (see Section 2.4.3.3).

Data from the southern MDB indicates that the average inundation frequency recorded for river red gum forest trees is one in three years, with an average duration of 1 to 7 months, and a maximum of 2 years (Roberts and Marsden 2011). Along the River Murray, river red gum forests experienced a natural average return interval (ARI) of one to two years, to one to three years (Overton and Doody 2007). For example, Barmah Forest received inundation 92 % to 46 % of years (Leitch 1989). River red gum forest on the Chowilla floodplain was naturally inundated in 83 per cent to 49 per cent of years (Sharley and Huggan 1995), with durations of river flow an average of 4.6 to 3.6 months on the Chowilla floodplain, and from an average of 5.2 to 1.2 months per year for Barmah Forest (Leitch 1989, Sharley and Huggan 1995).

River red gum forest sites in the Marshes received annual inundation of ≈4 months in the Post-MD period and had received ≈2 months mean average annual duration in the MD period and ≈3 months mean average annual inundation in the Pre-MD period. This is within is within the recommended range of inundation requirements for river red gum forest although at the lower end.

In this study the forest sites had greater % FC of RRG (canopy) than the woodland sites. The mean % FC was within the Intermediate/poor range for scoring (PAI of <0.7 – 0.5).

The median % LBA of forest sites was in the Excellent to Good (benchmark) range (≥80%). Median %DC was in the Intermediate range (>10 -40%), median %DL was in the benchmark range (≤10%). The median floristic condition score is in the Intermediate range (17). This is largely due to the %FC/PAI and %DC scores. Thus the condition class schema performed according to the underlying hypotheses regarding the response variables.

The inclusion of forest samples in other inundation regimes is desirable for a definitive test. However, river red gum forest usually occurs near permanent watercourses in the Marshes and therefore the influence of in river flows on condition is a confounding factor in any experimental design.

3.4.2.2 River red gum woodland tree stand condition

As with river red gum forests, the MRF analysis results found that inundation duration in the pre-MD period was the most important variable for predicting the % FC in the tallest stratum of ATw species such as river red gum (see Section 2.4.2.3) and mean number of days of inundation during the MD period was the most important variable, but duration in the Pre-MD and post-MD periods was also important for the tree stand condition response variables (see Section 2.4.5). The values for the rate of change of inundation frequency in Class 1 sites was lower (more negative) indicating that these sites had had a faster rate of change in inundation frequency in the MD period than the Class 2. Class 2 sites were drier (i.e. had a shorter average annual inundation duration) in the Pre-MD period. Rate of inundation change was found to be the most important is the predictor variable for PAI/%FC (see Section 2.4.5) and this might account for the sites in Class 1 not having a significantly different condition score to sites in Class 2 in the Post-MD period as more resources were required to regain canopy health in Class 1 sites.

All other tree stand condition response variable values were in the same categories as for the forest sites (above) in the tree stand condition class schema (see Section 3.2.2.1).

Sites of river red gum woodland were sampled in two regimes; Moderate-Moderate/Dry and Moderate/Dry-Moderate/Dry. Sites in Class 1 received ≈2months annual duration and sites in Class 2 had average inundation of in ≈1month in the Pre MD period, and decreased to 1 month (Class 1) and ≈3 weeks (Class 2) in the MD period. In the Post-MD period sites in Class 1 received ≈ 2.3 months and the sites in Class 2 received a≈ 1.7 months average annual inundation. Recorded inundation regimes for river red gum woodlands in the southern MDB are about every two to four years for about two to four months (Roberts and Marsden 2011). Thus the woodland sites in the study received inundation regimes at the lower end of this range in all three time periods. The condition scores for both Class 1 and Class 2 sites had median values in the Intermediate range, reflective of the inundation regimes they had received. These results indicate the condition class schema reflects the underlying hypotheses regarding response of tree stand condition variables to inundation regimes for river red gum woodland. More sites in woodland sites in class 2 would assist with testing the schema further.

3.4.2.2 River red gum grassy woodland tree stand condition

The optimum inundation regime for river red gum grassy woodland is recorded as less than five in fifteen years with duration of two to seven months (Roberts and Marsden 2011), or three to four times in 10 years, for up to 2 months, and a maximum dry interval of 5 to 7 years (DSE 2008). River red gum grassy woodland sites in the Marshes were sampled in two starting inundation regimes; Dry-Dry and Dry-Very Dry. In the MD period, Class 1 sites received 2 weeks on average every 1 to 1.5 years, sites in Class 2 received less than one-month inundation on average every 3 to 3.5 years and Class 3 received 2 days. The sites in

Classes 1 and 2 received an average annual inundation that was within the published range in the MD period whereas sites in Class 3 received almost no inundation. The MRF clustering analysis by wetland type found that in river red gum grassy woodland, tree stand condition variable scores were lower in clusters with lowest mean days flooded during the MD (see Section 2.4.6).

Means for %FC and PAI were significantly lower (Intermediate range) in the sites in the driest class than the other two classes and the medians for %DC (Intermediate/poor range) and %DL (Intermediate range). Median for % LBA were also lower in Class 3 though still within the good to benchmark range (≥80%). The mean tree stand condition scores for sites in Classes 1 and 2 were in the Intermediate range. Sites in Class 3 had a mean condition score in the Poor range. There were very few sites sampled in this PCT and only one site sampled in Class 2. Considering this the condition class schema followed the underlying hypotheses for tree stand condition variables for PCT 454 and assigned condition scores appropriate to the inundation regime history of the sites, even though the numbers of samples in Classes 1 and 2 were low. More sites in all inundation regimes are required for further test the tree stand condition schema for this PCT

3.4.2.3 Coolibah woodland tree stand condition

Although coolibah grassy woodland was sampled in two distinct inundation regimes; Dry-Dry and Very Dry-Very Dry, there were too few sites to enable any differences between the inundation classes to be determined, although sites in Class 2 had 2 to 3 weeks of inundation on average every 6 months to two years and sites in Class 3 had negligible inundation. The distribution of coolibah woodlands suggests that an inundation frequency of 1 in 10 to 20 years for several weeks is required (Foster 2015; Casanova 2015).

Median values for %FC, PAI, %LBA and %DL were in the benchmark range for sites in both classes while %DC was in the Intermediate range for sites in Class 2. Median values for condition scores were in Intermediate range for sites in both classes. While the condition class schema appears to have been effective there are two few sites in each class and further sampling is required for this PCT. Also as discussed in Section 3.5.1.8 it may be that two different PCTs with different inundation requirements, rather than the same PCT in two different classes have been sampled.

Chapter 4 Building ecological reference models for water-dependent vegetation communities in inland floodplain wetlands: Macquarie Marshes case study

4.1 Introduction

Most inland floodplain wetland vegetation communities in NSW, including the Marshes, have been degraded due to human-induced hydrological change over the last five decades. Therefore, meeting the objectives of the Basin Plan for water-dependent vegetation (MDBA 2014a) is essentially an exercise in ecological restoration. Ecological restoration is '*the undertaking intentional activities that seek to permanently change human-modified ecosystems, so they possess a range of more desirable attributes, such as a more appropriate species composition'* (Brudvig 2011). Historically, ecological restoration has been dominated by local-scale efforts with unpredictable outcomes mostly due to aiming for static endpoints, usually reference conditions (Hobbs and Norton 1996; Hobbs 2007; Hobbs and Suding 2009).

Ecological reference models (ERMs) provide advantages to ecological restoration by quantifying not only reference conditions, but also a range of degraded or sub-optimal states. Data-driven ERMs that incorporate both the consequences (e.g., altered species compositions), and causes of degradation (e.g., altered inundation regimes) can better identify factors that drive degradation of flood-dependent plant communities, help to prioritize restoration and management activities, and increase the odds of meeting the goals of restoration strategies, especially when the benchmark or reference condition cannot be met (Brudvig et al. 2014). Usually, ERMs are usually a minimally disturbed model (MDM), depicting the structure and function of the biota in the absence of significant disturbance, while acknowledging that it is usually impossible to completely avoid the influence of human activities (Paller et al. 2014).

ERMs were developed for each of the eight plant community types (PCTs) using Generalised Linear Mixed modelling (GLMM) to assess what inundation regimes each flood-dependent inland floodplain wetland plant communities need to be maintained in 'good to excellent' (i.e. 'reference') condition. These ERMs are based on 'relevant scale ecological communities' (Bestelmeyer et al. 2003), in this case flood-dependent (PCTs), and incorporate drivers of ecosystem degradation by linking site conditions to factors associated with degradation, in this case inundation duration and frequency predictor variables.

The optimal time-scale for modelling inundation was determined by modelling all possible time-scales and choosing the time scale contained in the model with the greatest likelihood. Using 'optimum regime' outputs from these models, water managers can operationalise these, by converting them to water delivery strategies. Thus, they will be able to plan their management actions to achieve specific outcomes for plant community and tree stand condition for each Plant Community Type (PCT) targeted for delivery of environmental water and meeting the objective of NSW under the Murray-Darling Basin Plan (Basin Plan), to; '*protect, sustain and/or improve the health of inland wetlands and floodplains in NSW*'

4.2 Methods

4.2.1 Data collection and preparation

Floristic condition variable data were collected from 74 plots in the Marshes from 2007/07 to 2016/17 (see Section 2.2.3). Tree stand condition data was collected from 40 of those sites from 2010/11 to 2016/17 (see Section 2.2.5). Full survey methods are at Appendix 3. Raw floristic data was transformed into condition variable data for each site. Each species was assigned to a WPFG. Species percentage cover data for each site was summed for each WPFG, calculated separately for each stratum and exotic species by stratum and percentage cover of bare ground was averaged for each site for each year (see Section 2.3.1.2 and Appendix 3).

Tree stand condition data was transformed into tree stand condition variable data. Percentage dead canopy and percentage dead limbs plot data was averaged for each replicate for each site. Percentage live basal area for the plot was calculated from the sum of the DbH of all live trees converted to basal area, divided by the sum of the DbH of all trees converted to basal area, and then averaged for the site. Plant Area Index (PAI), was calculated from percentage foliage cover of the plot × area of the plot, and divided by the total area of the plot. PAI plot data was then averaged for each site for each year (see Section 2.3.1.3 and Appendix 3).

4.2.2 Assigning floristic community and tree stand condition scores to sites

For each PCT, the response variables were site floristic community condition scores and tree stand condition scores, derived from site data collected during the Post-Millennium drought period (post-MD) (2008/09-2016/17). As part of this study, floristic and tree stand community benchmarks and condition classes for eight flood-dependent PCTs were developed (see Chapter 3). A set of functions were written into a *Microsoft Excel* macro enabled workbook to automate the calculation of floristic community ad tree stand condition scores using the condition class rules. The floristic community and tree stand condition from each sampled plot at each survey site for each year was run through the program to collate the percentages of the condition indicators for each PCT. The program then assigned the final score for the site depending they fell within (see Section 3.2.3.5).

4.2.3 Inundation predictor variables

Inundation predictor variables were derived from the annual inundation duration (number of days per year) for each site in the period 1987/88 to 2016/17 (see section 2.3.1.1). For the GLMM annual inundation duration data from each site, were transformed into data of average inundation at all possible time-scales (e.g. 1-year, 2-year, 3-year, …, 20-year average).

Other predictor variables modelled were; *Years since last flood* (i.e. in each year the number of years prior to that year that annual inundation duration = 0) and *Rainfall*; annual total rainfall, averaged from the nearest seven stations in the period 1988/09 to 2016/17.

4.3 Ecological Reference Models

4.3.1 Optimising time-scale for water regime of each plant community

Some plant communities, particularly those with long-lived tree species, respond to water regimes at time scales of longer than one year. To allow long-term water regimes to be used as predictor variables, the water regime was calculated at a range of time scales for each sample (site/year). These data were derived from data of 'number of days flooded per year'. For example, for a community condition sample, taken in 2005, the average number of flooded days per year at that site was calculated for the preceding 2 years (2004–2005), 3 years (2003–2005), 4 years (2002–2005), 5 years (2001–2005), and every annual time scale up to the maximum allowed by the data (1989–2005).

Inundation data commenced at 1988/89, so the number of time scales calculated was dependent on the number years between 1988/89 and when a sample was taken. Two further steps were undertaken to determine which time scale(s) of inundation were used in a predictive model. The 'optimal time-scale' for modelling inundation was determined by modelling all possible time-scales and choosing the time scale contained in the model with the greatest likelihood (lowest AIC).

4.3.1.1 Identifying correlation between inundation time-scales

Multiple time scales for water regime were used as predictors in a single model if not highly correlated. For each PCT, a matrix of correlations between water regime time scales was produced. Highly correlated time scales were those where the Pearson correlation > 0.6 (coloured red in Figure 49), and the two variables were not used in the same model. Correlations of less than 0.6 were acceptable and both variables were used in the same model. Generally, time scales longer than five years were not highly correlated with the one-year time scale, and both were used in a single model if desired. This was assessed individually for each PCT.

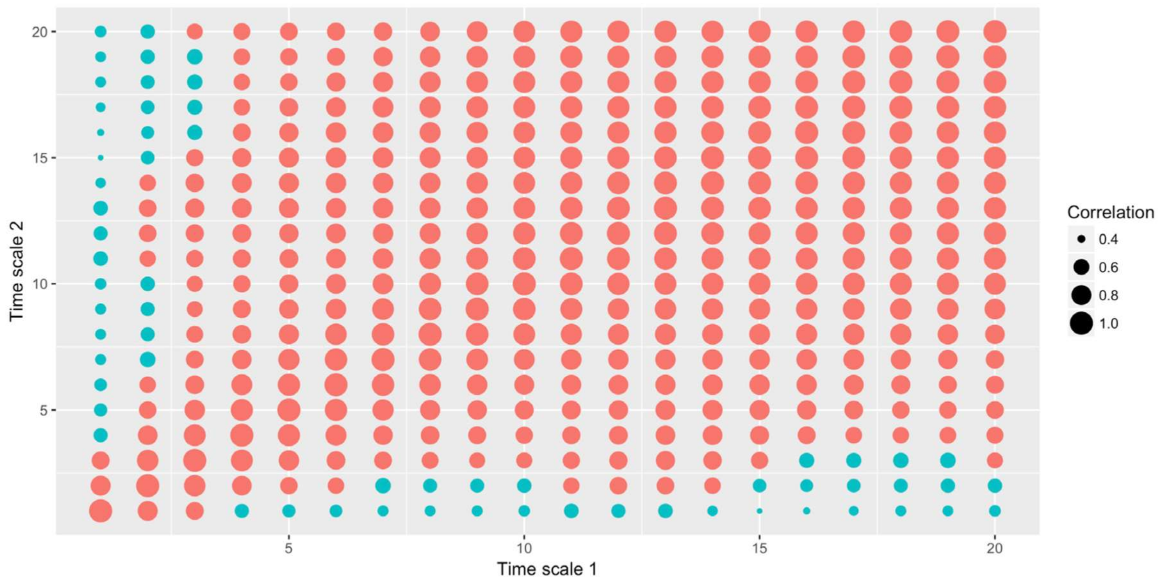


Figure 49 Correlations between flood data calculated at various time-scales

4.3.1.2 Optimal inundation time scale for each PCT

To determine the optimal inundation time scale for each PCT, a separate model was produced for each time scale, and models were compared for the amount of variation explained by each (Figure 49). Models were linear mixed effects models, with a random effect for site. Models with lower Akaike Information Criterion (AIC) explained more variation, though models less than 2 AIC apart were approximately equivalent in explanatory power. The optimal inundation time interval was selected from the model with the lowest AIC (Table 49). If the optimal inundation time scale was not correlated with the one-year water regime, both were used as predictors. If they were correlated, only the only the optimal time scale was used.

Table 49 The inundation time scales with lowest AIC

Wetland Type	PCT	Timescale (years)	AIC	Response
River red gum forest	36	12	65.5	Community condition
River red gum grassy woodland	454	3	57.3	Community condition
Flood-dependent woodland	40	3	57.3	Community condition
Mixed marsh sedgeland	53	2	325.5	Community condition
River red gum woodland	36A	2	334	Community condition
Water couch marsh grassland	204	1	334	Community condition
Floodplain grassland	214	1	67.1	Community condition
Shrubland wetland	247	4	85.9	Community condition
River red gum grassy woodland	454	4	132.8	Tree stand condition
Flood-dependent woodland	40	5	107.1	Tree stand condition
River red gum woodland	36A	6	439	Tree stand condition
River red gum forest	36	10	81.3	Tree stand condition

4.3.1.3 Removing correlated variables

For each model, correlations between all continuous predictor variables were inspected prior to modelling (see section 4.3.1.1). If a correlation above 0.6 was found between any two predictor variables, the least important of the variables was excluded from the analysis. If the optimal time-scale inundation data were correlated with the annual inundation data, the optimal time scale was used. Flood data were given priority over other predictor variables.Final model response and predictor variables are in Table 50.

Table 50 Response and predictor variables

Predictor variables
• Annual flood regime (days per year)
• Optimal time scale flood regime (average days per year)
• Years since last flood (number of years)
• Local rainfall (mm/year)
***Response* variables**
• Community Condition - score metric derived from percentage cover data for all PCTs.
• Tree Stand Condition - score metric derived from tree stand data for tree dominated PCTs

4.3.2 Modelling relationship between condition score and predictor variables

For each PCT, Generalised Linear Mixed Models (GLMMs) were used to model the relationship between condition score and inundation predictor variables to produce an ERM. GLMMs provide a more flexible approach for analyzing nonnormal data when random effects are present than using nonparametric tests (Bolker et al. 2008). All condition scores had a range of 0 to 20, and were logit transformed prior to modelling. The transformation used an offset of 0.1 to avoid values of 0 and 20, i.e. Score = log((Raw_score + offset) / (20 + offset - Raw_score)), where Score is the logit transformed score, Raw_ score is the untransformed score, and offset = 0.1.

'Site' was modelled as a random effect (random intercept) to account for autocorrelation between samples taken at the same site over time. All predicted variables were standardised (mean centred) prior to modelling, and back-transformed for plotting. A model averaging approach was taken using the package 'MuMIn' in the program 'R'. For each PCT and response variable, a full model was fitted which contained all predictor variables. All possible subsets of the full model were then fitted with an automated procedure, and models were ranked and averaged according to AIC.

The single best model was chosen, and parameter coefficients were averaged across the best model and all other models within a 95% confidence interval of the best model. The relative importance of coefficients included in this subset was calculated. The best model for each PCT was represented graphically. Two-dimensional plots were produced for models with a single significant predictor, and three-dimensional plots were produced from models with two significant predictors. No graphs were produced if the best model was an intercept-only model or had more than two significant predictors. The analytical process followed is presented in Figure 50.

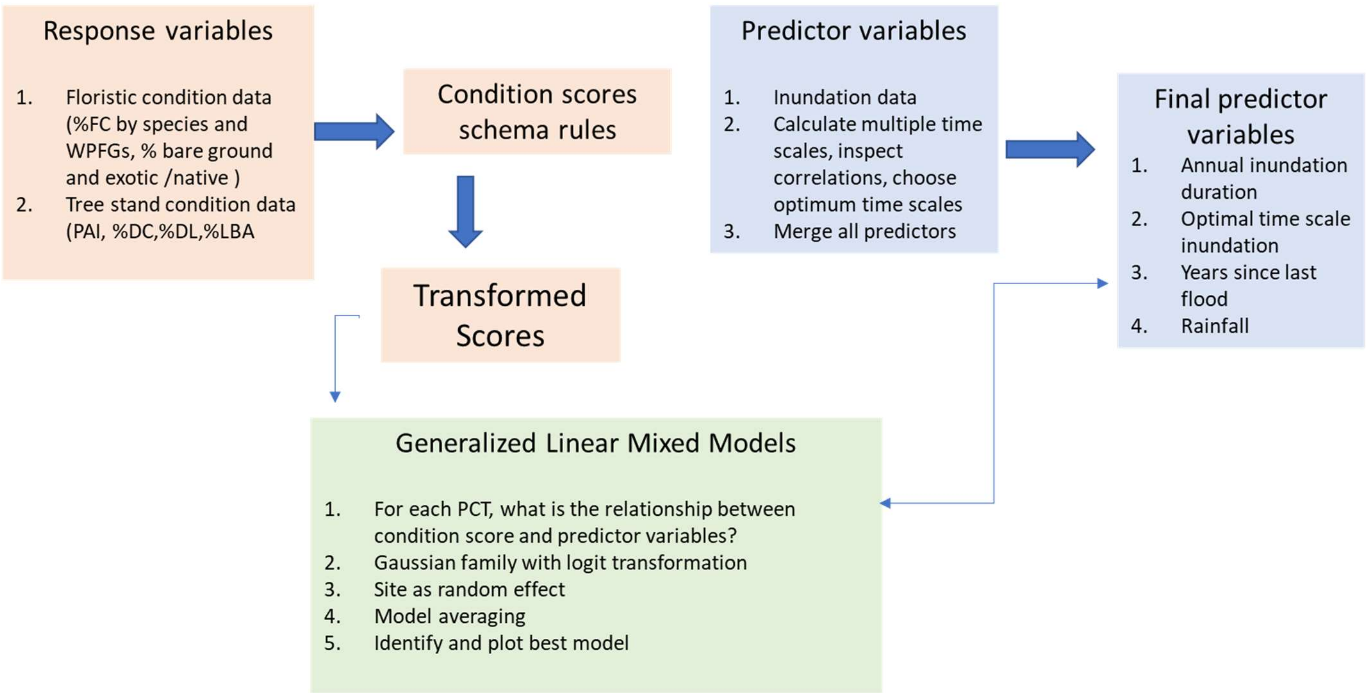


Figure 50 Analytical process

4.4 Results

The sections below graphically represent the best model (closest to P <0.05) for each PCT for community condtion and tree stand condtion (where applicable). No graphs were produced if the best model was an intercept only model. Three dimensional graphs are provided for the for both community condition and tree stand condition where the GLMM determined more than one variable to be of high importance (e.g. Figure 51).

Graphical representation of model selection and AIC weight rankings are shown for each model (e.g. Figure 52). In the graph, rows represent models, and columns represent variables. Models (rows) higher in the table have higher weight, proportional to row height. Variable importance is represented by the shading of cells (darker shading means more important). For each model, tables show the model averaged coefficients, standard errors, z-values, p-values, and relative importance. Included are coefficients in models within a 95% confidence interval. Tables for each PCT also show coefficients, standard errors and t-values from the single best model.

4.4.1 River red gum forest, PCT 36
4.4.1.1 Tree stand condition, PCT 36

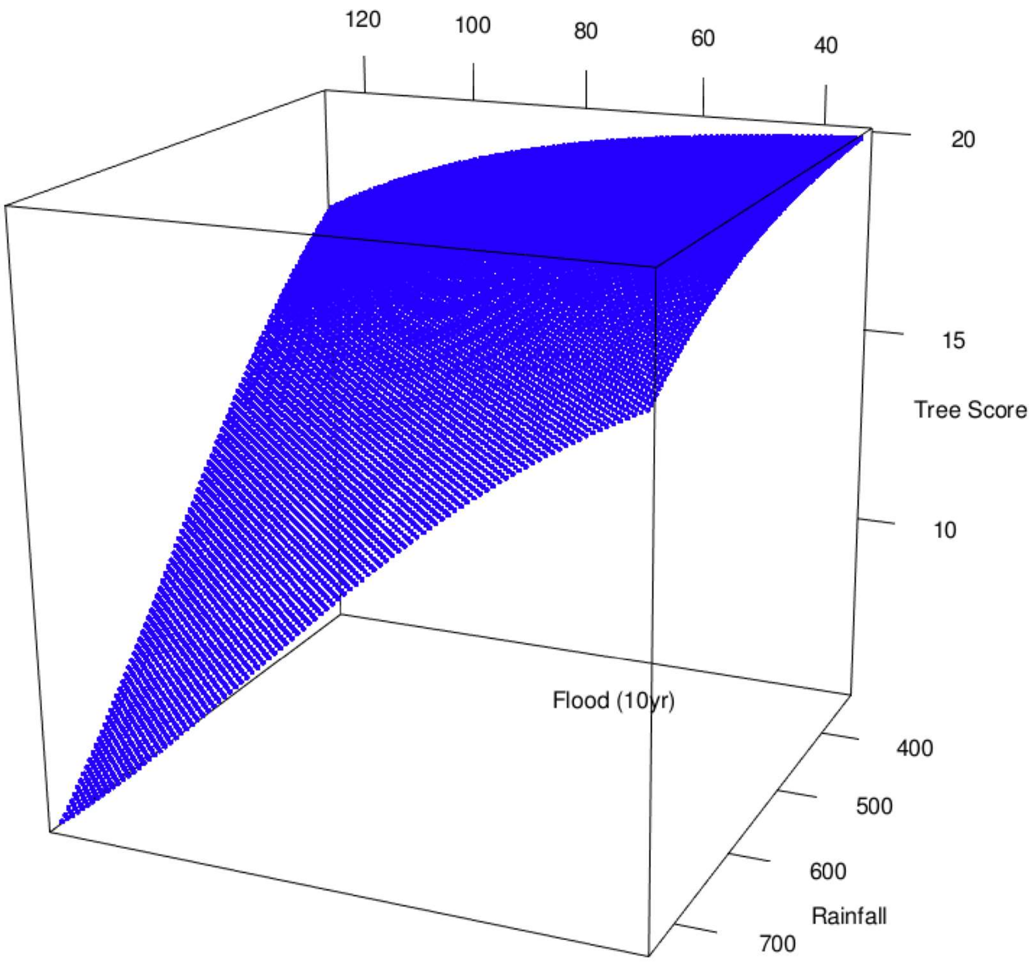


Figure 51 River red gum forest tree stand condition model output

The river red gum forest model shows the relationship between tree stand condition score, Flood (10yr) (average days flooded in 10 years) and rainfall (Figure 51).

The best predictor overall was the 10-year average flooding regime which exhibited a negative relationship with tree stand condition score. The model indicates that river red gum forests require 40 – 60 days flooding on average in a 10-year period to be in intermediate to good condition but decline in condition with prolonged flooding. Rainfall was the next most important predictor and also had a negative relationship with tree stand condition (Table 51, Table 52, and Figure 52).

The best model was: *logit (Condition score) ~ 2.182 + (-0.706)*Flood_10 + (-0.85)*Rainfall + (1|Site)*

These results are not as expected it could be that as these sites are located on the Bora Channel (NortNR16 and Nov2) and the Macquarie River (MM1 and U Block 3). It may be that they are receiving almost constant base flows from those water sources. However, it is also possible that these sites may be unavoidably watered to allow flows to reach other sites in the Marshes. More sites are required to refine this model.

Table 51 River red gum forest, tree stand condition modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	2.212	0.499	0.531	4.164	0	0
Flood_10	-0.664	0.371	0.392	1.694	0.09	0.675
Rainfall	-0.748	0.32	0.338	2.217	0.027	0.45
Years.since.flood	-0.117	1.644	1.744	0.067	0.946	0.444
Flood_1	-0.004	0.362	0.381	0.01	0.992	0.145

Table 52 River red gum tree stand condition best model co-efficients

	Estimate	Std. Error	t value
(Intercept)	2.182	0.544	4.012
Flood_10	-0.706	0.32	-2.205
Rainfall	-0.85	0.283	-2.999

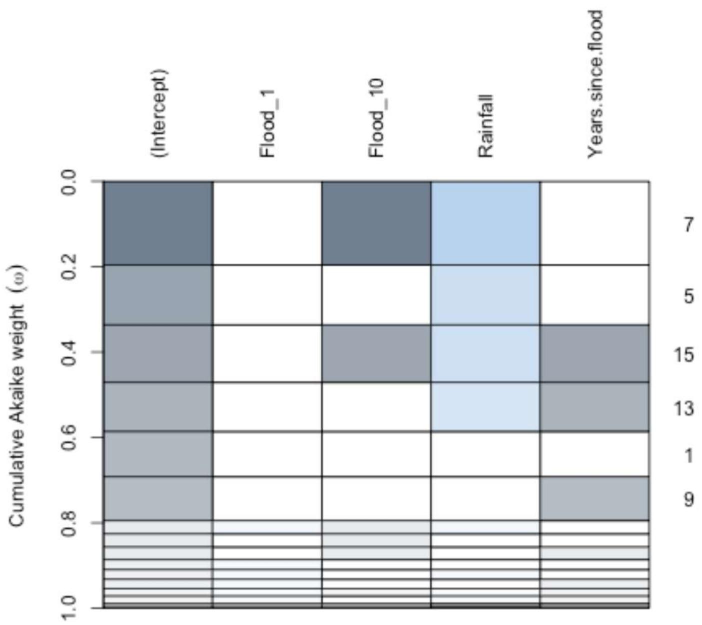


Figure 52 River red gum forest, modelling average coefficients (Akaike Weights) – tree stand condition score

4.4.1.2 Community condition, PCT 36

Years since flood was the best predictor overall for river red gum forest community condition, and the only predictor that was significant in the model-averaged results. Average flooding over three years was marginally non-significant. The best model was an intercept-only model, containing none of the predictor variables. The lack of significance of predictors in the best model is likely due to the low number of sites and sample size.

The best model was: *logit (Condition score) ~ 1.327 + (1|Site)*

4.4.2 River red gum woodland, PCT 36A

4.4.2.1 Tree stand condition, PCT 36A

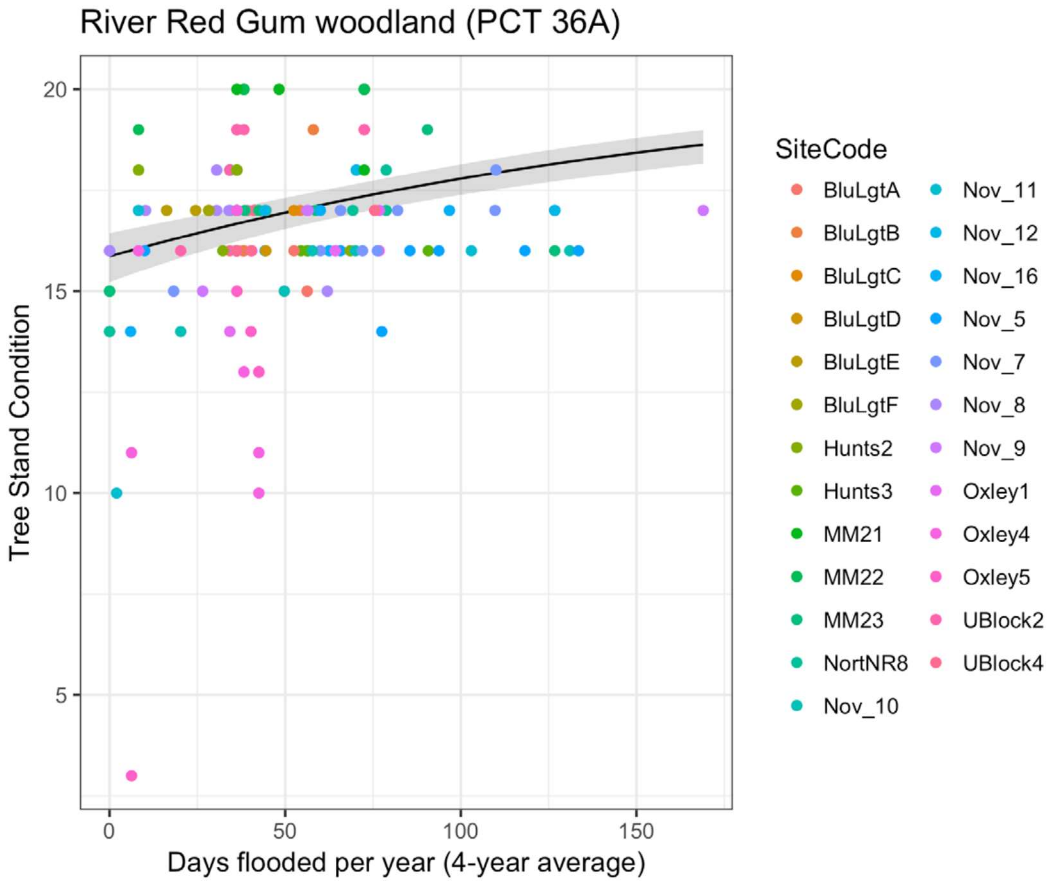


Figure 53 River red gum woodland tree stand condition model outputs

The 4-year average flooding regime was the best predictor overall, and the only predictor in the best model. There was a positive relationship between the 4-year average flooding regime and tree stand condition (Table 53, Table 54, Figure 53, and Figure 54). Points show raw data, coloured by Site. Solid black line shows the predicted values from the model, and the ribbon represents the standard error predictions.

The best model was: *logit (Condition score) ~ 1.681 + 0.227*Flood_4*

The model predicts that river red gum woodland requires an annual average of over 150 days (5 months), flooding over a 4-year period, to be in good tree stand condition.

Table 53 Red gum woodland tree stand condition modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	1.686	0.148	0.149	11.3	0	0
Flood_4	0.214	0.077	0.078	2.76	0.006	0.665
Rainfall	-0.166	0.074	0.075	2.214	0.027	0.383
Years.since.flood	-0.072	0.045	0.046	1.581	0.114	0.122
Flood_1	0.001	0.076	0.077	0.008	0.993	0.062

Table 54 Red gum woodland, tree stand condition best model co-efficients

	Estimate	Std. Error	t value
Intercept)	1.681	0.145	11.591
Flood_4	0.227	0.069	3.265

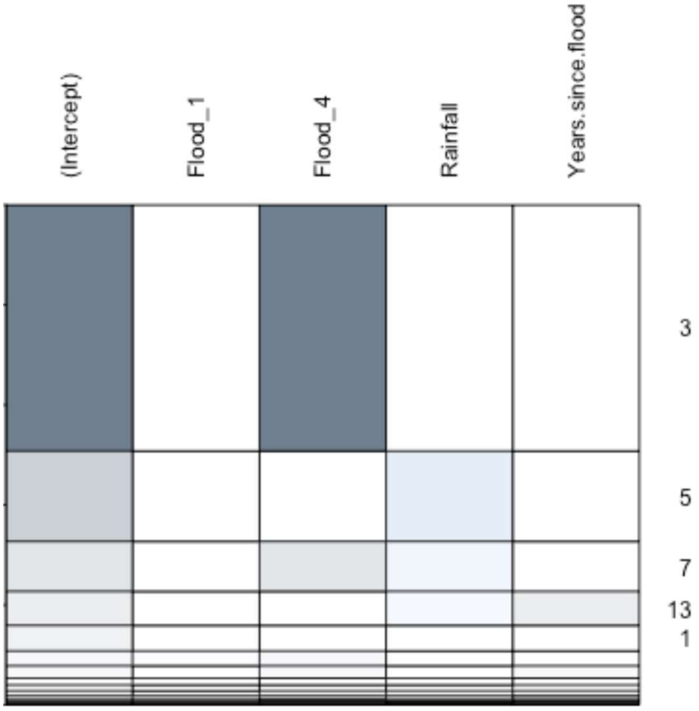


Figure 54 River red gum woodland, modelling average coefficients (Akaike Weights) – tree stand condition score

4.4.2.2 Community condition, PCT 36A

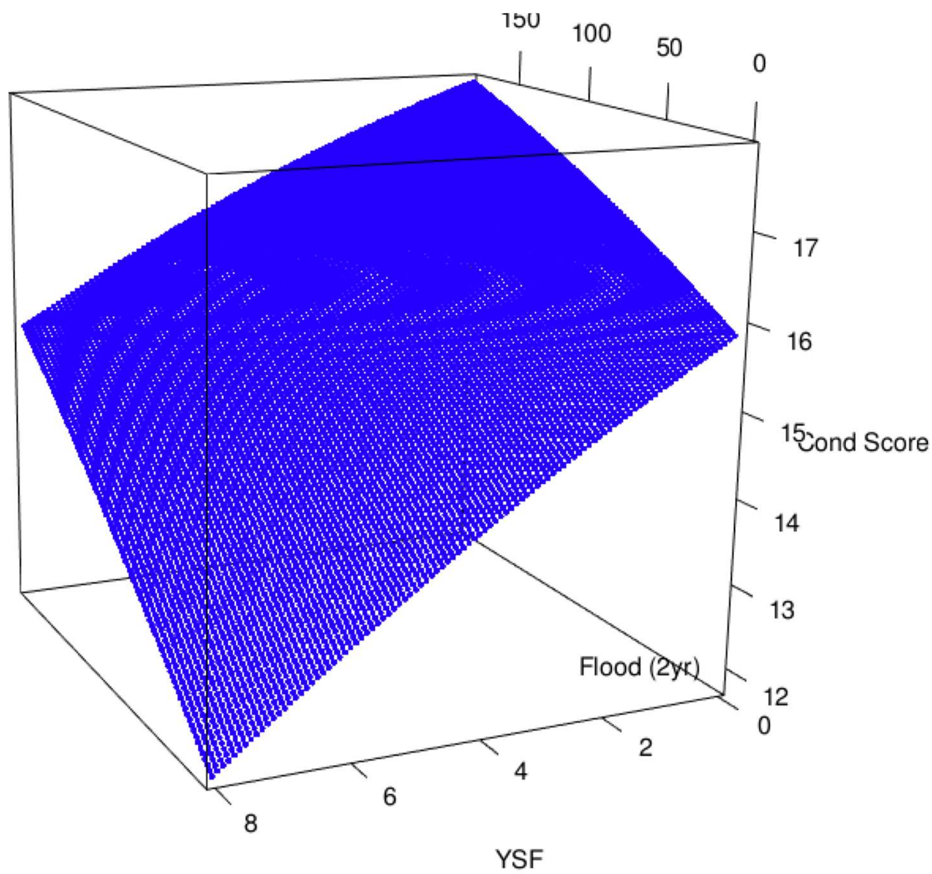


Figure 55 River red gum woodland model, community condition

The 2-year flooding average (Flood (2yr)) was the best predictor overall, followed by Years since last flood (YSF). No other model-averaged coefficients were statistically significant. There was a positive relationship between the 2-year flooding average and community condition, and a negative relationship between Years since last flood and community condition (Figure 55, Table 55, Table 56, and Figure 56).

The best model was: logit (Condition score) ~ 1.382 + 0.198*Flood_2 + (-0.218)*Years.since.flood + (1|Site)

The model predicts that river red gum woodland requires over 150 days of inundation in a two-year period and less than 2 years between floods, to be in good to benchmark floristic community condition.

Table 55 Red gum woodland community condition modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	1.386	0.194	0.196	7.089	0	0
Flood_2	0.205	0.079	0.08	2.575	0.01	1
Years.since.flood	-0.23	0.1	0.101	2.29	0.022	0.818
Flood_2 : Years.since.flood	0.092	0.166	0.168	0.551	0.582	0.106
Rainfall	0.063	0.049	0.05	1.259	0.208	0.06

Table 56 Red gum woodland, community condition best model co-efficients

	Estimate	Std. Error	t value
Intercept)	1.382	0.19	7.285
Flood_2	0.198	0.068	2.913
Years.since.flood	-0.218	0.064	-3.381

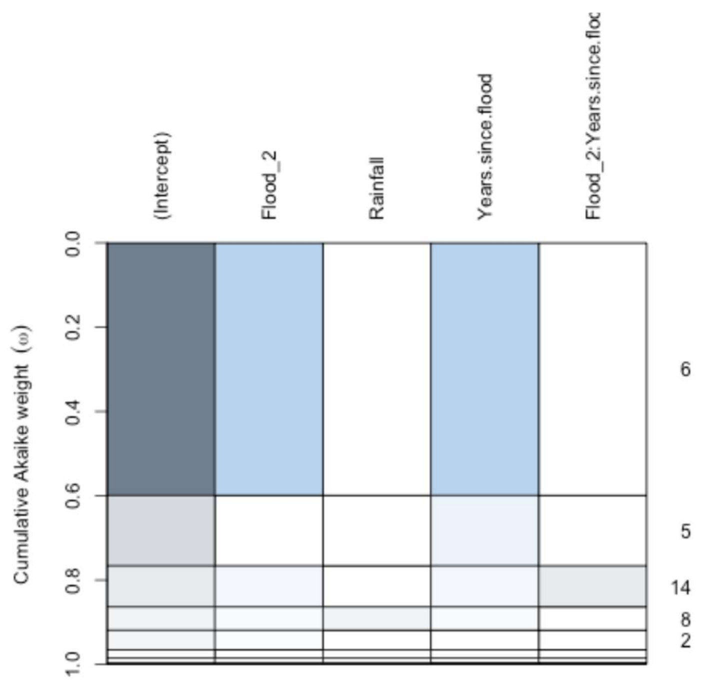


Figure 56 River red gum woodland, modelling average coefficients (Akaike Weights) – community condition score

4.4.3 Red gum grassy woodland, PCT 454

4.4.3.1 Tree stand condition, PCT 454

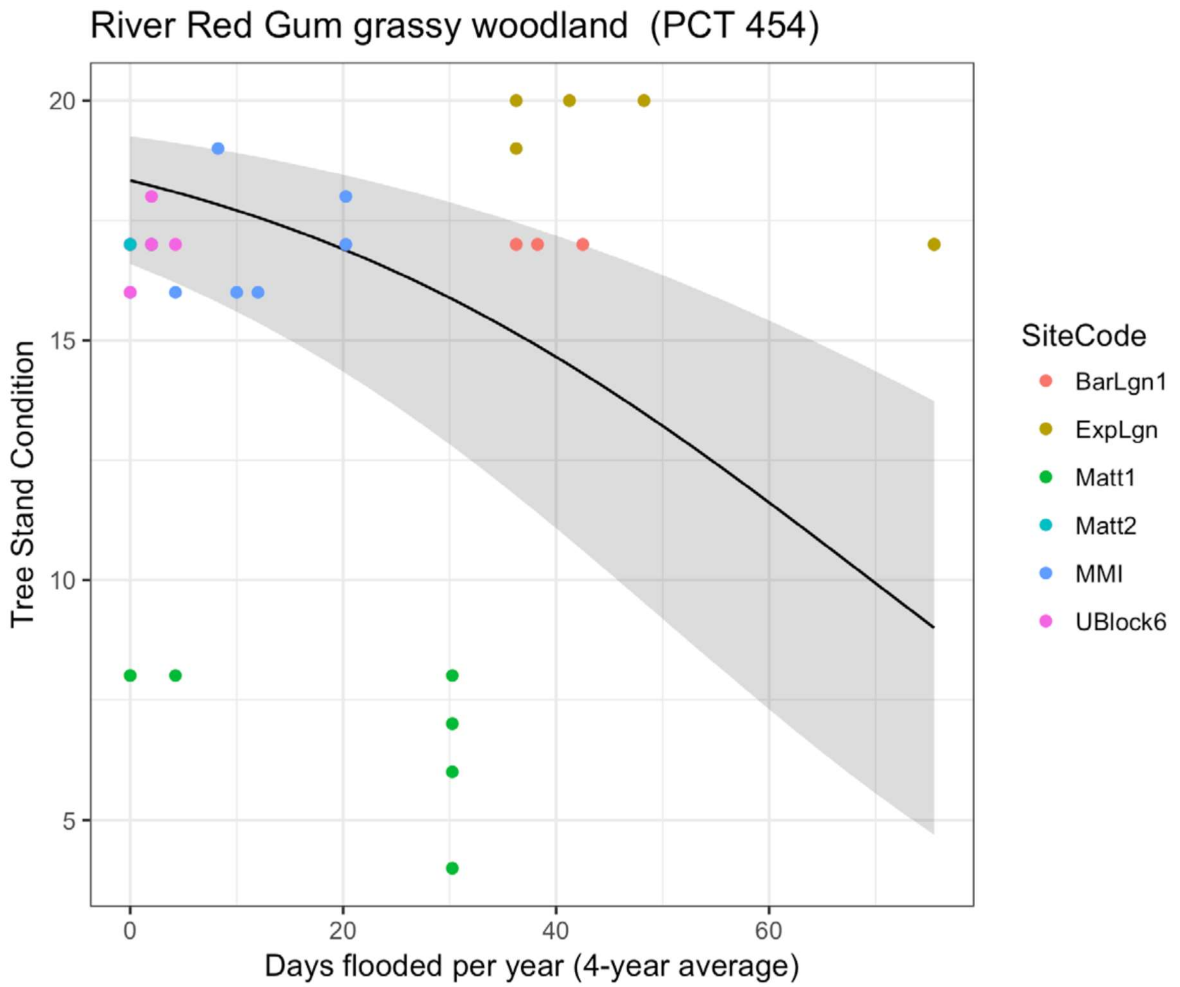


Figure 57 River red gum grassy woodland model, tree stand condition

The 4-year average flooding regime was the most important predictor, and the only predictor in the best model. There was a negative relationship between 4-year flooding average and tree stand condition (Figure 57, Table 57, Table 58 and Figure 58).

The best model was: logit(Condition score) ~ 1.718 + (-0.724*Flood_4) + (1|Site)

This result is unexpected and could be explained by the fact that there are very few sites in the model, and that two of the sites (Barlgn 1 and Explgn) are actually lagoon sites that may have a very different hydrology to the other sites. At the lagoon sites there may be access to ground water at times when there is little or no surface water inundation. More sites in this PCT are reqired to refine this model.

Table 57 Red gum grassy woodland community condition modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	1.758	0.756	0.787	2.233	0.026	0
Flood_4	-0.758	0.303	0.313	2.419	0.016	0.916
Years.since.flood	-0.113	0.251	0.257	0.44	0.66	0.418
Flood_4:Years.since.flood	0.455	0.249	0.258	1.765	0.077	0.198
Flood_1	0.078	0.298	0.308	0.254	0.799	0.105
Rainfall	-0.039	0.132	0.137	0.283	0.777	0.062
Flood_1:Years.since.flood	-0.32	0.561	0.587	0.544	0.586	0.011

Table 58 Red gum grassy woodland, community condition best model co-efficients

	Estimate	Std. Error	t value
Intercept)	1.718	0.752	2.286
Flood_4	-0.724	0.243	-2.981

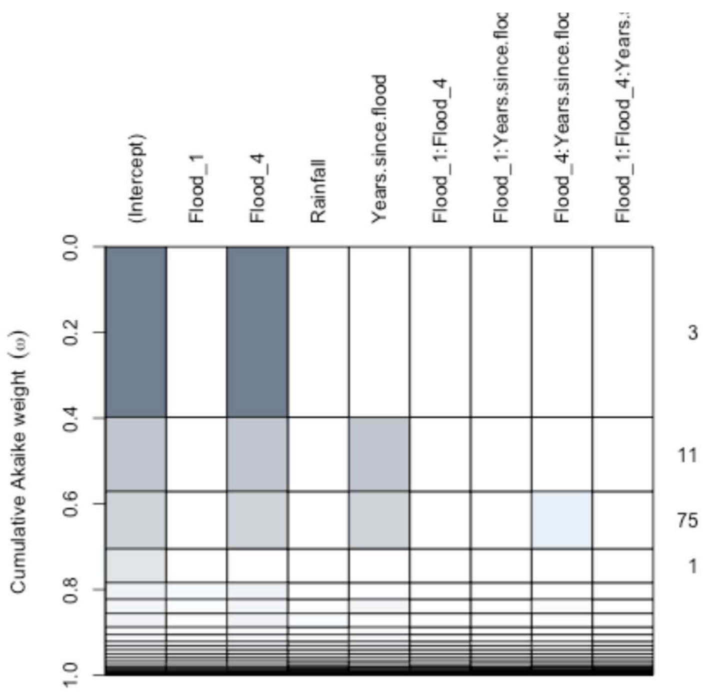


Figure 58 River red gum grassy woodland, modelling average coefficients (Akaike Weights) – tree stand condition score

4.4.3.2 Community condition, PCT 454

Years since flood was the best predictor overall, and the only predictor that was significant in the model-averaged results. Average flooding over three years was marginally non-significant. The best model was an intercept-only model, containing none of the predictor variables. The lack of significance of predictors in the best model is likley due to the low number of sites and sample size. The best model was: *logit(Condition score) ~ 0.439 + (1|Site).*

4.4.4 Flood-dependent woodland, PCT 40

4.4.4.1 Tree stand condition, PCT 40

The *5-year average flooding regime* was the best predictor overall, followed by *Rainfall* and *Years since flood*. These three predictor variables appeared in the best model. There was a negative relationship between each of these three predictor variables and Tree Stand Condition (Table 59, Table 60, Figure 60, and Figure 59). The best model was: *logit (Condition score) ~ 3.642 + (-1.672*Flood_5) + (-0.767*Rainfall) + -0.988*Years.since.flood) + (1|Site)*

Since there are three significant predictors in the final model, this model cannot be represented graphically. There are only 5 sites sampled for this PCT, more replication is required to refine this model.

Table 59 Flood-dependent woodland community condition modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	3.882	0.697	0.732	5.306	0	0
Flood_5	-1.177	0.812	0.852	1.381	0.167	0.971
Rainfall	-0.728	0.294	0.314	2.321	0.02	0.797
Years.since.flood	-0.509	1	1.049	0.485	0.628	0.625
Flood_5:Years.since.flood	1.233	1.489	1.588	0.776	0.437	0.343
Flood_1	-0.242	0.46	0.483	0.501	0.616	0.152

Table 60 Flood-dependent woodland, community condition best model co-efficients

	Estimate	Std. Error	t value
(Intercept)	3.642	0.257	14.178
Flood_5	-1.672	0.346	-4.832
Rainfall	-0.767	0.274	-2.797
Years.since.flood	-0.988	0.344	-2.871

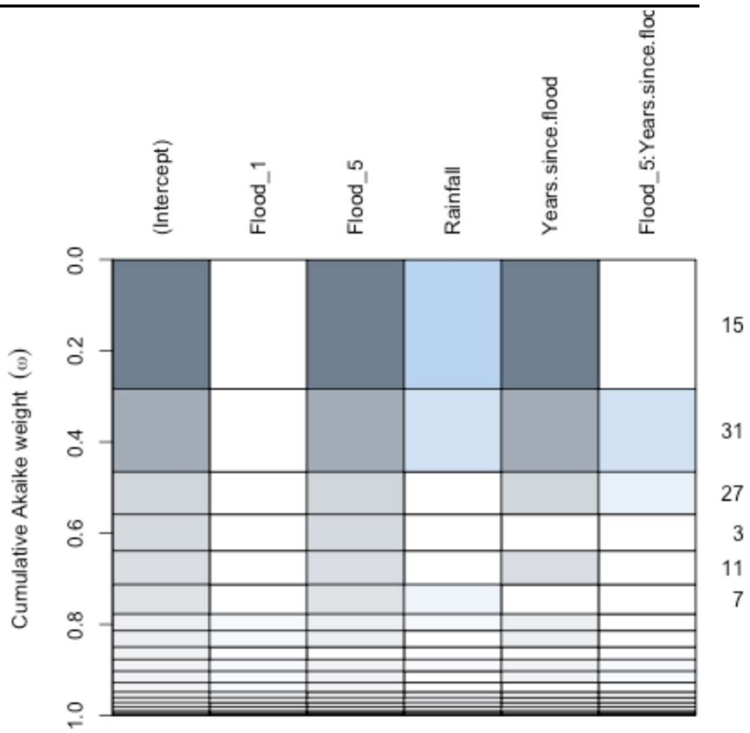


Figure 59 Flood-dependent coolibah woodland, modelling average coefficients (Akaike Weights) – tree stand condition score

4.4.4.2 Community condition, PCT 40

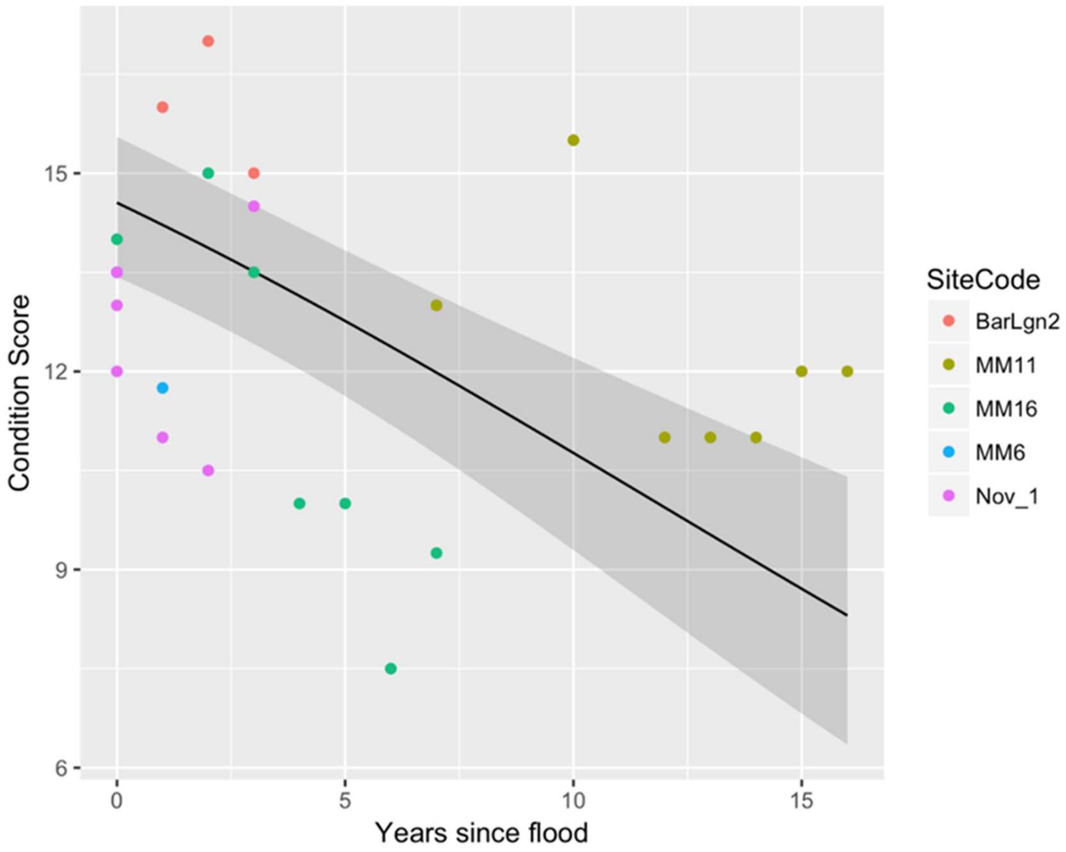


Figure 60 Flood-dependent woodland model, community condition

The best model for flood-dependent woodland community condition includes a negative relationship between condition score and years since flood (Figure 60, Table 61, Table 62, and Figure 61). Points show raw data, coloured by Site. The solid black line shows the predicted values from the model, and the ribbon represents the standard error predictions

This model shows that there is a steady decline in community condition with increasing years since flood. Sites that have the least time between floods have a higher condition score. This reflects the water needs of the floodplain grasses that are an indicator of good community condition in this community. This PCT requires flooding once in a five-year period. The best model was: *logit (Condition score) ~ 0,563 + -0.431*Years.since.flood + (1|Site)*

Table 61 Flood-dependent woodland community condition modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	0.579	0.221	0.233	2.483	0.013	0
Years.since.flood	-0.427	0.155	0.164	2.605	0.009	0.663
Flood_3	0.11	0.131	0.137	0.803	0.422	0.092
Rainfall	0.087	0.074	0.078	1.115	0.265	0.046

Table 62 Flood-dependent woodland community condition, best model co-efficients

	Estimate	Std. Error	t value
(Intercept)	0.563	0.237	2.376
Years.since.flood	-0.431	0.153	-2.807

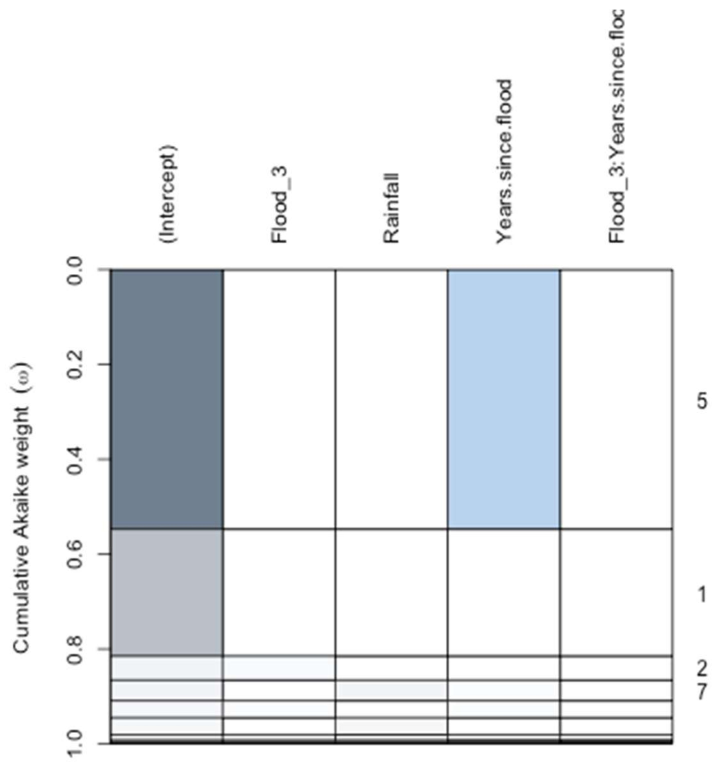


Figure 61 Flood-dependent woodland, community condition modelling average coefficients (Akaike Weights) – Condition Score

4.4.5 Water couch marsh grassland, PCT 204

4.4.5.1 Community Condition, PCT 204

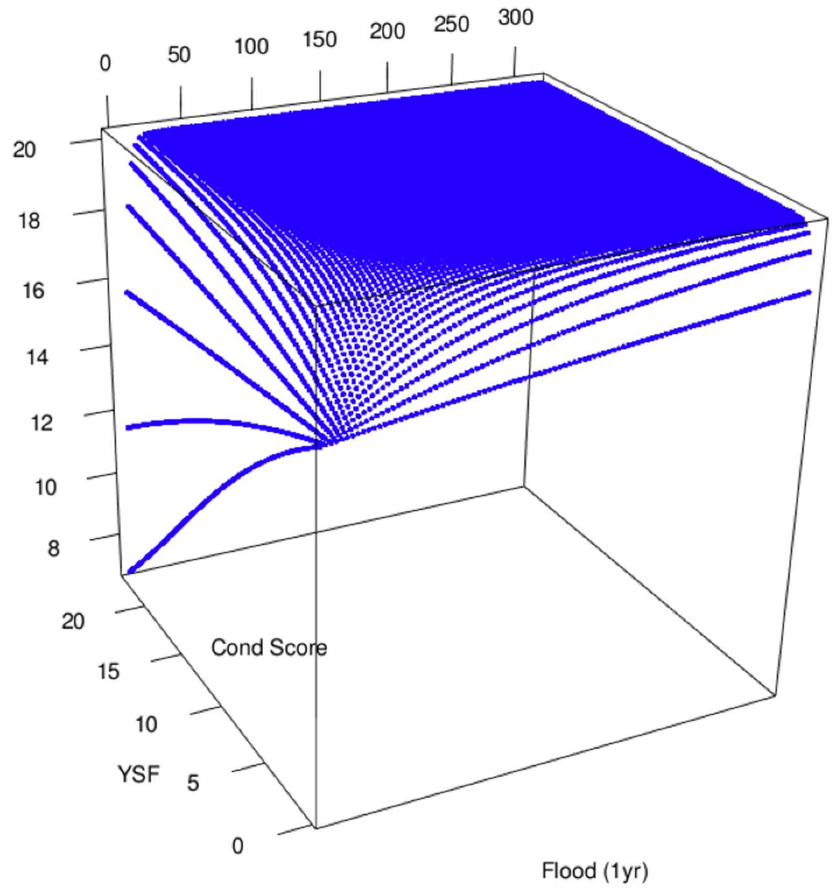


Figure 62 Water couch marsh grassland 3-dimensional model

Annual flooding *(Flood (1yr)),* Years since last flood *(YSF)*, and their interaction, were the best predictors in model-averaged results and all appeared in the best model, although none were statistically significant at $P < 0.05$. These two predictor variables and their interaction were all positively related to Community Condition (Figure 62, Table 63, Table 64, Figure 63). The best model was: *logit (Condition score) ~ 4.159 + 3.014*Flood_1 + 5.318*Years.since.flood + 6.377*Flood_1:Years.since.flood + (1|Site)*

The model predicts that water couch marsh grassland requires approximately 60 days of inundation annually. Further replication of sites is required to refine this model as the best although the best model was statistically significant P <0.05. The standard error associated is extremely large.

Table 63 Water couch marsh grassland, modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	3.203	2.933	2.971	1.078	0.281	0
Flood_1	2.776	3.62	3.674	0.756	0.45	1
Years.since.flood	3.107	6.725	6.811	0.456	0.648	0.685
Flood_1:Years.since.flood	6.419	8.321	8.453	0.759	0.448	0.624
Rainfall	0.13	0.172	0.174	0.748	0.455	0.142

Table 64 Water couch marsh grassland, best model co-efficients

	Estimate	Std. Error	t value
(Intercept)	4.159	3.35	1.241
Flood_1	3.014	3.694	0.816
Years.since.flood	5.318	7.676	0.693
Flood_1:Years.since.flood	6.377	8.316	0.767

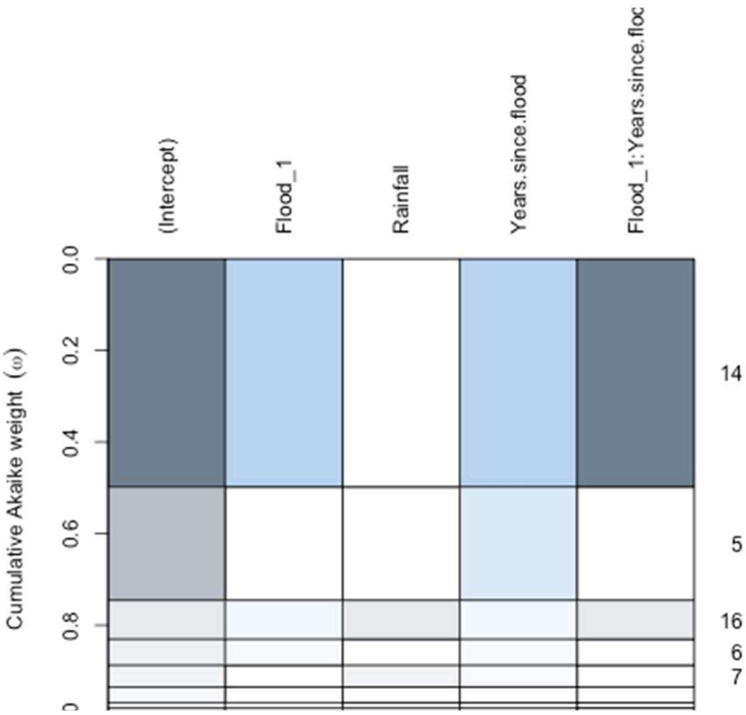


Figure 63 Water couch marsh grassland, modelling average coefficients (Akaike Weights) – Condition Score

4.4.6 Mixed Marsh sedgeland, PCT 53
4.4.6.1 Community condition, PCT 53

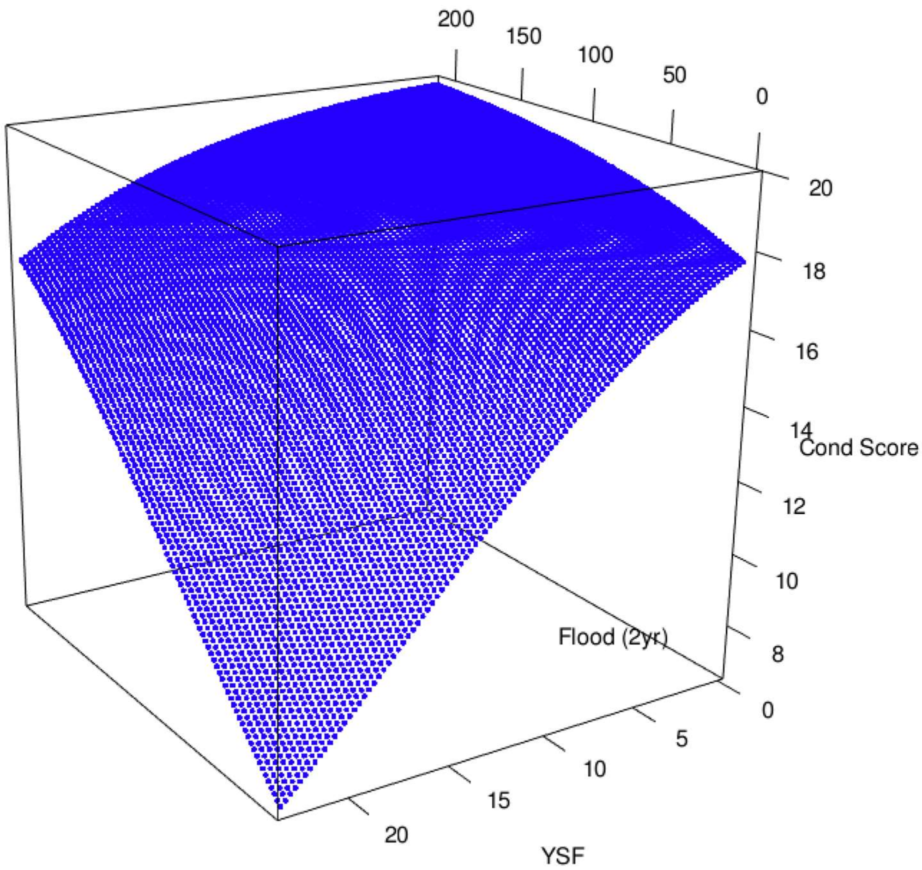


Figure 64 Mixed marsh sedgeland, community condition model output

The 2-year flooding average (Flood (2yr)), was the best predictor overall, followed by Years since last flood (YSF), and both were significant predictors in the best model. The 2-year flooding average was positively related to community condition, and Years since last flood was negatively related to community condition (Figure 64, Table 65, Table 66, and Figure 65). The best model was: *logit (Condition score) ~ 2.116 + 0.558*Flood_2 + (-0,748)*Years.since.flood + (1|Site)*

The model predicts that that mixed marsh sedgeland requires more than 50 days of inundation biennially to be in good to excellent condition and less than 5 years between floods.

Table 65 Mixed marsh sedgeland, community condition modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	2.116	0.227	0.232	9.114	0	0
Flood_2	0.558	0.256	0.261	2.136	0.033	1
Years.since.flood	-0.835	0.277	0.282	2.962	0.003	0.665
Rainfall	-0.243	0.229	0.234	1.038	0.299	0.231

Table 66 Mixed marsh sedgeland, community condition best model co-efficients

	Estimate	Std. Error	t value
(Intercept)	2.116	0.225	9.406
Flood_2	0.558	0.256	2.18
Years.since.flood	-0.748	0.256	-2.924

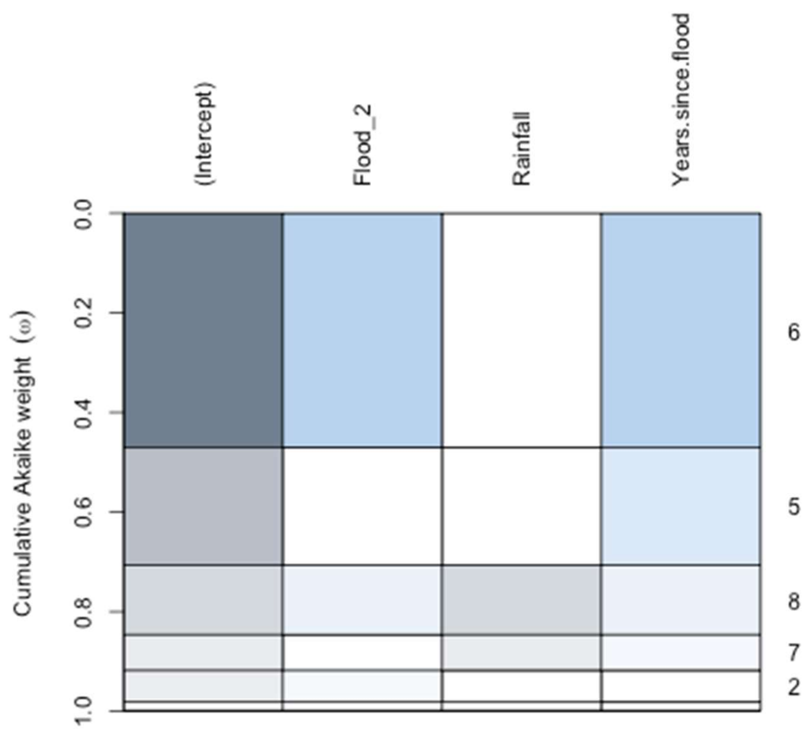


Figure 65 Mixed marsh sedgeland, modelling average coefficients (Akaike Weights) – Condition Score

4.4.7 Lignum shrubland wetland, PCT 247

4.4.7.1 Community condition, PCT 247

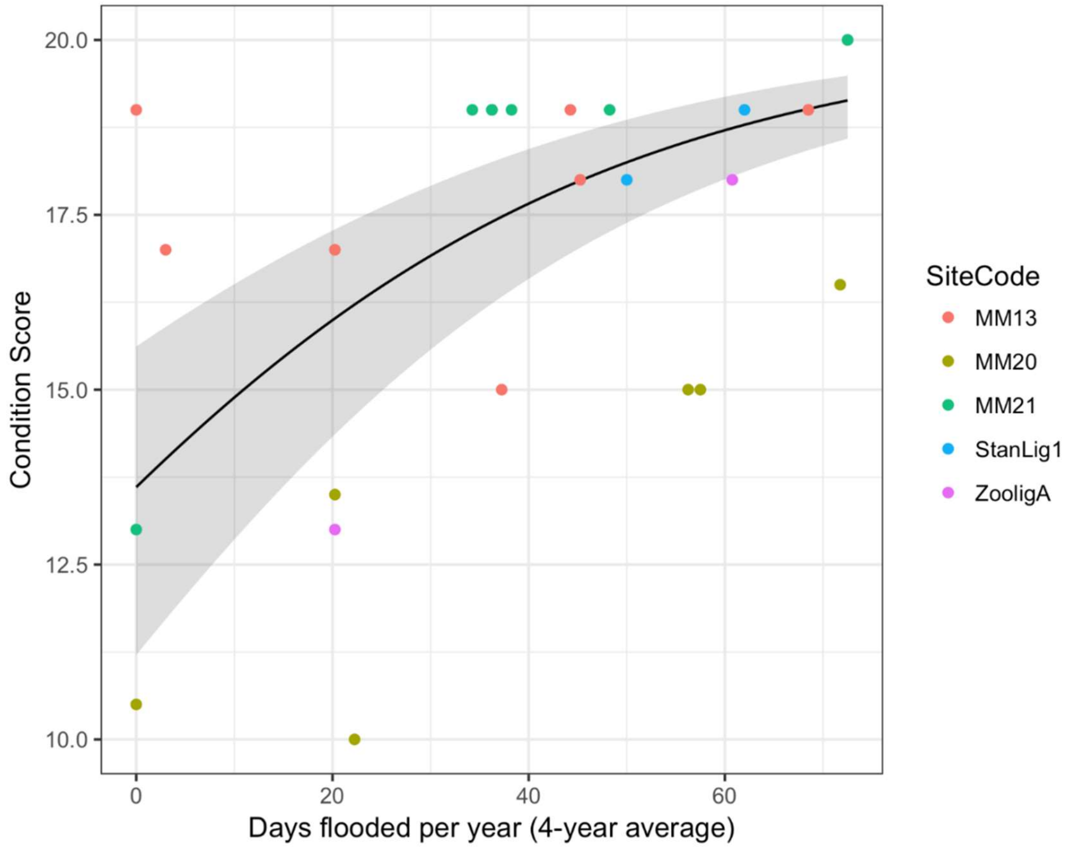


Figure 66 Lignum shrubland wetland model output

The 4-year flooding average was the best predictor overall, and the only predictor in the best model. No other model-averaged coefficients were statistically significant. There was a positive relationship between the 4-year flooding average and Community Condition. The model shows the relationship between community condition score and average days flooded in the previous 4 years. Points show raw data, coloured by Site. Solid black line shows the predicted values from the model, and the ribbon represents the standard error predictions (Figure 66). The duration of flooding in the last 4 years before sampling was the best predictor of Lignum shrubland wetland community condition (Table 67, Table 68, and Figure 67). The best model was: *logit (Condition score) ~ 1.952 + 0.73*Flood_4 + (1|Site)*

These results indicate that Lignum shrubland wetland requires more than 65 days of inundation per year in 4 years to have a condition score in the good to excellent range.

Table 67 Lignum shrubland, modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	1.952	0.428	0.455	4.291	0	0
Flood_4	0.756	0.187	0.198	3.828	0	1
Years.since.flood	0.219	0.249	0.265	0.827	0.408	0.138
Flood_1	-0.049	0.189	0.201	0.245	0.806	0.073
Rainfall	-0.017	0.162	0.172	0.098	0.922	0.061

Table 68 Lignum shrubland, best model co-efficients

	Estimate	Std. Error	t value
(Intercept)	1.952	0.428	4.561
Flood_4	0.73	0.158	4.636

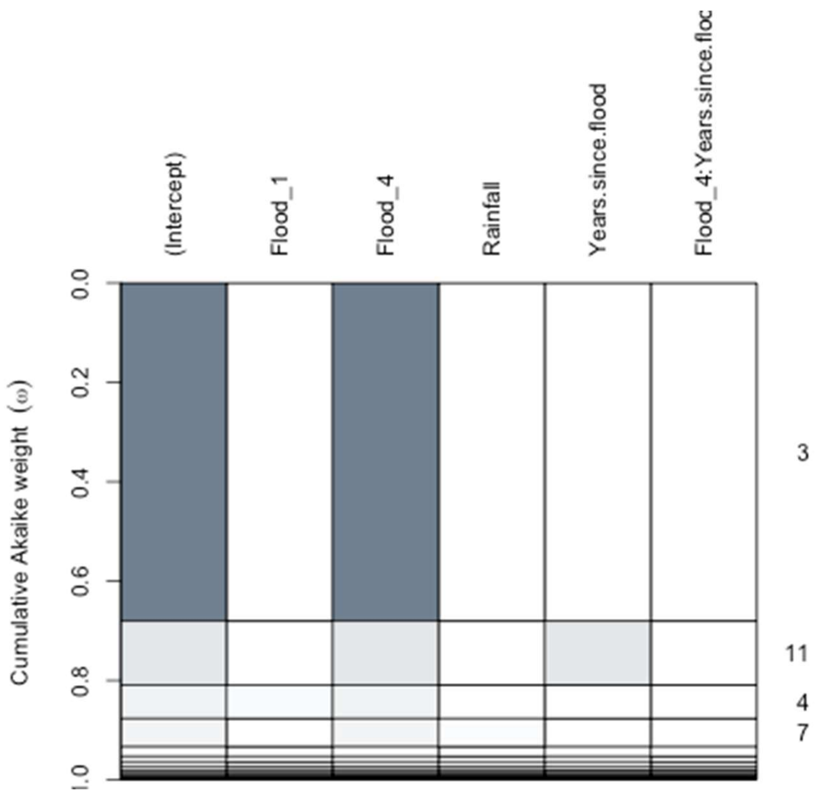


Figure 67 Shrubland wetland, modelling average coefficients (Akaike Weights) – Condition Score

4.4.8 Floodplain grassland, PCT 214

4.4.8.1 Community condition, PCT 214

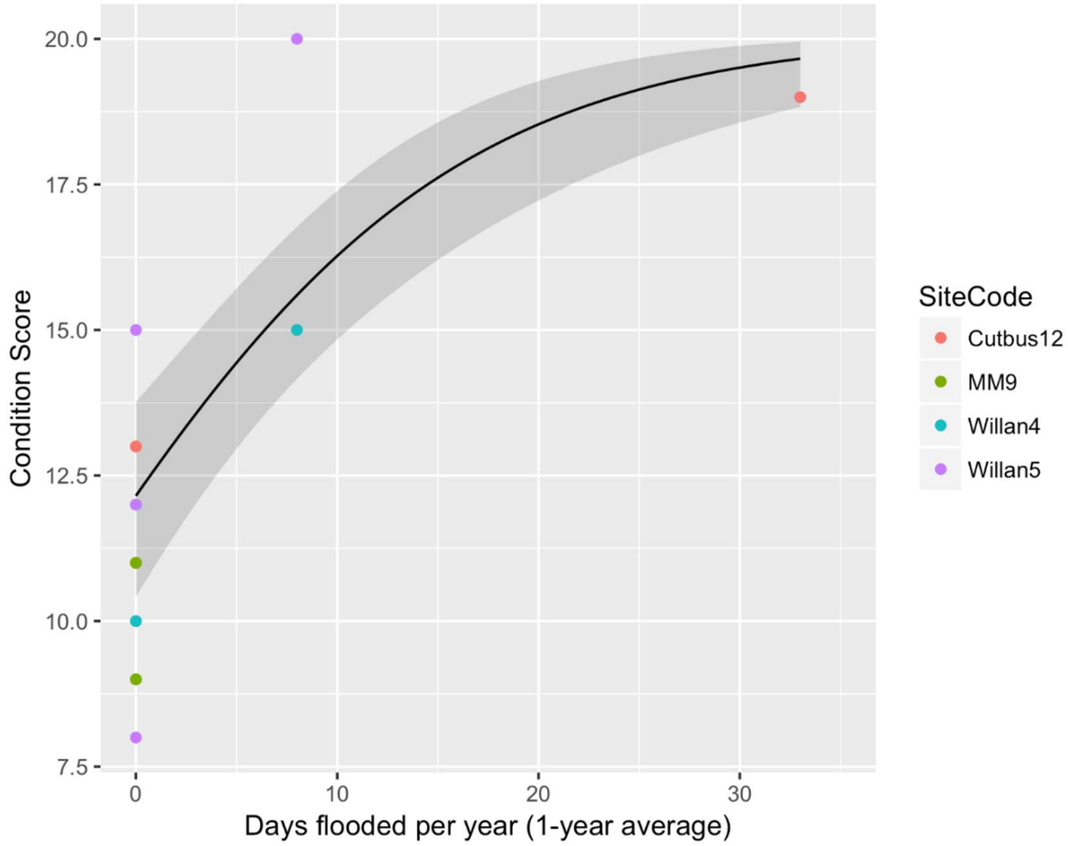


Figure 68 Floodplain grassland community condition model output

Annual flooding (*Days flooded in the previous year*) was the best predictor overall, followed by *Rainfall* and *Years since last flood*. Annual flooding was the only predictor in the best model and was positively related to Community Condition. The model shows the relationship between community condition score and average days flooded per year. Points show raw data, coloured by Site. Solid black line shows the predicted values from the model, and the ribbon represents the standard error predictions (Figure 68). The duration of flooding in the last 1 year before sampling was the best predictor of Floodplain grassland community condition (Table 69, Table 70, and Figure 69). The best model was: *logit (Condition score) ~ 0.719 + 0.838*Flood_1 + (1|Site).*

The model predicts that floodplain grassland requires between 10 and 30 days of flooding annually to improve its condition. More sites are required to improve the accuracy of the model. It does indicate that flooding is more important than rainfall in driving the condition of floodplain grassland in the Macquarie Marshes.

Table 69 Floodplain grassland community condition, modelled average co-efficients

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)	Importance
(Intercept)	0.707	0.329	0.363	1.949	0.051	0
Flood_1	0.775	0.301	0.331	2.344	0.019	0.533
Rainfall	0.66	0.27	0.299	2.211	0.027	0.442
Years.since.flood	-0.736	0.319	0.35	2.1	0.036	0.321

Table 70 Floodplain grassland community condition, best model co-efficients

	Estimate	Std. Error	t value
(Intercept)	0.719	0.333	2.163
Flood_1	0.838	0.288	2.909

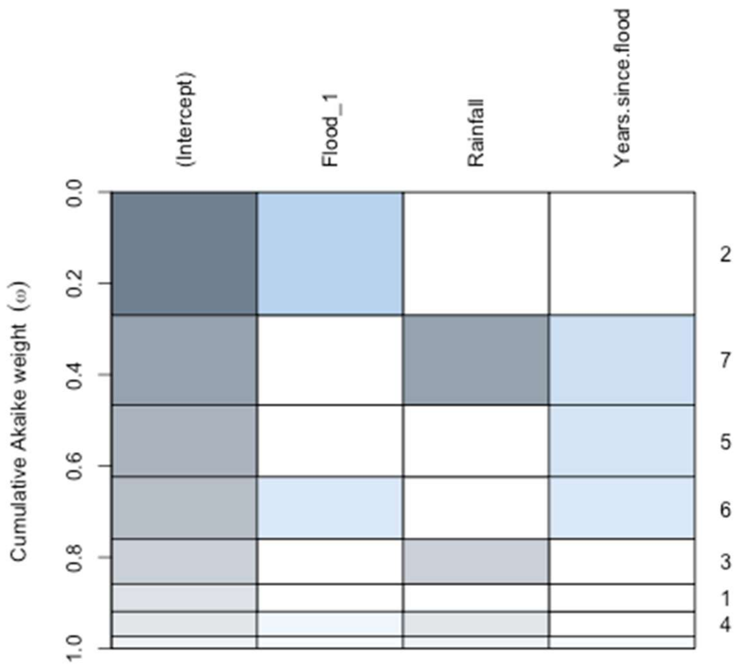


Figure 69 Floodplain grassland, modelling average coefficients (Akaike Weights) – Condition Score

4.5 Discussion

4.5.1 Flood-dependent vegetation community inundation regime requirements

This work helps to further the empirical knowledge of flood-dependent vegetation community water requirements in the Macquarie Marshes and these models can be used to test these requirements using data from other valleys that support these or other structurally and functionally similar PCTs.

Roberts et al. (2000) suggest that for plants, depth, duration, and season are the most important components of a water regime at an annual time scale, but that frequency, inter-flood interval and variability are most important over longer time-scales. This study shows that there were clear relationships between floristic community and tree stand condition scores and average inundation duration and/or years since last flood (inter-flood interval) for the flood-dependent PCTs; river red gum woodland, flood-dependent woodland (coolibah dominated), water couch marsh grassland, mixed marsh sedgeland, lignum shrubland and floodplain grassland. The timescale of the predictive water regime varied between woody and non-woody PCTs

A comparison between the published inundation regime requirements of the key flood-dependent PCTs (or its dominant species), derived from the literature and the results from this study, the MRF analysis in Chapter 3, is presented in Table 71. An interesting result of this study is that inundation is important for coolibah woodland community condition. It also indicates that some coolibah woodlands require more frequent inundation (less than five yearly) to support their understorey community. Tree stand condition modelling was not conclusive, but the literature records the water requirements for coolibah woodland of one in ten to twenty years for several weeks (Foster 2015; Casanova 2015).

Table 71 Comparison between published water regime and results

BWS Water-dependent community or species / Inland wetland PCT	Compiled from the literature				Macquarie Marshes Analysis Results DI#- Data Insufficient for modelling			
	Flood frequency	Flood duration	Max Inter flood period	Timing	Flood frequency	Flood duration	Max Inter flood period	Timing (actual)
River red gum forests (tree stand condition) PCT 36	1 in 1-3 years	5-7 months.	4 years	spring and summer	Average over 10 years	2-3 months per year	DI#	Spring
River red gum forests (community condition) PCT 36	Not specified	Not specified	Not specified	Not specified	1 in 1 year (DI#)	4 months	2 years	Spring
River red gum woodlands (tree stand condition) PCT 36A	1 in 2-4 years	2-4 months	4 years	spring and summer	1 in 4 years	5 months	4 years	Spring
River red gum woodlands (community condition) PCT36A	Not specified	Not specified	Not specified	Not specified	1 in 2 years	5 months	1 year	Spring
River red gum grassy woodlands (tree stand condition) PCT 454	3 to 4 in 10 years	2 months	5-7 years	Not specified	1 in 4 years	1 month	4 years	Spring
River red gum grassy woodlands (community condition) PCT 454	Not specified	Not specified	Not specified	Not specified	1 in 3 years (DI#)	1-2 months (DI#)	3 years (DI#)	Spring
Coolibah woodlands (tree stand condition) PCT 40	1 in 10-20 years	Several weeks	unknown	Not critical	1 in 5 years	1 month	5 years	Spring
Coolibah woodlands (community condition) PCT 40	Not specified	Not specified	unknown	Not specified	1 in 1 year	1 month	1 year	Spring
Non-woody Wetlands - Water couch marsh grassland PCT 204	1 in 1-2 years	4-6 months	3 years	Not critical	1 in 1 year	2 months	<1year	Spring
Non-woody Wetlands - Mixed Marsh sedgeland PCT 53	1-3 years	3-10 months	5-7 years	Not specified	1 in 2 years	2 months	2 years	Spring
Floodplain grassland PCT 214	Not specified	Not specified	Not specified	Not specified	1 in 1 year	1 month	1 year	Spring
Lignum shrubland PCT 247	1 in 1-3 years large Small 1 in 7-10	3-7 months for vigorous canopy	Not specified	Not critical	1 in 4 years	2 months	4 years	Spring

Conversely water couch marsh grassland in the Marshes may require more frequent but shorter duration of inundation (two months annually), than that recorded in the literature; every two to eight years for four to six months (Casanova 2015), or five to eight months (Roberts and Marston 2011).

Floodplain grassland is not listed in the BWS however the model suggest that inundation is an important factor for floodplain grasslands, usually considered as non-flood-dependent.

4.5.2 Use of the model outputs

Models can be used to guide water management by identifying the water regime required for PCT to reach a desired condition score level. Note that the desired (or acceptable) condition score may not necessarily be the maximum value (20), given that water resources are limited. Managers can then calculate the water needed to change the average annual inundation regime from its current value to the required value. In some cases, this may require calculation of water required to reach desired average inundation over five years. For example, if a PCT's ERM suggests that a PCT requires a 5-year average water regime of 50 days per year to reach the desired condition score, and the current average is 30 days per year, a simple calculation can determine the additional water required to reach the desired state.

Models can be used in this way from either the model equations, or from the graphical plots of model predictions. In the case of model equations, parameter estimates from summary tables should be inserted into the model, taking care to use the appropriate transformation. Since these models are all binomial, estimates should be exponentiated to account for the log transformation.

Chapter 5 General discussion

5.1 Significance of the study

This study utilised a long-term data set that was collected at a most fortuitous time, enabling the study of the effects of rewetting in inland floodplain wetland plant communities that had been wet or dry during the Millennium drought of 1996 to 2010. An experiment on this scale would not have been possible without the intervention of nature, namely the La Niña conditions of 2010 and 2011. These La Niña conditions were characterised by heavy rainfall during summer giving Australia its wettest two year period on record, and this effectively ended the extremely dry hydrological conditions that were a signature of the Millennium Drought (Australian Government 2015).

Question-driven, long-term data sets can identify emerging environmental problems, as well as insights about the mechanisms or ecological processes giving rise to these emergent patterns (Lindenmayer and Likens 2010a). The best way of maintaining long-term, high quality data, is the frequent examination and interrogation of these data to stimulate new research and management questions (Lindenmayer and Likens 2010b). Medium to long-term vegetation monitoring data sets, especially those collected by government agencies, are expensive to collect and maintain and are often underutilised. The approach described this study provides a technique that will allow such datasets to be put to better use to inform water management in a drying climate.

The study is novel, original and has wide-ranging application. Since 2005, there has been a significant investment of public funds to procure and deliver water to the floodplain wetlands and rivers of the MDB, and to assess the condition of their flood-dependent species and communities. Under the Basin Plan, the target for water recovery for environmental purposes set by the MDBA was 2,750 GL per year, plus 450 GL of efficiency savings by 2024 (DAWR 2018). To do this, the Australian Government has bought up water rights estimated at more than $AUD 3.1 billion (Kingsford et al. 2017).

This research addresses this important need to effectively quantify measures of condition for flood-dependent inland floodplain wetland plant communities, for use in predictive modelling for environmental water use, to define vegetation restoration targets and management strategies, and for efficient ecological monitoring and research. It is a novel approach as it assesses the condition of defined flood-dependent PCTs, rather than target species, and quantifies their community dynamics in relation to key parameters of inundation. It is applicable at the management scale, i.e. in a large inland floodplain wetland of 200,000ha.

This research builds on previous excellent work; on wetland plant physiological responses to water (e.g. Brock and Casanova 1997; Casanova 2011), on wetland plant community dynamics (e.g. Reid and Quinn 2004; Capon, 2005; Campbell et al. 2014), and work on assessing flood-dependent tree health by Cunningham et al. (2007) who defined the most reliable, objective indicators of tree stand condition. This current work went further, as benchmarks and condition classes were defined and developed specifically for the assessment of condition of inland floodplain wetland PCTs defined under the NSW BioNet VIS (OEH 2017a). The Benchmark or excellent condition in this study was defined as; '*the state in which water availability meets the life history needs of <u>all diagnostic indicators</u> most of the time*' whereas poor condition was defined as; '*the state in which water availability meets the life history needs of <u>non-diagnostic indicators</u> most of the time'*.

5.2 Research question one: response and predictor variables of flood-dependent floristic community condition

The research question '*what are the key indicators of condition (response variables) for floristic community condition in inland floodplain wetland plant communities?*' was addressed by testing several widely accepted hypotheses regarding inland floodplain wetland plant community dynamics in relation to inundation regimes identifying these in a conceptual model and applying these to specific PCTs. Most of these hypotheses were supported, and the results allowed the selection of robust condition response variables for floristic community and tree stand condition for defined PCTs.

5.2.1 Usefulness of water PCT indicators and plant functional groups

The results of the hypothesis testing allowed confidence in using percentage foliage cover of both diagnostic PCT indicator species and amphibious, aquatic and semi-aquatic WPFG species as response variables to inundation at the regime scale. This is an extension of work on utilising wetland plant functional groups as response variables in studies of wetland species dynamics. Casanova (2015) outlined the use of WPFGs for various purposes; e.g. to inform ecosystem responses to environmental watering (Reid and Quinn 2004), assess floodplain vegetation resilience (Colloff and Baldwin 2010), communication of vegetation responses to environmental flows to the general public (Nielsen et al. 2013), assessment of weediness (Stokes et al. 2010), the relative diversity of wetlands with different water requirements (Casanova 2011), and the comparison of wetlands with the same water regimes, but different suites of species (Campbell et al. 2014). This study further supports the use of WPGFs and demonstrates its usefulness as a tool to assess the response of PCTs to inundation regimes and to assess PCT condition at any period.

Nichol et al. (2016) discuss that the WPFGs were developed in wetlands on the New England Tablelands in New South Wales (Australia) (Brock and Casanova 1997) and Mount Lofty Ranges streams in South Australia (Casanova (2015); both are not arid zone river floodplains. Nichol et al. (2016) recommend that an additional functional group of species that are intolerant to inundation, but with a requirement for inundation to complete their life cycle and exploit a small window of favourable conditions for growth on arid floodplains, be considered. For example, Nicol (2004) recorded 36 species in the seed bank and extant vegetation of the Menindee Lakes that were intolerant of inundation as adult or juvenile plants, but are only recorded in areas subjected to periodic inundation (Cunningham et al. 1981), These species persist in the seed bank during dry conditions and periods of inundation, then germinate as water level recede, and then grow and reproduce whilst there is sufficient soil moisture (Nicol 2004).

In this study, species that exhibited these lifecycle requirements (i.e. those limited to germination on damp soil) were classed as Terrestrial damp (Tda) species. However a separate group for those species that exhibit a persistent seed bank component of their lifecycle and utilise damp conditions to germinate would be considered advantageous. This study supports the need for a uniform, continent-wide and consistent allocation of species to groups that would allow WPFGs to be used effectively throughout the MDB (Casanova 2015).

5.2.2 Usefulness of bare ground, exotic species and litter

The results of the hypothesis testing allowed confidence in using percentage foliage cover of exotic species and the percentage cover of bare ground, as response variables to inundation at the regime scale.

Although fallen timber (woody litter of greater than 10 cm cross sectional diameter) is considered to be an important indicator of ecosystem health in river red gum forests, particularly in regards to fauna ecology (e.g. MacNally and Parkinson 2005; MacNally and Horrocks 2008; MacNally et al. 2011), the results of this study did not support the hypothesis that the percentage cover of litter; (i.e. dead plant matter and woody debris of less than 10 cm cross sectional diameter), as a reliable indicator of response to inundation regimes. Thus, even though it is used as a condition metric in the NSW Biodiversity Assessment Method (BAM) (State of NSW 2017), it is not considered a reliable condition indicator in the inland floodplain wetland PCTs sampled in the Marshes. There is insufficient evidence that the PCTs sampled, particularly non-woody communities, retain or lose litter in response to inundation regime drivers. The litter is mostly fine and ephemeral and probably important in the annual trophic cycle of these communities, but it is not an indicator of condition at any point in time.

5.2.3 Usefulness of grazing pressure

At the regime scale, grazing pressure as measured in this study, was not a significant predictor variable for the percentage foliage cover of the floristic condition response variables in the PCTS sampled in the Marshes, when compared to inundation predictors. This does not however, indicate that grazing pressure may not alter the relative proportions of species at any one site, or that the effects of high grazing pressure may not be significant at the site level (Cunningham et al. 1997; Robertson and Rowling 2000; Wilson et al. 2008; DECCW 2010c; Robinson and Rowling 2000).

5.2.4 Most important water regime components

Water depth, inundation duration, and season are considered to be the most important components of a plants' water regime at an annual time scale, but that frequency, inter-flood interval and variability are more important over longer time-scales (Roberts et al. 2000). van Eck et al. (2004), found that the duration of inundation was more important than plant growth response type in determining the distribution of 20 floodplain plant species studied in the Netherlands. Most studies on wetland plant species dynamics agree on the importance of the cumulative effects of inundation events over several years (Reid and Quinn 2004).

Inundation duration, frequency and interflood period (time since last flood) at the regime timeframe, were the key inundation variables tested in this study. The current study did not use measurements of water depth, as the scale of the study and lack of equipment such as depth loggers meant that water depth data was not available at all sampled sites. If there was consistent and reliable water depth data then this variable could have been tested in the MRF. Water depth is a function of landscape position and is one of the factors that influences the distribution of any PCT.

Predictor variable importance analysis for pooled data by stratum regardless of wetland type, showed that annual inundation duration during the post-MD period (i.e. within the last seven years of the study), and the number of years since last flood were the key drivers of change for the majority of WPFGs in the lower stratum and thus for most non-woody wetland vegetation PCTs.

In the middle stratum, for woody species and species in the WPFG Se: non-woody species that require flooding and/or permanent bodies of water that have underground storage organs (rhizomes or lignotubers) to withstand dry periods, the key predictor variables also included inundation duration during the MD period and to a lesser extent the number of floods in the Pre-MD period.

The tallest stratum species (trees in the WPGFs ATe and Tda), were most influenced by the number of days flooded in the pre-MD period and the slope of the trend of change in inundation frequency from the Pre-MD to the end of the MD period. This indicates the importance to wetland plant communities of receiving inundation during a prolonged drought period to maintain their resilience, thus water availability during drought increases the resilience (i.e. affects response to inundation post drought) of these communities.

5.3 Research questions two and three: identifying benchmarks and inundation regimes of flood-dependent wetland plant communities

In Chapter 2 the research question '*what inundation regime does each inland floodplain wetland plant community need to be maintained in optimal or benchmark condition?*' was addressed by analysing the data by wetland type and clustering data into inundation classes based on the most important predictor variable/s for that wetland type (i.e. forest, woodland, shrubland or non-woody wetland). The highest total percentage cover of most species in the amphibious and submerged WPFGs in lower stratum of flood-dependent shrubland wetland and non-woody wetland were in sites with the longest duration regime in the post-MD period, and were lowest in the sites with shortest duration regime. Conversely the percentage cover of bare ground and Terrestrial dry (Tdr) species were highest in sites with the shortest duration regime in the post-MD period.

In the middle stratum of flood dependent shrubland, woodlands and forest, the percentage cover of species in the woody amphibious WPFG ATw, the non-woody amphibious WPFG ATe and the Terrestrial dry group Tdr, were highest in sites in the moderate inundation regime class in the MD period with a moderate rate of change in inundation frequency, and lowest in the sites with the shortest duration regime in the MD period. The percentage cover of Se species was highest in the longest duration inundation regime class and with a low rate of change in inundation frequency in the MD period.

In the tallest stratum there was only one ATw species modelled; river red gum. Within each of the wetland types the percentage cover of the ATw species was higher in the moderate inundation regime in the river red gum woodland, and higher in the highest inundation regime in river red gum forest.

The relationships between the response variables and condition scores was investigated using the data collected from each individual PCT. 'Optimal' condition states or 'benchmarks' for the response variables identified for each PCT were set utilising published information on PCT structure and floristics, and condition class schemas were developed by developing the hypotheses outlined in Chapter 1, utilising the trends in the response variables to inundation regimes undertaken by MRF analysis from Chapter 2. The range of condition scores generated from applying the floristic condition schemas for each PCT to the dataset from each inundation regime class were then compared to address the research questions; '*what is 'optimal' or 'benchmark' for floristic community condition in inland floodplain wetland plant communities*?' and '*what inundation regime does each inland floodplain wetland plant community need to be maintained in optimal or benchmark condition?*'.

Optimal condition states or 'benchmarks' for each PCT were the diagnostic %FC of the indicator species and/or amphibious and semi aquatic WPFGs species identified for each PCT and were designed provide an 'aspirational' end target or goal for any management intervention. The condition class schema provides additional ‘sub-optimal’ classes or states which a PCT can function to varying degrees.

These sub-optimal classes are given names that reflect the ecological characteristics of the states in relation to the benchmark. They are denoted as ‘good’, ‘intermediate’, ‘intermediate/poor, ‘poor’ and ‘very poor’ simply to communicate to stakeholder groups with a variety of levels of technical knowledge, the relative status of the sub-optimal states in relation to the benchmark. They are not absolute value judgements and could be given alternative names. However, if targets are set in an adaptive management framework, then various desirable outcomes are inherent in that framework, as wetland managers acknowledge that some wetlands are different to others in their ecological functioning and diversity of biota (U.S. EPA. 2002; Johnston et al. 2009), and most managers seek to attain management goals that improve or maintain some agreed level of ecosystem function. This study seeks to set a quantitative framework for assessing condition of wetland PCTs, to allow for decisions to be made about current and future states to guide ecological restoration activities to attain *‘more desirable attributes, such as a more appropriate species composition’* (Brudvig 2011).

Examination of the data of each PCT for the spread of the response variables and condition scores from sites clustered into inundation regimes in the MRF analysis, showed that the condition schemas were assigning condition scores that reflected changes in the response variables driven by regime scale predictor variables. Thus the data was behaving as predicted by the MRF analysis and modelling in Chapter 2. This indicated strongly that the benchmarks and the condition class schemas were meaningful ecologically, and therefore useful for measuring condition and for planning and monitoring restoration or maintenance activities relating to water management for the target PCT. Further sampling of those PCTs that were least data rich, or that had not been sampled across all possible inundation regimes would be most advantageous.

This analysis also indicated which of the sampled inundation regimes were the most conducive to achieving the benchmark or nearest to benchmark class or state. It also indicated the response of PCTs in relation to the inundation regime that they had received in the MD period.

5.4 Research question one: tree stand condition response and predictor variables

In Chapter 2 the research question '*what are the key indicators of condition (response variables) for tree stand condition in inland floodplain wetland plant communities*?' was addressed by testing several underlying hypotheses regarding inland floodplain wetland tree stand condition response in relation to inundation regimes. All these hypotheses were supported, and the results allowed confidence in the utilisation of both existing and novel response variables for tree stand condition. The results of the hypothesis testing allowed confidence in using percentage foliage cover/PAI, percentage dead canopy, percentage live basal area and percentage dead limbs as response variables to inundation at the regime scale. This is an extension of work on utilising the response variables; PAI, percentage dead canopy and percentage live basal area developed by Souter et al. (2012) and Cunningham et al. (2014) and supports the importance of quantifying the degree of dieback of woody material (Horton et al. 2011; Overton et al. 2014) in assessing tree stand condition.

In Chapter 2, analysis of the response of Plant Area index PAI, percentage live basal area and percentage dead limbs (as scores), found that scores are highest in the sites that had the longest inundation duration during the MD period and lowest in sites with the lowest duration during the MD period, when data was pooled regardless of wetland type. When data was analysed separately for wetland type, percentage live basal area and percentage dead limbs were highest in the sites that had the longest inundation duration during the MD period for river red gum woodland sites and grassy woodland sites. The trends for PAI were less clear, however it was lowest in sites with the lowest duration during the MD period.

5.5 Research questions two and three: benchmarks and inundation regimes for flood-dependent tree stand condition

The research questions; '*what is 'optimal' or 'benchmark' condition for floodplain wetland tree stand condition*? And '*what inundation regime does each inland floodplain wetland plant community need to be maintained in optimal or benchmark tree stand condition?* were addressed in Chapter 3 by investigating the relationships between the trends in the response variables and the identified inundation variables of most importance, using the data collected from the individual tree dominated PCTs over several years.

'Optimal' condition states or 'benchmarks' for the response variables identified for each tree dominated wetland type (i.e.; woodland or forest) were set utilising published information on PCT tree structure and used the diagnostic percentage foliage cover for woodland and forest (Specht 1970; Walker and Hopkins 1990), and condition class schemas were developed utilising the trends in the tree stand response variables to inundation regimes undertaken by MRF analysis in Chapter 2.

Optimal condition states or 'benchmarks' for tree stand condition for woodland or forest were simply the diagnostic state for the tree dominated PCTs sampled in the Marshes and were designed provide an end target or goal for any management intervention. Like the floristic community condition class schemas for each PCT, the tree stand condition class schema provides additional 'sub-optimal' classes or states in which the tree dominated PCTs can exist. Again, like the floristic condition sub-optimal classes, they are given names that reflect the tree stand physiological characteristics of the states in relation to the benchmark. They are denoted as 'good', 'intermediate', 'intermediate/poor, 'poor' and 'very poor' simply to communicate to stakeholder groups with a variety of levels of technical knowledge, the relative status of the sub-optimal state in relation to the benchmark. They are not absolute value judgements and could be given alternative names (see 5.3 above).

The range of condition scores generated from applying the tree stand condition schema for tree stand condition to the dataset from each inundation regime class were compared to address the research question: '*what inundation regime does each inland floodplain wetland plant community need to be maintained in optimal or benchmark condition?*'. Examination of the data of each tree dominated PCT for the spread of the response variables and condition scores from sites clustered into different inundation regimes, showed that the condition schemas were assigning tree stand condition scores that reflected changes in the response variables that were driven by regime scale predictor variables and that the data behaved as predicted from the results of the MRF analysis in Chapter 2. This indicated strongly that the benchmarks and the condition class schemas were meaningful ecologically and therefore useful for planning and monitoring of restoration or maintenance activities relating to water management for the target PCT. There is need for further sampling the tree stand condition of those PCTs that were least data rich or that had not been sampled across all possible inundation regimes.

This analysis also indicated which of the sampled inundation regimes were the most conducive to achieving the benchmark or nearest to benchmark possible 'desired' class or state for each tree dominated PCT.

5.6 Ecological reference models and water requirements for inland floodplain PCTs in the Marshes

In Chapter 4 Ecological Response Models (ERMs) were developed for each PCT. These models allowed the prediction of the water needs for the benchmark condition for tree stand condition and floristic communities from the available sample data. These ERMs are specific to the PCTs within the Marshes, however these or very similar models could be developed and applied to other areas of the MDB with a similar climate and similar PCTs. Some PCTs did not have sufficient data to model their water requirements for tree stand or floristic community condition adequately. Each PCT is discussed separately in the following sections.

5.6.1 River red gum forest, PCT 36

River red gum forest (PCT 36) was only sampled from one inundation regime type in the Marshes, however as its distribution in the Marshes was 2,527 ha in 2013 (Bowen et al 2014), and is limited by the topology and hydrology of the Marshes, it is likely that it occurs in this one regime type.

The tree stand condition ERM predicted that river red gum forests require 1 to 2 months annual flooding on average in a 10-year period to be in intermediate to good tree stand condition, but trees decline in condition with more prolonged flooding. The published watering requirements of river red gum forests are inundation about every 1 to 3 years for about 5 to 7 months (Roberts and Marston 2011). The results of the MRF analysis indicated that the sites that had received around 4 months of inundation on average in the Post-MD period were in intermediate to good tree stand condition, even though the average inundation duration had increased from around 3 months per year in the Pre-MD period. These sites had been mapped as in good condition in 1991 (Bowen et al. 2014).

The model could be improved for this PCT by increasing the number of sites sampled and increasing the variety of distance of sites to watercourses as these may provide a source of water for these communities. Also proximity to watercourses may have influenced the inundation duration mapping from satellite imagery that provided the annual duration data for the modelling. Depth loggers and soil moisture measurements may also be required to identify water sources of riparian communities.

The river red gum forest floristic community condition ERM was inconclusive due to insufficient data. From the outputs of the MRF analysis it is likely that the lower stratum requires annual flooding. While no sites sampled scored the benchmark condition score in any year, many years were scored in the intermediate to good range for floristic community condition (see Appendix 16). Therefore, it is likely that the watering requirements of this community are slightly more than 4 months per year. The lower stratum of this community is mostly comprised of species in the semi-aquatic, amphibious tolerator and amphibious responder species that require annual inundation.

5.6.2 River red gum woodland with wetland understorey, PCT 36A

River red gum woodland with wetland understorey (PCT 36A), is a sub set of PCT 36, as it only differs from 36 in the structural form, as it is woodland as opposed to forest. It is the most widely distributed woodland community in the Marshes and covered 20,798 ha in 2013 (Bowen et al 2014). Sites were sampled in one starting inundation regime, however this community was the best sampled community in the study. The tree stand condition ERM predicted water requirements of 5 months over 4 years with a maximum interflood period of 4 years. This result is similar to the range described in the published literature of 1 in 4 to 4 years for 2 to 4 months with an interflood period of 4 years (Roberts and Marston 2011; MDBA 2011) but has a longer average inundation duration. The results of the MRF analysis found that woodland sites in the study received inundation regimes at the lower end of this range (1 to 2.3 months average annual inundation) in all three time periods. The condition scores for sites in both classes had median values in the Intermediate range

The floristic community condition ERM for river red gum woodland with a wetland understorey predicted that river red gum woodland requires over 5 months of inundation in a two-year period and less than 2 years between floods, to be in good to benchmark condition. The MRF analysis found that with a moderate regime of 2 to 3 months average annual inundation the sites were in Intermediate condition in the Post-MD period

5.6.3 River red gum grassy woodland, PCT 454

River red gum grassy woodland (PCT 454) occurs on the higher areas of the Marshes away from the main river channels and differs from PCT 36A both structurally and floristically. PCT 454 usually has a sparser canopy and a grassy understorey. There was 18,534 ha of this community mapped in the Marshes in 2013 (Bowen et al. 2014). The tree stand condition ERM result was interesting in that it indicated that this vegetation community could receive too much water, as the relationship between condition score and duration was a negative one. However, this is probably an artefact of the lack of data as there were a limited number of sites sampled in this PCT, and the condition of the sites was either Intermediate or poor. Not enough sites in any condition were sampled. The MRF analysis showed that sites received an average annual inundation of 2 to 3 weeks in the wetter class, and 2 days in the drier class in the MD period, and that this did not increase by much in the Post-MD period. Therefore, the tree stand condition of sites did not change during the Post-MD period from the starting conditions in 2008.

This community occupies a number of topographic positions in the landscape from floodplain to fringing shallow ephemeral lagoon sites. These different landscape positions would have different hydrologies. For example, lagoon sites may have subsurface water storages that are available to trees in dry periods. Hydrologic survey of the sites would be beneficial to determine the sources of water available to the trees at these sites.

The floristic community condition ERM for river red gum grassy woodland was inconclusive due to insufficient data, but the results of the MRF cluster analysis indicated that as all sites scored in the poor to intermediate/poor ranges that no sites sampled were receiving adequate water in any year. This would indicate that the community requires more than 1 to 2 months inundation every 1 to 2 years. The MRF analysis found that the sites in Intermediate condition sampled had received between 1 to 1.5 months mean average annual inundation. The published water requirements for river red gum grassy woodlands in Victoria is; inundation 3 to 4 times in 10 years, for up to 2 months, and a maximum dry interval of five to seven years (DSE 2008). The results from this study indicate that the frequency and duration of inundation required may be longer and more frequent, and the published maximum interflood period may be too long, especially for floristic community condition. More sites are required to better model the water requirements of river red gum grassy woodland.

5.6.4 Coolibah grassy woodland, PCT 40

Coolibah grassy woodland (PCT 40) covered an area of 8,645 ha in 2013 (Bowen et al. 2014). This community was sampled in two inundation regimes one of which was an extremely dry regime of negligible inundation. There were relatively few sites of PCT 40 sampled in the study. The tree condition ERM had a negative relationship between the 5-year average flooding, rainfall, years since flood and the condition score. It seems unlikely that the relationships with all three significant predictor variables would be negative. The MRF analysis shows that the sites within the two inundation classes sampled showed very similar ranges and medians for tree stand condition scores, both in the Intermediate range, from two widely disparate inundation regimes. The water requirements of coolibah woodland are an inundation frequency of one in ten to twenty years for several weeks (Foster 2015; Casanova 2015).

The ERM for floristic condition for coolibah woodland predicts a steady decline in community condition with increasing years since flood from 0 to 5 years. The MRF analysis for floristic condition found that sites in inundation one class had two to three weeks of inundation on average every six months to two years, and sites in the drier class had negligible inundation, however as in the tree stand analysis, the condition scores were in the same range for sites in both classes (poor to intermediate poor). The sites in the wetter inundation class also had more amphibious and semi-aquatic WPFG species in the lower stratum than those in the drier class. This would indicate that the sampling was inadequate and that it may be that sites have been in sampled from two widely different hydrologic regions, and that some sites may be accessing sub-surface water, and /or two different PCTs have been sampled. PCT 39: Coolibah – River cooba -Lignum woodland is a community that usually occurs in areas of more frequent and longer duration inundation than PCT 40: Coolibah grassy woodland. This community (or communities) requires more sites and more replication in the Marshes to redevelop the ERM for tree stand condition.

5.6.5 Lignum shrubland, PCT 247

Lignum shrubland (PCT 247) is restricted in distribution in the Marshes and covered 1,442 ha in 2013 (Bowen et al. 2014). The floristic community ERM for lignum shrubland predicted that lignum shrubland wetland requires more the 2 months inundation per year in 4 years to have a condition score in the Good to Excellent range. The MRF analysis showed that the sites in both the inundation regimes had similar median range for condition class (Intermediate -Good) after a regime of 1.5–3 months. Sites in Class 2 had a Very Dry regime during the MD period whereas those in Class 1 had a Moderate/dry regime in the same period. This supports the view that lignum shrubland is resilient to periods of drought (Craig et al. 1991; Roberts and Marsden 2011). This ERM could be further developed by increasing the number of sites of this PCT in the Marshes.

5.6.6 Floodplain grassland, PCT 214

Floodplain grassland (PCT 214) occurs on the less frequently flooded areas on the floodplain in the Marshes and had a mapped extent of 54,966 ha in 2013 (Bowen et al. 2014). The floodplain grassland ERM predicts that the community requires between 10 and 30 days of flooding annually to improve its condition. The MRF analysis does not fully support this outcome because the sites sampled were only in Poor to Intermediate condition and one inundation regime (Very Dry in all three periods) in the Marshes, and from very few sites. It is not possible to determine a point at which the floodplain grasslands would be unable to recover from a change to a permanent terrestrial state with the data collected, as there were insufficient sites and no sites in the wetter inundation classes. The ERM found that Annual flooding (Days flooded in the previous year) was the best predictor of condition overall, followed by Rainfall and Years since last flood. Annual flooding was the only predictor in the best model and was positively related to Community Condition, even with limited data. More sites are required.

5.6.7 Water couch marsh grassland, PCT 204

Water couch marsh grassland (PCT 204) is distributed in the areas of higher frequency inundation in the Marshes with a total mapped extent of 5,354 ha in 2013 (Bowen et al. 2014). The water couch marsh grassland ERM was not conclusive but indicated that shows that annual flooding, interflood period and their interaction were all positively correlated with condition score and it predicted that water couch marsh grassland requires approximately 2 months of inundation annually. This is much shorter duration inundation than the water requirements recorded in the literature, which indicate continuous inundation for 4 to 6 months or 2 to 3 times per year (Casanova 2015), or 5 to 8 months (Roberts and Marston 2011).

Water couch marsh grassland was sampled in three inundation regimes in the Marshes The MRF analysis showed that the range of condition scores for sites in Class 2 in which the inundation regime had returned to Pre-MD levels after becoming drier in the MD period, had a wider range of condition scores and a slightly higher median score, compared to the sites in Class 1 that had increased in average annual inundation in the Post-MD period. This has important implications for management as the total amount of water required to maintain or improve the condition of water couch marsh grassland sites in any one year may be less than was previously thought. Again more sites are required to further test the model.

5.6.8 Mixed marsh sedgeland, PCT 53

Mixed marsh sedgeland is distributed in areas of higher frequency inundation in the Marshes, with a total mapped extent of 6,475.5 ha in 2013 (Bowen et al. 2014). The ERM for community condition of mixed marsh sedgeland showed that 2-year flooding average was positively related and interflood period was negatively related to community condition scores. The model predicts that that mixed marsh sedgeland requires around 2 months of inundation biennially to be in Good to Excellent condition and less than 5 years between floods. The dominant species of mixed marsh sedgeland are Amphibious Tolerator species in the genera *Juncus* and *Eleocharis*. Species such as *E. acuta*, require annual flooding with a duration of 3 to 10 months (OEH 2012), with seed longevity in dry sediments of six years (Brock 2011). Rhizomes can survive in unflooded wetland soil for about five years, but not as long as 10 years (Roberts and Marsden 2011). As these species can regenerate from rhizomes, an interflood period of 5 years can be tolerated if plants are solely relying on rhizome regrowth (Roberts and Marston 2011).

Sites of mixed marsh sedgeland were sampled in three inundation regimes in the study. Mixed marsh sedgeland sites in Class 1 had the longest average duration in the Pre-MD period, a halving of average duration in the MD-period and an increase of 40% in the average duration of inundation in the Post-MD study period whilst sites in Class 2 had lower average duration during the Pre-MD period and returned to slightly more than their Pre-MD inundation regime in the Post-MD period. Results of the MRF analysis showed that although the ranges and median values for community condition were similar in Classes 1 and 2 the assemblage of species were different with the sites in Class 2 retaining a more diagnostic assemblage of sedges and rushes than sites in Class 1. This indicates that the mixed marsh sedgelands in the Marshes may require less frequent and shorter duration inundation than was previously believed when looking at the water requirements of the component genera.

5.7 Limitation of this study and further work

The main limitation to the power of this study is the relatively low number of sites and samples of floristic data for some PCTs. Since 'Site' was used as a random effect in the GLMM analysis, power comes from both the number of sites and the number of replicates per site. Adding sites and samples within sites would improve power, particularly for PCTs 214, 247, 40, 36, and 454 which have a small sample size. Even after 8 years of sampling there was insufficient data to build models for the community condition of some communities. Some modelled PCTs had a paucity of replication and this indicates that the continued monitoring of these PCTs and some expansion of the study would be beneficial. Expansion of the study into other valleys would allow an increase in the numbers of sites and replicates and the ability to compare between valleys. The ERMs could be further tested with more data in the Marshes, particularly in the river red gum forest and grassy woodland and coolibah PCTs. They have not been tested with data from black box communities, this would also be beneficial.

5.8 Potential uses of the research outputs

5.8.1 Adaptive management of environmental water

In NSW, Water Resource Plans (WRPs) and Long-Term Watering Plans (LTWPs) for each valley in the NSW MDB are required under the Basin Plan. Under these plans the environmental watering requirements (EWRs) of key water dependent vegetation types proscribed under the BWS (MDBA 2014b) must be defined, and then river operational rules devised to allow environmental water deliveries to be planned to meet their water requirements over 5, 10 and 20-year timeframes. This research assists in the creation and verification of those EWRs for several water-dependent vegetation types prescribed under the BWS. Further refinement of the ERMs developed in this study will assist with the quantification of the EWRs for BWS vegetation types and will also assist with the adaptive management of environmental water. An algorithm based on models in this report could be created to optimise water management at a regional scale. Given the total volume of water to be managed, the algorithm would partition delivery between sites to determine the most effective use of water.

Effective use could be defined in a variety of ways, including maximising average increase in condition score across all sites, aiming to increase condition score above a minimum value across all sites, or to target sites of special interest.

5.8.2 Communication tools

5.8.2.1 Web application

A user-friendly management tool could be a web application developed from the ERMs in this study that allows users to specify the desired condition score for a given site and use models to predict the future water requirements to reach this state. This would allow uses to utilise model predictions without interpreting model equations or graphs.

5.8.2.2 Website reporting tool

The condition classes are a simple way to communicate complex information to stakeholders. The condition classes could be applied at different scales from assessing whole of catchment condition or tracking a single sites condition over time or in response to a management intervention. Appendix 19 shows the results of the 8 years of data presented by PCT by site so that the trends in site condition can be tracked visually over time. Appendices 10 and 11 show a potential tool for reporting results in a spatial context that allows visual comparison between sites and years.

5.9 Conclusions

This study has provided a template for the creation of condition benchmarks, derived from data rather than mere observation. It has provided refinements in our knowledge of floodplain plant water requirements for different flood-dependent vegetation types and has developed a way to assess overall floodplain condition using appropriate aggregation of data (i.e. species group responses to water regime, and vegetation typology). Specifically, this study has developed a quantitative framework for assessing condition of eight key inland wetland PCTs. This could assist in decision making about current and future ecological restoration activities to attain 'more desirable attributes' for managed wetland PCTs; primarily a more appropriate species composition.

This research addresses the need to quantify measures of condition for efficient ecological monitoring and use in predictive modelling, by quantifying specific vegetation restoration condition targets. Instead of relying less targeted measures such as change in species richness or reduction in numbers of exotic species as measures of positive change in relation to water availability, this work provides an empirical set of criteria to measure change and track towards targets for specific community outcomes. It provides a novel approach by quantifying the condition assessment of pre -defined flood-dependent plant communities in relation to the parameters of inundation, in a large inland floodplain wetland of 200,000 ha.

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Appendices

Appendix 1 Numbers of sites in each water management region in each PCT

WMR	Hydro-ecological Functional Group	Wetland Type	Mapped condition in 2008 (Bowen and Simpson 2009)	Dominant species	No of Sites
East	Flood-dependent woodland	Flood dependent woodland	Intermediate	Coolibah (Eucalyptus coolibah)	1
East	Floodplain grasslands	Floodplain grasslands	Poor	Native grasses	1
East	Non-woody wetland	Marsh Grassland	Very Poor	Water Couch (Paspalum distichum)	1
East	Non-woody wetland	Sedgeland	Poor	*Eleocharis* spp.	2
East	River red gum woodland (wetland)	River Red Gum woodland	Intermediate	River red gum (Eucalyptus camaldulensis)	4
East	Woody wetland	Shrubland wetland	Intermediate	Lignum (Duma florulenta)	2
North	Flood dependent woodland	Flood dependent woodland	Intermediate	Coolibah (*Eucalyptus coolibah*)	2
North	Non-woody wetland	Marsh Grassland	Intermediate	Water Couch (*Paspalum distichum*)	1
North	Non-woody wetland	Sedgeland	Intermediate	Eleocharis spp.	3
North	Non-woody wetland	Sedgeland	Very Poor	Eleocharis spp.	2
North	River red gum forest (Wetland)	River Red Gum forest	Good	River red gum (*Eucalyptus camaldulensis*)	1
North	River red gum forest (Wetland)	River Red Gum forest	Intermediate	River red gum (*Eucalyptus camaldulensis*)	1
North	River red gum woodland	River Red Gum grassy woodland	Intermediate	River red gum (*Eucalyptus camaldulensis*)	2
North	River red gum woodland	River Red Gum grassy woodland	Poor	River red gum (*Eucalyptus camaldulensis*)	1
North	River red gum woodland (wetland)	River Red Gum woodland	Intermediate	River red gum (*Eucalyptus camaldulensis*)	7
North	River red gum woodland (wetland)	River Red Gum woodland	Intermediate/poor	River red gum (*Eucalyptus camaldulensis*)	3
North	River red gum woodland (wetland)	River Red Gum woodland	Poor	River red gum (*Eucalyptus camaldulensis*)	7
North	River red gum forest (Wetland)	River Red Gum forest	Good	River red gum (*Eucalyptus camaldulensis*)	1
North	River red gum forest (Wetland)	River Red Gum forest	Intermediate	River red gum (*Eucalyptus camaldulensis*)	1
North	Woody wetland	Shrubland wetland	Good	Lignum (*Duma florulenta*)	1
North	Woody wetland	Shrubland wetland	Intermediate	Lignum (*Duma florulenta*) / River Cooba (*Acacia stenophylla*)	1
North	Woody wetland	Shrubland wetland	Poor	Lignum (*Duma florulenta*)	1

Appendix 1 Numbers of sites in each water management region in each PCT

WMR	Hydro-ecological Functional Group	Wetland Type	Mapped condition in 2008 (Bowen and Simpson 2009)	Dominant species	No of Sites
North	Woody wetland	Shrubland wetland	Poor	Lignum (*Duma florulenta*) / River Cooba (*Acacia stenophylla*)	1
South	Flood dependent woodland	Flood dependent woodland	Intermediate	Coolibah (*Eucalyptus coolibah)*	1
South	Flood dependent woodland	Flood dependent woodland	Very Poor	Coolibah (*Eucalyptus coolibah*)	1
South	Floodplain grasslands	Floodplain grasslands	Poor	Native grasses	1
South	Floodplain grasslands	Floodplain grasslands	Very Poor	Native grasses	2
South	Non-woody wetland	Marsh grassland	Intermediate	Water Couch (*Paspalum distichum*)	6
South	Non-woody wetland	Marsh grassland	Very Poor	Water Couch (*Paspalum distichum*)	4
South	Non-woody wetland	Reedbed	Intermediate	Common Reed (*Phragmites australis*)	1
South	Non-woody wetland	Sedgeland	Intermediate	*Eleocharis* spp.	3
South	Non-woody wetland	Sedgeland	Very Poor	Eleocharis spp.	1
South	River red gum woodland	River Red Gum grassy woodland	Intermediate	River red gum (*Eucalyptus camaldulensis*)	1
South	River red gum woodland	River Red Gum grassy woodland	Poor	River red gum (*Eucalyptus camaldulensis*)	1
South	River red gum woodland (wetland)	River Red Gum woodland	Intermediate	River red gum (*Eucalyptus camaldulensis*)	1
South	River red gum woodland (wetland)	River Red Gum woodland	Poor	River red gum (*Eucalyptus camaldulensis*)	3
South	River red gum woodland	River Red Gum grassy woodland	Intermediate	River red gum (*Eucalyptus camaldulensis*)	1
Total					74

Appendix 2 Survey sites in the Macquarie Marshes 2008 - 2017

Site Code	Macquarie Marshes Region	Water Management Area	Location	NSW OEH Vegetation Class	NSW OEH Wetland Type	PCT No.	Dominant Species	Mapped Condition 1991	Mapped Condition 2008	Average Return Interval (years)
BarLgn1	South	Monkey Swamp	South Marsh - Monkey Swamp	Inland Riverine Forests	River Red Gum grassy woodland	454	River red gum	Good	Intermediate	4 to 5
BarLgn2	South	Monkey Swamp	South Marsh - Monkey Swamp	North-west Floodplain Woodlands	Flood dependent woodland	40	Coolibah	Good	Very Poor	3 to 4
Bennet11	East	Long Plain Cowal	East Marsh - Dusty creek	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Intermediate	Poor	4 to 5
BluLgtA	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Intermediate	Intermediate	1 to 2
BluLgtB	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Intermediate	Intermediate	1 to 2
BluLgtC	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Intermediate	Intermediate	1 to 2
BluLgtD	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Intermediate	Intermediate /poor	1 to 2
BluLgtE	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Intermediate	Intermediate /poor	1 to 2
BluLgtF	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Intermediate	Intermediate /poor	3 to 4
BuEfloB	South	Buckiinguy Swamp	South Marsh - Buckiinguy	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Intermediate	1 to 2
BuEfloC	South	Buckiinguy Swamp	South Marsh - Buckiinguy	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Intermediate	<1
BuEfloD	South	Buckiinguy Swamp	South Marsh - Buckiinguy	Inland Floodplain Swamps	Semi-permanent wetland	181	Common Reed	Good	Intermediate	1
Cutbus12	East	Dusty Creek	East Marsh - Dusty creek	Semi-arid floodplain grasslands	Floodplain grasslands	214	Native Millet	Intermediate	Poor	6 to 8
Cutbus7	East	Long Plain Cowal	East Marsh - Dusty creek	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Intermediate	Poor	4 to 5
ExpLgn	South	Monkeygar Wetlands	Southern Nature Reserve - Monkeygar wetlands	Inland Riverine Forests	River Red Gum grassy woodland	454	River red gum	Good	Intermediate	4 to 5
Hunts1	North	North Marsh (northern)	Northern Nature Reserve - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	1 to 2
Hunts2	North	North Marsh (northern)	Northern Nature Reserve - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	3 to 4
Hunts3	North	North Marsh (northern)	Northern Nature Reserve - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	1 to 2
KeyteLig 1	North	North Marsh (southern)	Northern Nature Reserve - West	Inland Floodplain Shrublands	Flood-dependent shrubland	247	Lignum	Good	Good	3 to 4

Appendix 2 Survey sites in the Macquarie Marshes 2008 - 2017

Site Code	Macquarie Marshes Region	Water Management Area	Location	NSW OEH Vegetation Class	NSW OEH Wetland Type	PCT No.	Dominant Species	Mapped Condition 1991	Mapped Condition 2008	Average Return Interval (years)
MM1	North	North Marsh (southern)	Northern Nature Reserve - South	Inland Riverine Forests	River Red Gum forest	36	River red gum	Good	Intermediate	<1
MM10	South	Monkey Swamp	South Marsh - Monkey Swamp	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Very Poor	4 to 5
MM11	South	Monkey Swamp	South Marsh - Monkey Swamp	North-west Floodplain Woodlands	Flood dependent woodland	40	Coolibah	Good	Intermediate	4 to 5
MM12	South	Old Macquarie	South Marsh - Old Macquarie	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Very Poor	4 to 5
MM12A	South	Old Macquarie	South Marsh - Old Macquarie	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Intermediate	Very Poor	4 to 5
MM13	North	North Marsh (southern)	Northern Nature Reserve - West	Inland Floodplain Shrublands	Flood-dependent shrubland	247	Lignum/River Cooba	Good	Good	3 to 4
MM14	North	North Marsh (southern)	Northern Nature Reserve - West	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Good	Intermediate	3 to 4
MM15	North	North Marsh (southern)	Northern Nature Reserve - South	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Good	Intermediate	3 to 4
MM16	North	Ginghet	Northern Nature Reserve - South	North-west Floodplain Woodlands	Flood dependent woodland	40	Coolibah	Good	Intermediate	6 to 8
MM19	North	North Marsh (northern)	Northern Nature Reserve - North	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Poor	Very Poor	4 to 5
MM20	North	North Marsh (southern)	North Marsh - Zoo Paddock	Inland Floodplain Shrublands	Flood-dependent shrubland	247	Lignum/River Cooba	Good	Poor	3 to 4
MM21	North	North Marsh (southern)	Northern Nature Reserve - Pillicawarrina	Inland Floodplain Shrublands	Flood-dependent shrubland	247	Lignum/River Cooba	Good	Intermediate	4 to 5
MM22	North	North Marsh (southern)	Northern Nature Reserve - Pillicawarrina	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	3 to 4
MM23	East	Gum Cowal - Terrigal	East Marsh - Wilgara	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	3 to 4
MM24	East	Gum Cowal - Terrigal	East Marsh - Wilgara	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Very Poor	3 to 4
MM6	East	Dusty Creek	East Marsh - Dusty creek	North-west Floodplain Woodlands	Flood dependent woodland	40	Coolibah	Good	Intermediate	4 to 5
MM8	South	Old Macquarie	Southern Nature Reserve - Monkeygar wetlands	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Very Poor	4 to 5
MM9	South	Old Macquarie	Southern Nature Reserve	Semi-arid floodplain grasslands	Floodplain grasslands	214	Native Millet	Intermediate	Poor	10 to 20
MMA	South	Mole Marsh	South Marsh - Mole Marsh	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Good	Intermediate	1 to 2

Appendix 2 Survey sites in the Macquarie Marshes 2008 - 2017

Site Code	Macquarie Marshes Region	Water Management Area	Location	NSW OEH Vegetation Class	NSW OEH Wetland Type	PCT No.	Dominant Species	Mapped Condition 1991	Mapped Condition 2008	Average Return Interval (years)
MMH	North	North Marsh (southern)	Northern Nature Reserve - South	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Good	Intermediate	1 to 2
MMI	North	North Marsh (southern)	Northern Nature Reserve - South	Inland Riverine Forests	River Red Gum grassy woodland	454	River red gum	Good	Intermediate	4 to 5
MoEfloA	South	Mole Marsh	South Marsh - Mole Marsh	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Good	Intermediate	1
NortNR16	North	North Marsh (southern)	Northern Nature Reserve - Bora	Inland Riverine Forests	River Red Gum forest	36	River red gum	Good	Good	1 to 2
NortNR8	North	North Marsh (southern)	Northern Nature Reserve - East	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	3 to 4
Nov_1	North	North Marsh (southern)	Northern Nature Reserve - Bora	North-west Floodplain Woodlands	Flood dependent woodland	40	Coolibah	Good	Intermediate	3 to 4
Nov_10	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	1
Nov_11	North	North Marsh (northern)	North Marsh - North	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	3 to 4
Nov_12	North	North Marsh (southern)	North Marsh - West	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	3 to 4
Nov_13	North	North Marsh (southern)	North Marsh - West	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Intermediate	1 to 2
Nov_16	East	Gum Cowal - Terrigal	Central Marsh	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	3 to 4
Nov_2	North	North Marsh (southern)	Northern Nature Reserve - Bora	Inland Riverine Forests	River Red Gum forest	36	River red gum	Good	Good	1
Nov_4	South	Buckiinguy Swamp	South Marsh - Buckiinguy	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Intermediate	1
Nov_5	South	Buckiinguy Swamp	South Marsh - Buckiinguy	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	1
Nov_7	East	Gum Cowal - Terrigal	East Marsh - Wilgara	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	1
Nov_8	East	Gum Cowal - Terrigal	East Marsh - Wilgara	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	3 to 4
Nov_9	North	North Marsh (northern)	North Marsh - East	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Intermediate	1
Oxley3	South	Monkey Swamp	South Marsh - Monkey Swamp	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Good	Intermediate	1
Oxley4	South	South Macquarie	South Marsh - Oxley	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	3 to 4

Appendix 2 Survey sites in the Macquarie Marshes 2008 - 2017

Site Code	Macquarie Marshes Region	Water Management Area	Location	NSW OEH Vegetation Class	NSW OEH Wetland Type	PCT No.	Dominant Species	Mapped Condition 1991	Mapped Condition 2008	Average Return Interval (years)
Oxley5	South	South Macquarie	South Marsh - Oxley	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	4 to 5
PoorRG1	North	North Marsh (southern)	Northern Nature Reserve - South	Inland Riverine Forests	River Red Gum grassy woodland	454	River red gum	Intermediate	Poor	4 to 5
PoorRG2	South	Old Macquarie	South Marsh - Old Macquarie	Inland Riverine Forests	River Red Gum grassy woodland	454	River red gum	Intermediate	Poor	6 to 8
StanLig1	East	Gum Cowal - Terrigal	East Marsh	Inland Floodplain Shrublands	Flood-dependent shrubland	247	Lignum	Good	Intermediate	3 to 4
StanLig2	East	Gum Cowal - Terrigal	East Marsh	Inland Floodplain Shrublands	Flood-dependent shrubland	247	Lignum	Good	Intermediate	3 to 4
UBlock1	South	Mole Marsh	South Marsh - Mole Marsh	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Intermediate	1 to 2
UBlock2	North	North Marsh (southern)	North Marsh - Mole Marsh	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	3 to 4
UBlock3	North	North Marsh (southern)	North Marsh - Mole Marsh	Inland Riverine Forests	River Red Gum forest	36	River red gum	Good	Intermediate	1
UBlock4	North	North Marsh (southern)	North Marsh - Mole Marsh	Inland Riverine Forests	River Red Gum woodland	36A	River red gum	Good	Poor	3 to 4
UBlock5	North	North Marsh (southern)	North Marsh - Mole Marsh	Inland Floodplain Swamps	Semi-permanent wetland	53	Mixed Marsh / sedge	Good	Very Poor	4 to 5
UBlock6	North	Mole Marsh	North Marsh - Mole Marsh	Inland Riverine Forests	River Red Gum grassy woodland	454	River red gum	Good	Intermediate	4 to 5
WiEfloA	South	Monkeygar Wetlands	South Marsh - Monkeygar Wetlands	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Intermediate	1
WiEfloB	South	Monkeygar Wetlands	South Marsh - Monkeygar Wetlands	Inland Floodplain Swamps	Semi-permanent wetland	204	Water Couch	Good	Intermediate	1 to 2
Willan4	South	Monkey Swamp	South Marsh - Monkey Swamp	Semi-arid floodplain grasslands	Floodplain grasslands	214	Native Millet	Good	Very Poor	10 to 20
Willan5	South	Monkey Swamp	South Marsh - Monkey Swamp	Semi-arid floodplain grasslands	Floodplain grasslands	214	Native Millet	Intermediate	Very Poor	10 to 20
ZooligA	North	North Marsh (southern)	North Marsh - Zoo Paddock	Inland Floodplain Shrublands	Flood-dependent shrubland	247	Lignum	Good	Poor	3

Appendix 3 Survey methods

1. Floristic community condition - Non-woody submerged and floating aquatic and fringing or dense wetland vegetation (e.g.: reeds, club-rush, and lignum)

Transect method (Point intercept method). One 50 metre transect is placed from fringing edge into water to depth where vegetation no longer occurs, or 1.25 metres depth is reached. Photos are taken at each end of the transect or when 1.25 metres depth is reached. Photos are taken at each end of the transect. Three transects per 500 ha of wetland are the minimum. IF placed in dense shrubland the transect are run parallel and not within 100 m of each other.

1.1 At each 10 centimetre point the species, bare ground or litter directly below or and/or touching the tape are recorded.

1.2 Height of each species is recorded in metres.

1.3 Reproductive status is recorded.

1.4 Dead plants are recorded.

1.5 Water depth in cm.

1.6 Percent live foliage

1. Floristic community condition - Non-woody wetland vegetation and woody shrub lands

For non-tree dominated vegetation communities; i.e.; non-woody wetlands without standing water bodies and flood dependent open shrub lands.

2.1 Site markup

Appendix 3 Survey methods

2.1.1 At each survey location (per wetland) 3 replicate plots of 0.04 ha are used within each vegetation community. The dimensions of each sample plot are usually 20x20 m but 40x10m can be used in narrow sites (e.g. riverine corridors).

2.1.2 The NE corner is marked (permanently if possible with a fibreglass pole of 2 metres height) and a GPS point taken.

2.1.3 Plot is oriented north/south (i.e. tape is run 20 m S and 20 m W, then 20 m S starting from the NE corner). Alternate orientation is allowable but must be recorded. Corners should be marked (temporarily or permanently) with sighting flags or pegs.

2.1.4 Four site photographs are taken; 1. from the NE corner looking SE, 2, mid-point of N boundary looking S, 3. NE corner looking SW and 4. midpoint of S boundary looking N.

2.2 Vegetation diversity and structure (0.04 ha plot)

Recorded for all vascular species and recorded separately for each structural component of the vegetation (Tallest stratum, mid-stratum (>1m) and lower (≤1 m) stratum). Any species not able to be identified in the field is tagged, given a code, recorded and collected for identification.

2.2.1 Percent Foliage Cover (%FC) the percentage of the sample plot occupied by the vertical projection of *foliage and branches* (if woody) of a species for in each stratum in which it occurs.

Appendix 3 Survey methods

2.2.2 Crown Extent (CE) and Canopy openness (CO) is collected for all tree species in the tallest stratum in treed communities to allow the calculation of FC and Canopy Cover (CC) for the plot for each.

Note: Crown cover (CC) is the percentage of the samples site within the vertical projection of the periphery of crowns. In this case, crowns are treated as opaque. (Ayers et al 2009).

2.2.3 Litter is the percentage of the sample plot occupied by litter (non-attached plant matter e.g. leaves and branches less than 10 cm diameter) and is recorded as the sum of submerged and non-submerged litter in flooded plots.

Note: where plants are dry or dead but can still be identified to species and are attached to the base of the plant, their cover is included in the species cover not in per cent litter.

2.2.4 Bare ground is the percentage of the sample plot occupied by bare earth and is recorded as the sum of submerged and non-submerged bare ground in flooded plots.

Note: Total %FC for lower stratum (≤1 m) = (Σ%FC $_{(Species)}$ + % litter + %bare ground) =100%, unless lower stratum space is occupied by mid storey emergent tussock form graminoid or spreading shrub species >1m tall (e.g. Lignum, rushes or reeds).

Thus, the sum of the lower stratum items plus the sum of the middle stratum species percentage foliage cover = 100%, i.e.: (Σ%FC $_{(LS\ Species)}$ + % litter + %bare ground) - Σ%FC $_{(MS\ Species)}$ = 100%

In flooded sites total %FC lower (ground) stratum includes; submerged vegetation, submerged bare ground and submerged litter.

2.2.5 Species Abundance (Number of individuals = actual count or (estimated number from subquadrats for superabundant species) in each stratum in which it occurs.

2.2.6 Upper height (average) of each species is recorded (metres)

2.2.7 Strata type (T=tallest, M=mid (>1m), L = lower (≤1 m)

3. Tree stand condition

For vegetation communities dominated by flood dependent trees in the over storey (e.g. River red gum, Black box or Coolibah). A 0.1 ha (20x50 m) survey plot is used. This an extension of the 20x20 m plot created by extending the eastern and western boundaries by 30 m thus creating a nested 0.04 ha plot within the 0.1 ha survey plot. (See DECC 2011 pg. 80). The orientation of the plot can be altered to suit the site however the orientation of the plot must be noted in the notes column of the data entry form if other than south.

3.1 Understorey floristics (plant community condition)

Floristic data is collected from the 0.04ha subplot as described in Section 2.2 above.

3.2 Tree size, canopy health and population demographics

For trees >10 cm dbh tree health data and tree size data is collected from the entire 0.1 ha plot. Tree canopy health metrics recorded are comparable to those used in the Living Murray (TLM), Tree and Stand condition method of Cunningham et al (2009).

Appendix 3 Survey methods

3.2.1 Tree size classes

Each tree within the 0.1 ha plot of dbh (diameter at breast height), greater than 10 cm (live or dead), is numbered starting from the tree closest to the NE corner of the 0.04 ha plot. Each live tree is tagged for future relocation (e.g. numbered aluminium tag and galvanized nails). All trees are recorded as within the 0.04 ha or within the remainder of the 0.1 ha subplots to allow separate calculation of values for %CC and %FC for species in the tallest stratum in the 0.04 ha plot.

3.2.1.1 <u>Tree height</u> (m) of all over storey trees (live or dead) is estimated and recorded.

3.2.1.2 <u>Diameter at breast height</u> (dbh) (in centimetres) of all over storey trees recorded as live or dead) over 10 cm dbh is recorded (cm using a dbh tape).

3.2.1.3 <u>Saplings</u> (trees 5-10 cm dbh), a record of the total number of (live and dead) in this size class is recorded separately for the 0.04 ha and remainder of the 0.1 ha plot.

3.2.2 Tree stand condition - Field Metrics

The following metrics are used assess the size and canopy health of each numbered tree (live or dead): Dead trees only numbered for counting and demographic analysis purposes at first monitoring sample point. Dead trees are only assessed for size class analysis at time of first sampling.

3.2.2.1 <u>Canopy Extent</u> - $CE_{(tree)}$.

The 2-dimensional lateral spread (length x width) of the branches and foliage of a live tree, or the limbs of a dead tree, measured from the edge to edge of the remaining bare limbs or branches.

Note: CE $_{(tree)}$ is used to derive Canopy Cover (CC $_{(Species)}$) for the plot (live trees only) and size distribution classes of trees within population at site (all trees).

3.2.2.2 Canopy openness - CO $_{(tree)}$

Is estimated as the percentage of the sky that is obscured by the canopy (leaves and small branches).

3.2.2.3 Percentage Dead Canopy - DC $_{(tree)}$

Is the percentage of the tree canopy CE $_{(tree)\ that}$ is dead or severely damaged.

For example, a large dead tree with spreading bare branches measuring 10 m x 10 m and no existing foliage would have a remnant CE of 100 m^2 but would have CO = 0% and %DC = 100%. A large live tree with dimensions of 10 m x 10 m would have CE of 100 m^2, and a %DC < 100% and a CO > 0%).

3.2.2.4 Percentage dead limbs - %DL $_{(tree)}$

Is the number of dead major limbs as a percentage of the total number recorded.

Major limbs are limbs arising from the main trunk or from multiple stems but not branches. For example: a tree with 4 major limbs and one dead, %DL = 1 of 4 or 25%.

3.2.3. Tree breeding status and tree site habitat value – field Metrics

3.2.3.1 Breeding status - the presence of flowers (F) and / or buds (B) and or / fruit (Fr) is recorded for each numbered tree.

3.2.3.2 Number of hollows - appropriate for hollow dependent (fauna that can be seen with the aid of binoculars is recorded for each numbered tree.

Note: Hollows are defined as in Rayner *et al*. (2013): cavity with entrance diameter >1cm and depth = ≥ entrance dimension.

3.2.3.3 Number of nests is recorded for each numbered tree.

3.2.3.4 Mistletoe presence is recorded for each numbered tree.

3.2.3.5 Insect damage (Heavy (H), Moderate (M) or Light (L) is recorded for each numbered tree.

3.2.4. Tree Recruitment – Field Metrics

For all individuals of the over storey tree species present as recruits in the population the following data is recorded:

3.2.4.1 Total number of seedlings - stems that are <10 dbh and < 1 m tall and are not sprouting from a coppiced rootstock, are treated as seedlings and the number is recorded separately for the 0.04 ha and remainder of the 0.1 ha plot.

3.2.4.2 Total number of saplings - stems that are <10cm dbh and > 1 m tall and are not sprouting from a coppiced rootstock, are treated as saplings and the number is and the number is recorded separately for the 0.04 ha and remainder of the 0.1 ha plot.

4. Site Flooding Data – Field metrics

Appendix 3 Survey methods

At all floristic sites the following site flooding parameters are recorded within the 0.04 ha plot to define its inundation state:

4.1. % plot flooded

4.2 % plot wet soil (if not underwater)

4.3 % open water (recording the following components)

i. % submerged litter

ii. % submerged bare ground

iii. % submerged veg (species)

4.4 % unsubmerged litter

4.5 % unsubmerged bare ground

4.6 Average water depth (cm)

5. Tree stand condition - Derived metrics

A number of metrics are derived from the field collected metrics above for each species in the tallest stratum in treed communities:

5.4 Average canopy openness

The average of the canopy openness CO of all trees of each species for the plot expressed as a per cent. I.e.: $\bar{x}CO_{(Species\ x)}$.

5.1 Total Crown Cover - $CC_{(Species\ x)}$

Crown cover is a measure used to classify vegetation structural type and is used in the OEH Vegetation Type Standard (Sivertsen 2009). It is derived for each species in the overstorey stratum of the plot by the sum of canopy extent $CE_{(tree)}$ of all trees of that species. I.e.: ($\sum CE_{(tree)}$) of Species x = $CC_{(Species\ x)}$.

5.2 Total Percentage Foliage Cover - $\%FC_{(Species\ x)}$

The percentage of the sample site occupied by the vertical projection of foliage and branches (Walker and Hopkins 1998). Equivalent to the amount of shadow that would be cast on the ground if there were a light source directly overhead (Ayers et al 2009; DECC 2011). Percentage foliage cover is derived from Foliage Cover for that species $FC_{(Species\ x)}$).

Foliage cover is the sum of all the Crown Cover CC for species x ($\sum CC_{(Species\ x)}$) multiplied by the average Crown openness ($\bar{x}CO_{(Species\ x)}$) for species x to give the area covered by that species, i.e.: $\sum CC_{(Species\ x)}$ x $\bar{x}CO_{(Species\ x)}$. For example, if $\sum CC_{(Species\ x)} = 450m^2$ and the $\bar{x}CO_{(Species\ x)} = 45\%$ then: $FC_{(Species\ x)} = 450\ m^2 \times 0.45 = 202.3\ m^2$

Percentage foliage cover for species x $\%FC_{(Species\ x)}$ in a 1000 m^2 plot is then 202.3/1000 = 0.203 or 20.3%.

5.3 Plant Area Index (PAI)

In a 1000 m^2 plot PAI is analogous to %Foliage Cover and is a value between 0 and 1, derived by dividing the percentage foliage cover for the plot by 100. E.g. $\%FC_{(Species\ x)} = 20.3\%$ and plot size is 1000m^2 then $PAI_{(Species\ x)} = 20.3/100 = 0.203$.

5.4 Average percentage dead canopy

The average of the percentage dead canopy %DC of all trees of each species for the plot expressed as a per cent. I.e.: $\bar{x}$ %DC $_{(\text{Species x})}$.

5.5 Average percentage Dead limbs

The average % dead limbs as a proportion of total limbs for the plot expressed as a per cent. I.e.: $\bar{x}$%DL $_{(\text{Species x})}$.

5.6 Percentage live basal area

Percentage live basal area for the plot was calculated from the sum of the DbH of all live trees converted to basal area, divided by the sum of the DbH of all trees converted to basal area, and then averaged for the site:

1. For each species calculate the Basal Area (BA) of each stem using the following formula:

$$BA\ (cm^2) = \pi \times (dbh\ (cm)/2)^2.$$

2. Calculate total Live Basal Area for the plot by calculating the sum of the BA for all 'live trees'.
3. Calculate Total Basal Area for the plot by calculating the sum of the BA for all trees (live and dead).
4. Calculate LBA for the plot using the following formula:

$$\%LBA_{(\text{Species x})} = 100 \times (\text{total live BA}_{(\text{Species x})} / \text{total BA}_{(\text{Species x})})$$

Appendix 4 Rate of change in inundation frequency MD and Post MD period

The blue line represents the trend analysis for the period incorporating the major drought period. The red line represents the rate of inundation change post drought. Text annotations are the other flood variables in the model; The sum of floods in the periods 1988-1998, 1998-2008, 2008-2017. Not presented are the other predictors; Grazing Pressure, Year, or Wetland Type

Appendix 5 Species list for the Macquarie Marshes with Water Plant Functional Groups

Growth habit; C - Chenopod Shrub, E - Fern, Ep - Epiphyte, F - Forb, G - Tussock Grass, L - Vine, R - Rush, S - Shrub, T - Tree, V – Sedge. Strata type; L – Lower, M – Mid, T - Tallest. Species Code; Census of Australian Plant Species (CAPS) Number (OEH 2012). Tdr = Terrestrial dry, Tda = Terrestrial damp, ATw = Amphibious Tolerator (woody), ATe = Amp. Tol. (emergent), ARp = Amp. Responder (plastic), ARl = Amp. Resp. (low growing), ARf = Amp. Resp. (floating), Se and Sr = Semi- Aquatic

Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Abutilon fraseri	3627	Dwarf Lantern-flower	Tdr	F	L	N	Malvaceae
Abutilon halophilum	3629	Plains LanternBush	Tdr	F	L	N	Malvaceae
Abutilon otocarpum	7184	Desert Lantern	Tdr	F	L	N	Malvaceae
Abutilon oxycarpum	3632	Straggly Lantern-bush	Tdr	F	L	N	Malvaceae
Abutilon spp.	ABUT	Lantern-bush	Tdr	F	L	N	Malvaceae
Abutilon theophrasti	3633	Swamp Chinese Lantern	Tdr	F	L	Ex	Malvaceae
Acacia melvillei	3825	Yarran	Tdr	T	T	N	Fabaceae (Mimosoideae)
Acacia oswaldii	3843	Miljee	Tdr	S	M	N	Fabaceae (Mimosoideae)
Acacia pendula	3848	Boree	Tdr	T	M	N	Fabaceae (Mimosoideae)
Acacia salicina	3872	Cooba	Tdr	T	M	N	Fabaceae (Mimosoideae)
Acacia spp.	ACAC	Wattle	Tda	S	M	N	Fabaceae (Mimosoideae)
Acacia stenophylla	3879	River Cooba	ATw	T	T	N	Fabaceae (Mimosoideae)
Acacia victoriae	3898	Prickly Wattle	Tdr	S	M	N	Fabaceae (Mimosoideae)
Acacia victoriae subsp. arida	9701	Prickly Wattle	Tdr	S	M	N	Fabaceae (Mimosoideae)
Actinobole uliginosum	1253	Flannel Cudweed	Tdr	F	L	N	Asteraceae
Aeschynomene indica	7513	Budda Pea	Tda	S	L	N	Fabaceae (Faboideae)
Alectryon oleifolius	7015	Western Rosewood	Tdr	T	M	N	Sapindaceae
Alectryon oleifolius subsp. canescens	6639	Western Rosewood	Tdr	T	M	N	Sapindaceae
Alopecurus geniculatus	4735	Marsh Foxtail	Tda	G	L	Ex	Poaceae
Alternanthera denticulata	6478	Lesser Joyweed	Tda	F	L	N	Amaranthaceae
Alternanthera nana	7079	Hairy Joyweed	Tda	F	L	N	Amaranthaceae
Alternanthera nodiflora	1049	Common Joyweed	Tda	F	L	N	Amaranthaceae
Alternanthera pungens	7191	Khaki Weed	Tda	F	L	Ex	Amaranthaceae
Alternanthera spp.	ALTE	Joyweed	Tda	F	L	N	Amaranthaceae
Amaranthus macrocarpus	1057	Dwarf Amaranth	Tdr	F	L	N	Amaranthaceae
Amaranthus mitchellii	1058	Boggabri Weed	Tdr	F	L	N	Amaranthaceae
Amaranthus spp.	AMAR	Amaranth	Tdr	F	L	N	Amaranthaceae
Ammannia multiflora	7877	Jerry-jerry	Tda	F	L	N	Lythraceae
Amphibromus neesii	6548		ATe	G	L	N	Poaceae
Amphibromus nervosus	6842	Swamp Wallaby Grass	Tda	G	L	N	Poaceae

Appendix 5 Species list for the Macquarie Marshes with Water Plant Functional Groups

Growth habit; C - Chenopod Shrub, E - Fern, Ep - Epiphyte, F - Forb, G - Tussock Grass, L - Vine, R - Rush, S - Shrub, T - Tree, V – Sedge. Strata type; L – Lower, M – Mid, T - Tallest. Species Code; Census of Australian Plant Species (CAPS) Number (OEH 2012). Tdr = Terrestrial dry, Tda = Terrestrial damp, ATw = Amphibious Tolerator (woody), ATe = Amp. Tol. (emergent), ARp = Amp. Responder (plastic), ARl = Amp. Resp. (low growing), ARf = Amp. Resp. (floating), Se and Sr = Semi- Aquatic

Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Amyema lucasii	3604	Yellow-flowered Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Amyema miquelii	6394	Box Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Amyema miraculosum	3606	Fleshy Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Amyema preissii	3608	Wire-leaf Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Amyema quandang	3609	Grey Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Amyema quandang var. quandang	7630	Grey Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Anagallis arvensis	5334	Scarlet Pimpernel	Tda	F	L	Ex	Myrsinaceae
Apophyllum anomalum	1942	Warrior Bush	Tdr	S	M	N	Capparaceae
Argemone ochroleuca subsp. ochroleuca	7115	Mexican Poppy	Tdr	F	L	Ex	Papaveraceae
Aristida calycina	4756	Dark Wiregrass	Tdr	G	L	N	Poaceae
Aristida leptopoda	4762	White Speargrass	Tdr	G	L	N	Poaceae
Asperula conferta	5653	Common Woodruff	Tdr	F	L	N	Rubiaceae
Asperula gemella	10203	Twin-leaved Bedstraw	Tda	F	L	N	Rubiaceae
Aster subulatus	1280	Wild Aster	Tda	F	L	Ex	Asteraceae
Asteraceae indeterminate	ASTRC	Daisies	Tdr	F	L	N	Asteraceae
Astrebla elymoides	7273	Hoop Mitchell Grass	Tda	G	L	N	Poaceae
Astrebla lappacea	4778	Curly Mitchell Grass	Tdr	G	L	N	Poaceae
Astrebla pectinata	7565	Barley Mitchell Grass	Tda	G	L	N	Poaceae
Atalaya hemiglauca	6365	Whitewood	Tdr	T	M	N	Sapindaceae
Atriplex eardleyae	2049	Small Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex leptocarpa	6368	Slender-fruit Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex lindleyi	2056	Eastern Flat-top Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex muelleri	2061	Mueller's Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex nummularia	2063	Old Man Saltbush	Tdr	C	M	N	Chenopodiaceae
Atriplex pseudocampanulata	2066	Mealy Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex semibaccata	2070	Creeping Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex spinibractea	2071	Spiny-fruit Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex spp.	ATRI	A Saltbush	Tdr	C	L	N	Chenopodiaceae
Atriplex suberecta	2075		Tdr	C	L	N	Chenopodiaceae

Appendix 5 Species list for the Macquarie Marshes with Water Plant Functional Groups

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Atriplex vesicaria	2078	Bladder Saltbush	Tdr	C	L	N	Chenopodiaceae
Auranticarpa rhombifolia	11201	Diamond-leaf Pittosporum	Tda	T	T	N	Pittosporaceae
Austrodanthonia caespitosa	10621	Ringed Wallaby Grass	Tdr	G	L	N	Poaceae
Austrodanthonia richardsonii	10631	Straw Wallaby-grass	Tdr	G	L	N	Poaceae
Austrodanthonia setacea	10632	Smallflower Wallaby Grass	Tdr	G	L	N	Poaceae
Austrodanthonia spp.	AUSR	A Wallaby Grass	Tdr	G	L	N	Poaceae
Austrostipa aristiglumis	10384	Plains Grass	Tdr	G	L	N	Poaceae
Austrostipa bigeniculata	10386	Yanganbil	Tdr	G	L	N	Poaceae
Austrostipa nitida	10375		Tdr	G	L	N	Poaceae
Austrostipa ramosissima	9918	Stout Bamboo Grass	Tda	G	L	N	Poaceae
Austrostipa scabra	10377	Speargrass	Tdr	G	L	N	Poaceae
Austrostipa scabra subsp. scabra	10378	Rough Speargrass	Tdr	G	L	N	Poaceae
Austrostipa setacea	10382	Corkscrew Grass	Tdr	G	L	N	Poaceae
Austrostipa spp.	AUSO	A Speargrass	Tdr	G	L	N	Poaceae
Austrostipa verticillata	10371	Slender Bamboo Grass	Tdr	G	L	N	Poaceae
Avena fatua	4780	Wild Oats	Tdr	G	L	Ex	Poaceae
Azolla filiculoides	9260	Pacific Azolla	ARf	F	L	N	Azollaceae
Azolla spp.	AZOL		ARf	F	L	N	Azollaceae
Bergia trimera	7880	Small Water-fire	Tdr	F	L	N	Elatinaceae
Bidens pilosa	1283	Cobbler's Pegs	Tdr	F	L	Ex	Asteraceae
Boerhavia dominii	6841	Tarvine	Tdr	F	L	N	Nyctaginaceae
Bolboschoenus caldwellii	2305	Club-rush	Se	V	M	N	Cyperaceae
Bolboschoenus fluviatilis	2306	Marsh Club-rush	Se	V	M	N	Cyperaceae
Bolboschoenus spp.	BOLB	Club-rush	Se	V	L	N	Cyperaceae
Brachyachne ciliaris	4798	Hairy Native Couch	Tda	G	L	N	Poaceae
Brachyscome basaltica var. gracilis	10401	Swamp Daisy	Tda	F	L	N	Asteraceae
Brachyscome dentata	11056		Tda	F	L	N	Asteraceae
Brachyscome goniocarpa	7562	Dwarf Daisy	Tda	F	L	N	Asteraceae
Brachyscome gracilis	6542	Dookie Daisy	Tdr	F	L	N	Asteraceae
Brachyscome melanocarpa	6566	Black-seeded Daisy	Tda	F	L	N	Asteraceae
Brachyscome spp.	BRAC		Tda	F	L	N	Asteraceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Brassica spp.	BRAS	Brassica	Tdr	F	L	Ex	Brassicaceae
Brassica tournefortii	1790	Mediterranean Turnip	Tdr	F	L	Ex	Brassicaceae
Bromus catharticus	7813	Praire Grass	Tdr	G	L	Ex	Poaceae
Brunonia australis	1863	Blue Pincushion	Tdr	F	L	N	Goodeniaceae
Brunoniella australis	1003	Blue Trumpet	Tdr	F	L	N	Acanthaceae
Brunoniella spp.	BRUN	Blue Trumpet	Tdr	F	L	N	Acanthaceae
Buglossoides arvensis	8707	Sheepweed	Tdr	F	L	Ex	Boraginaceae
Bulbine bulbosa	3531	Bulbine Lily	Tdr	F	L	N	Asphodelaceae
Bulbine semibarbata	3532	Wild Onion	Tdr	F	L	N	Asphodelaceae
Burnettia cuneata	4368	Lizard Orchid	Tda	F	L	N	Orchidaceae
Bursaria spinosa	4674	Native Blackthorn	Tdr	F	L	N	Pittosporaceae
Bursaria spp.	BURS	Native Blackthorn	Tdr	S	L	N	Pittosporaceae
Callitris endlicheri	2279	Black Cypress Pine	Tdr	T	T	N	Cupressaceae
Callitris glaucophylla	6379	White Cypress Pine	Tdr	T	T	N	Cupressaceae
Calocephalus sonderi	1332	Pale Beauty-heads	Tda	F	L	N	Asteraceae
Calostemma purpureum	3537	Garland lily	Tdr	F	L	N	Amaryllidaceae
Calotis hispidula	1342	Bogan Flea	Tda	F	L	N	Asteraceae
Calotis lappulacea	1344	Yellow Burr-daisy	Tdr	F	L	N	Asteraceae
Calotis scabiosifolia	1347	Rough Burr-daisy	Tdr	F	L	N	Asteraceae
Calotis scabiosifolia var. scabiosifolia	7929	Rough Burr-daisy	Tdr	F	L	N	Asteraceae
Calotis scapigera	1348	Tufted Burr-daisy	Tdr	F	L	N	Asteraceae
Calotis spp.	CALI	A Burr-daisy	Tdr	F	L	N	Asteraceae
Capparis lasiantha	6374	Nepine	Tdr	S	M	N	Capparaceae
Capparis mitchellii	1945	Native Orange	ATe	S	M	N	Capparaceae
Capsella bursa-pastoris	1794	Shepherd's Purse	Tdr	F	L	Ex	Brassicaceae
Carex appressa	2310	Tall Sedge	ATe	V	L	N	Cyperaceae
Carex inversa	2327	Knob Sedge	Tda	V	L	N	Cyperaceae
Carex spp.	CARE	Knob Sedge	ATe	V	L	N	Cyperaceae
Carthamus lanatus	1358	Saffron Thistle	Tdr	F	L	Ex	Asteraceae
Cassytha melantha	3468	Dodder	Tdr	V	L	N	Lauraceae
Cassytha spp.	CASY	Dodder	Tdr	V	L	N	Lauraceae
Casuarina cristata	2019	Belah	Tdr	T	T	N	Casuarinaceae
Casuarina pauper	9289	Black Oak	Tdr	T	T	N	Casuarinaceae
Cenchrus ciliaris	6413	Buffel Grass	Tda	G	L	Ex	Poaceae
Centaurea melitensis	1382	Maltese Cockspur	Tdr	F	L	Ex	Asteraceae

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Centaurea solstitialis	1383	St Barnabys Thistle	Tdr	F	L	Ex	Asteraceae
Centaurium tenuiflorum	3133	Branched Centaury, Slender Centaury	Tdr	F	L	Ex	Gentianaceae
Centipeda cunninghamii	1384	Common Sneezeweed	Tda	F	L	N	Asteraceae
Centipeda minima subsp. minima	14360	Small Sneezeweed	Tda	F	L	N	Asteraceae
Centipeda pleiocephala	12719	Tall Sneezeweed	Tda	F	L	N	Asteraceae
Centipeda spp.	CENT	Sneezeweed	Tda	F	L	N	Asteraceae
Centipeda thespidioides	1386	Desert Sneezeweed	Tda	F	L	N	Asteraceae
Chamaesyce dallachyana	9193	Caustic Weed	Tda	F	L	N	Euphorbiaceae
Chamaesyce drummondii	9193	Caustic Weed	Tdr	F	L	N	Euphorbiaceae
Chamaesyce spp.	CHAM	Caustic Weed	Tdr	F	L	N	Euphorbiaceae
Chara spp.	11408	Chara	Sr	F	L	N	Characeae
Chenopodium album	2084	Fat Hen	Tdr	C	L	Ex	Chenopodiaceae
Chenopodium ambrosioides	2085	Mexican Tea	Tdr	C	L	N	Chenopodiaceae
Chenopodium auricomiforme	2086		Tdr	C	L	N	Chenopodiaceae
Chenopodium desertorum	2091	Desert Goosefoot	Tdr	C	L	N	Chenopodiaceae
Chenopodium melanocarpum	2095	Black Crumbweed	Tdr	C	L	N	Chenopodiaceae
Chenopodium murale	2097	Nettle-leaf Goosefoot	Tdr	C	L	N	Chenopodiaceae
Chenopodium nitrariaceum	2098	Nitre Goosefoot	Tdr	C	L	N	Chenopodiaceae
Chenopodium pumilio	2099	Small Crumbweed	Tdr	C	L	N	Chenopodiaceae
Chenopodium spp.	CHEN	Goosefoot, Crumbweed	Tdr	C	L	N	Chenopodiaceae
Chloris divaricata var. divaricata	9134	Slender Chloris	Tda	G	L	N	Poaceae
Chloris gayana	4831	Rhodes Grass	Tdr	G	L	Ex	Poaceae
Chloris truncata	4833	Windmill Grass	Tdr	G	L	N	Poaceae
Chloris ventricosa	4834	Tall Chloris	Tdr	G	L	N	Poaceae
Chrysocephalum apiculatum	8559	Common Everlasting	Tdr	F	L	N	Asteraceae
Chrysocephalum pterochaetum	9409	Perennial Sunray	Tdr	F	L	N	Asteraceae
Cichorium intybus	1397	Chicory	Tdr	F	L	Ex	Asteraceae
Cirsium vulgare	1400	Spear Thistle	Tdr	F	L	Ex	Asteraceae
Citrullus lanatus	2250	Camel Melon	Tdr	L	L	Ex	Cucurbitaceae

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Citrullus lanatus var. lanatus	9436	Wild Melon, Camel Melon,Bitter	ATe	L	L	Ex	Cucurbitaceae
Citrus glauca	10760	Desert Lime	Tdr	S	M	N	Rutaceae
Commelina cyanea	2209	Native Wandering Jew	Tda	F	L	N	Commelinaceae
Convolvulus erubescens	2220	Pink Bindweed	Tda	L	L	N	Convolvulaceae
Convolvulus graminetinus	11616		Tda	L	L	N	Convolvulaceae
Convolvulus spp.	CONV	A Bindweed	Tda	L	L	N	Convolvulaceae
Conyza albida	1402	Tall Fleabane	Tda	F	L	Ex	Asteraceae
Conyza bonariensis	1404	Flaxleaf Fleabane	Tdr	F	L	Ex	Asteraceae
Conyza spp.	CONY	A Fleabane	Tdr	F	L	Ex	Asteraceae
Conyza sumatrensis	10442	Tall fleabane	Tda	F	L	Ex	Asteraceae
Corymbia tessellaris	9744	Carbeen	Tda	T	T	N	Myrtaceae
Cotula australis	1412	Common Cotula	Tdr	F	L	N	Asteraceae
Cotula coronopifolia	1414	Water Buttons	ARp	F	L	Ex	Asteraceae
Craspedia haplorrhiza	10154	Billy Buttons	Tda	F	L	N	Asteraceae
Crassula colorata	2237	Dense Stonecrop	Tdr	F	L	N	Crassulaceae
Cressa australis	11066		ATe	L	L	N	Convolvulaceae
Crinum flaccidum	6607	Darling Lily	Tdr	F	L	N	Amaryllidaceae
Cucumis melo subsp. agrestis	7330	Ulcardo Melon	Tdr	L	L	N	Cucurbitaceae
Cucumis myriocarpus subsp. leptodermis	11072	Paddy Melon	Tdr	L	L	Ex	Cucurbitaceae
Cullen cinereum	10668	Annual Verbine	Tdr	S	L	N	Fabaceae (Faboideae)
Cullen tenax	10674	Emu-foot	Tda	F	L	N	Fabaceae (Faboideae)
Cuscuta campestris	2287	Golden Dodder	Tdr	L	L	Ex	Convolvulaceae
Cyclospermum leptophyllum	11195	Slender Celery	Tdr	F	L	Ex	Apiaceae
Cymbidium canaliculatum	6399	Tiger Orchid	Tdr	Ep	Canopy	N	Orchidaceae
Cymbidium spp.	CYMB		Tdr	Ep	Canopy	N	Orchidaceae
Cynodon dactylon	6540	Common Couch	Tda	G	L	N	Poaceae
Cyperus bifax	2351	Downs Nutgrass	ATe	V	L	N	Cyperaceae
Cyperus concinnus	2357	Trim Flat-sedge	ATe	V	L	N	Cyperaceae
Cyperus difformis	7143	Dirty Dora	ATl	V	L	N	Cyperaceae
Cyperus exaltatus	2366	Giant Sedge	ATe	V	L	N	Cyperaceae
Cyperus gracilis	2374	Slender Flat-sedge	ATe	V	L	N	Cyperaceae
Cyperus gunnii subsp. gunnii	9145	Flecked Flat-sedge	ATe	V	L	N	Cyperaceae

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Cyperus spp.	CYPE	Flat-sedge	ATe	V	L	N	Cyperaceae
Dactyloctenium radulans	7178	Button Grass	Tdr	G	L	N	Poaceae
Damasonium minus	1044	Starfruit	ARp	F	L	N	Alismataceae
Daucus glochidiatus	1109	Native Carrot	Tdr	F	L	N	Apiaceae
Daucus spp.	DAUC		Tdr	F	L	N	Apiaceae
Desmodium campylocaulon	2835	Creeping Tick-trefoil	Tdr	F	L	N	Fabaceae (Faboideae)
Desmodium varians	2840	Slender Tick-trefoil	Tdr	F	L	N	Fabaceae (Faboideae)
Dianella spp.	DIAN		Tdr	F	L	N	Phormiaceae
Dichanthium sericeum	7485	Queensland Bluegrass	Tda	G	L	N	Poaceae
Dichondra spp.	DICN		Tdr	F	L	N	Convolvulaceae
Digitaria ammophila	4901	Silky Umbrella Grass	Tdr	G	L	N	Poaceae
Digitaria divaricatissima	4907	Umbrella Grass	Tdr	G	L	N	Poaceae
Digitaria hubbardii	4908		Tdr	G	L	N	Poaceae
Digitaria spp.	DIGI	A Finger Grass	Tdr	G	L	N	Poaceae
Diplachne fusca	4920	Brown Beetle Grass	ATe	G	L	Ex	Poaceae
Dissocarpus biflorus	2102	Twin-horned Copperburr	Tdr	C	L	N	Chenopodiaceae
Dissocarpus paradoxus	2103	Cannonball Burr	Tdr	C	L	N	Chenopodiaceae
Duma florulenta	14542	Lignum	ATw	S	M	N	Polygonaceae
Dysphania pumilio	2099	Small Crumbweed	Tdr	C	L	N	Chenopodiaceae
Echinochloa colona	7607	Awnless Barnyard Grass	Tda	G	L	N	Poaceae
Echinochloa crus-galli	4923	Barnyard Grass	Tda	G	L	Ex	Poaceae
Echinochloa inundata	4925	Marsh Millet	ATe	G	L	N	Poaceae
Echinochloa spp.	ECHI		Tda	G	L	Ex	Poaceae
Echinochloa turneriana	7290	Channel Millet	ATe	G	L	N	Poaceae
Echium plantagineum	1751	Patterson's Curse	Tdr	F	L	Ex	Boraginaceae
Eclipta platyglossa	7903	Yellow Twin-heads	Tda	L	L	N	Asteraceae
Eichhornia crassipes	5305	Water Hyacinth	ARf	F	L	Ex	Pontederiaceae
Einadia hastata	2110	Berry Saltbush	Tda	C	L	N	Chenopodiaceae
Einadia nutans	2111	Climbing Saltbush	Tdr	C	L	N	Chenopodiaceae
Einadia nutans subsp. linifolia	6481	Climbing Saltbush	Tdr	C	L	N	Chenopodiaceae
Einadia nutans subsp. nutans	6482	Climbing Saltbush	Tdr	C	L	N	Chenopodiaceae
Einadia polygonoides	2112	Knotweed Goosefoot	Tda	C	L	N	Chenopodiaceae
Elatine gratioloides	2579	Waterwort	ATl	F	L	N	Elatinaceae
Eleocharis acuta	2408	Common Spike Rush	ATe	V	L	N	Cyperaceae

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Eleocharis gracilis	2414	Spike Rush	ATe	V	L	N	Cyperaceae
Eleocharis pallens	2418	Pale Spike Sedge	ATe	V	L	N	Cyperaceae
Eleocharis plana	2421	Flat Spike-sedge	ATe	V	L	N	Cyperaceae
Eleocharis pusilla	2422	Small Spike Rush	ATe	V	L	N	Cyperaceae
Eleocharis sphacelata	6988	Tall Spike Rush	ATe	V	L	N	Cyperaceae
Eleocharis spp.	ELEO	Spike-rush, Spike-sedge	ATe	V	L	N	Cyperaceae
Emex australis	5266	Spiny Emex	Tdr	F	L	Ex	Polygonaceae
Enchylaena spp.	ENCH		Tdr	C	M	N	Chenopodiaceae
Enchylaena tomentosa	2114	Ruby Saltbush	Tdr	C	M	N	Chenopodiaceae
Enneapogon avenaceus	6720	Bottle Washers	Tda	G	L	N	Poaceae
Enneapogon nigricans	4945	Niggerheads	Tdr	G	L	N	Poaceae
Enteropogon acicularis	6721	Curly Windmill Grass	Tdr	G	L	N	Poaceae
Enteropogon spp.	ENTE	Windmill Grass	Tdr	G	L	N	Poaceae
Epilobium hirtigerum	4330		Tda	F	L	N	Onagraceae
Eragrostis australasica	4949	Canegrass	ATe	G	M	N	Poaceae
Eragrostis cilianensis	6387	Stinkgrass	Tdr	G	L	Ex	Poaceae
Eragrostis elongata	4955	Clustered Lovegrass	Tda	G	L	N	Poaceae
Eragrostis lacunaria	4958	Purple Lovegrass	Tda	G	L	N	Poaceae
Eragrostis leptocarpa	7483	Drooping Lovegrass	Tda	G	L	N	Poaceae
Eragrostis parviflora	4967	Weeping Lovegrass	Tdr	G	L	N	Poaceae
Eragrostis setifolia	6378	Neverfail	Tdr	G	L	N	Poaceae
Eragrostis sp. 'Pilliga Scrub'	13442		Tdr	G	L	N	Poaceae
Eragrostis spp.	ERAG	A Lovegrass	Tdr	G	L	N	Poaceae
Eremophila bignoniiflora	3933	Eurah	ATw	S	M	N	Myoporaceae
Eremophila debilis	8602	Amulla	Tdr	F	L	N	Myoporaceae
Eremophila maculata	3943	Spotted Fuchsia	Tda	S	M	N	Myoporaceae
Eremophila mitchellii	3944	Budda	Tdr	S	M	N	Myoporaceae
Eremophila spp.	EREM		Tdr	S	M	N	Myoporaceae
Eriochloa australiensis	7907	Australian Cupgrass	ATe	G	L	N	Poaceae
Eriochloa crebra	4983	Cup Grass, Tall Cupgrass	Tdr	G	L	N	Poaceae
Eriochloa procera	7228	Spring Grass	Tda	G	L	N	Poaceae
Eriochloa pseudoacrotricha	7335	Early Spring Grass	Tda	G	L	N	Poaceae
Eriostemon australasius	5776		Tdr	S	M	N	Rutaceae
Erodium crinitum	3142	Blue Crowfoot	Tda	F	L	N	Geraniaceae

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Erodium spp.	EROI	Crowfoot	Tda	F	L	N	Geraniaceae
Eucalyptus camaldulensis	6360	River Red Gum	ATw	T	T	N	Myrtaceae
Eucalyptus chloroclada	6798	Dirty Gum	Tdr	T	T	N	Myrtaceae
Eucalyptus coolabah	8930	Coolibah	Tda	T	T	N	Myrtaceae
Eucalyptus largiflorens	4114	Black Box	ATw	T	T	N	Myrtaceae
Eucalyptus oleosa subsp. oleosa	10891	Red Mallee	Tdr	T	T	N	Myrtaceae
Eucalyptus populnea subsp. bimbil	10023	Bimble Box	Tdr	T	T	N	Myrtaceae
Euchiton involucratus	9904	Star Cudweed	Tda	F	L	N	Asteraceae
Euchiton sphaericus	9690	Star Cudweed	Tdr	F	L	N	Asteraceae
Euphorbia planiticola	2722	Plains Spurge	Tdr	F	L	N	Euphorbiaceae
Euphorbia spp.	EUPR		Tdr	F	L	N	Euphorbiaceae
Fimbristylis dichotoma	7435	Common Fringe-sedge	Tda	V	L	N	Cyperaceae
Flindersia maculosa	5795	Leopardwood	Tdr	T	T	N	Rutaceae
Gahnia spp.	GAHN		ATe	V	L	N	Cyperaceae
Galium aparine	5679	Goosegrass	Tdr	F	L	Ex	Rubiaceae
Galium gaudichaudii	5684	Rough Bedstraw	Tdr	F	L	N	Rubiaceae
Geijera parviflora	5800	Wilga	Tdr	S	M	N	Rutaceae
Glandularia aristigera	12422	Mayne's Pest	Tdr	F	L	Ex	Verbenaceae
Glinus lotoides	6381	Hairy Carpet-weed	Tda	F	L	N	Aizoaceae
Glossocardia bidens	13989	Cobbler's Tack	Tdr	F	L	N	Asteraceae
Glyceria spp.	GLYE		ATe	G	L	N	Poaceae
Glycine tabacina	2861	Variable Glycine	Tdr	F	L	N	Fabaceae (Faboideae)
Glycyrrhiza acanthocarpa	2862	Native Liquorice	Tda	S	L	N	Fabaceae (Faboideae)
Gnaphalium spp.	GNAP	Cudweed	Tdr	F	L	N	Asteraceae
Goodenia fascicularis	3181	Mallee Goodenia	Tda	F	L	N	Goodeniaceae
Goodenia glauca	3183	Pale Goodenia	Tda	F	L	N	Goodeniaceae
Goodenia hederacea	3188	Ivy Goodenia	Tdr	F	L	N	Goodeniaceae
Goodenia heteromera	3189		Tda	F	L	N	Goodeniaceae
Goodenia pinnatifida	3193	Scrambles Eggs	Tdr	F	L	N	Goodeniaceae
Goodenia spp.	GOOD		Tdr	F	L	N	Goodeniaceae
Haloragis aspera	3249	Rough Raspwort	Tda	F	L	N	Haloragaceae
Haloragis glauca f. glauca	7455		Tda	F	L	N	Haloragaceae
Haloragis spp.	HALR	A Raspwort	Tda	F	L	N	Haloragaceae
Heliotropium curassavicum	1760	Smooth Heliotrope	Tda	F	L	Ex	Boraginaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Heliotropium europaeum	1761	Potato Weed	Tdr	F	L	Ex	Boraginaceae
Heliotropium spp.	HELT	A Heliotrope	Tda	F	L	Ex	Boraginaceae
Heliotropium supinum	1762	Prostrate Heliotrope	Tda	F	L	Ex	Boraginaceae
Herniaria cinerea	9667		Tda	F	L	Ex	Caryophyllaceae
Hibiscus brachysiphonius	3640	Low Hibiscus	Tda	F	L	N	Malvaceae
Hibiscus spp.	HIBI		Tda	F	L	N	Malvaceae
Hibiscus trionum	3648	Flower-of-an-hour	Tda	F	L	N	Malvaceae
Hordeum leporinum	5012	Barley Grass	Tdr	G	L	Ex	Poaceae
Hordeum spp.	HORD	A Barley Grass	Tdr	G	L	Ex	Poaceae
Hordeum vulgare	5014	Barley	Tdr	G	L	Ex	Poaceae
Hydrocotyle spp.	HYDR		Tdr	F	L	Ex	Arialaceae
Hypochaeris glabra	1540	Smooth Catsear	Tdr	F	L	Ex	Asteraceae
Hypochaeris microcephala var. albiflora	8960	White Flatweed	Tdr	F	L	Ex	Asteraceae
Hypochaeris radicata	8788	Catsear	Tdr	F	L	Ex	Asteraceae
Ipomoea lonchophylla	2228		Tdr	L	L	N	Convolvulaceae
Ipomoea spp.	IPOM		Tdr	L	L	N	Convolvulaceae
Isoetopsis graminifolia	1542	Grass Cushion	Tda	F	L	N	Asteraceae
Jasminum lineare	6398	Desert Jasmine	Tdr	L	L	N	Oleaceae
Juncus aridicola	3315	Tussock Rush	ATe	R	L	N	Juncaceae
Juncus bufonius	3318	Toad Rush	Tda	R	L	N	Juncaceae
Juncus flavidus	3330		ATe	R	L	N	Juncaceae
Juncus holoschoenus	3332		ATe	R	L	N	Juncaceae
Juncus laeviusculus subsp. laeviusculus	8780		ATe	R	L	N	Juncaceae
Juncus spp.	JUNC	A Rush	ATe	R	L	N	Juncaceae
Juncus usitatus	3350	Tall Tussock Rush	ATe	R	L	N	Juncaceae
Lachnagrostis filiformis	11388	Blown Grass	ATe	G	L	N	Poaceae
Lachnagrostis spp.	LACH	Blown Grass	ATe	G	L	N	Poaceae
Lactuca saligna	1549	Willow-leaved Lettuce	Tdr	F	L	Ex	Asteraceae
Lactuca serriola	1550	Prickly Lettuce	Tdr	F	L	Ex	Asteraceae
Lemna disperma	7508	Duck weed	ARf	F	L	N	Lemnaceae
Lepidium bonariense	1817	Argentine Peppercress	Tdr	F	L	Ex	Brassicaceae
Lepidium fasciculatum	1820	Bundled Peppercress	Tda	F	L	N	Brassicaceae
Lepidium hypenantion	7804	A Peppercress	Tdr	F	L	N	Brassicaceae
Lepidium hyssopifolium	1822	Aromatic Peppercress	Tda	F	L	N	Brassicaceae
Lepidium pseudohyssopifolium	6643	Peppercress	Tdr	F	L	N	Brassicaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Lepidium sp. B	9927		Tdr	F	L	N	Brassicaceae
Lepidium spp.	LEPI	A Peppercress	Tdr	F	L	N	Brassicaceae
Leptochloa digitata	7726	Umbrella Canegrass	ATe	G	M	N	Poaceae
Leptomeria acida	5865	Sour Currant Bush	Tdr	S	M	N	Santalaceae
Limosella australis	5972	Australian Mudwort	ATl	F	L	N	Scrophulariaceae
Limosella curdieana	5973	Large Mudwort	ATl	F	L	N	Scrophulariaceae
Lolium perenne	5032	Perennial Ryegrass	Tdr	G	L	Ex	Poaceae
Lolium spp.	LOLI	A Ryegrass	Tdr	G	L	Ex	Poaceae
Ludwigia octovalvis	7297	Willow Primrose	Tda	F	L	N	Onagraceae
Ludwigia peploides subsp. montevidensis	7375	Water Primrose	ARp	F	L	N	Onagraceae
Ludwigia spp.	LUDW	Water Primrose	ARp	F	L	N	Onagraceae
Lycium ferocissimum	6040	African Boxthorn	Tdr	S	M	Ex	Solanaceae
Lysiana exocarpi subsp. exocarpi	8227	Harlequin Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Lysiana subfalcata	7910	Northern Mistletoe	Tdr	Ep	Canopy	N	Loranthaceae
Lythrum hyssopifolia	3623	Hyssop Loosestrife	Tda	F	L	N	Lythraceae
Lythrum salicaria	7974	Purple loosestrife	Tda	F	L	N	Lythraceae
Maireana aphylla	2119	Cotton Bush	Tda	C	M	N	Chenopodiaceae
Maireana appressa	2120		Tdr	C	M	N	Chenopodiaceae
Maireana brevifolia	2122		Tdr	C	M	N	Chenopodiaceae
Maireana coronata	2126	Crown Fissure-weed	Tdr	C	M	N	Chenopodiaceae
Maireana decalvans	2127	Black Cotton Bush	Tdr	C	M	N	Chenopodiaceae
Maireana enchylaenoides	2128	Wingless Fissure-weed	Tdr	C	M	N	Chenopodiaceae
Maireana microcarpa	2137		ATe	C	M	N	Chenopodiaceae
Maireana microphylla	2138	Small-leaf Bluebush	Tdr	C	M	N	Chenopodiaceae
Maireana pentagona	2140	Hairy Bluebush, Slender Fissure-weed	Tdr	C	M	N	Chenopodiaceae
Maireana pyramidata	2142	Black Bluebush	Tdr	C	M	N	Chenopodiaceae
Maireana spp.	MAIR	Cotton Bush, Bluebush, Fissure-weed	Tdr	C	M	N	Chenopodiaceae
Malacocera tricornis	2155	Soft Horns	Tdr	C	M	N	Chenopodiaceae
Malva parviflora	3657	Small-flowered Mallow	Tdr	F	L	Ex	Malvaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Malva spp.	MALV	Mallow	Tdr	F	L	Ex	Malvaceae
Malvastrum americanum	7206	Spiked Malvastrum	Tdr	F	L	Ex	Malvaceae
Marrubium spp.	MARR		Tdr	F	L	Ex	Lamiaceae
Marrubium vulgare	3381	White Horehound	Tdr	F	L	Ex	Lamiaceae
Marsdenia australis	8908	Doubah	Tdr	V	L	N	Apocynaceae
Marsilea drummondii	8803	Common Nardoo	ARp	E	L	N	Marsileaceae
Marsilea spp.	MARI	A Nardoo	ARp	E	L	N	Marsileaceae
Medicago arabica	2916	Spotted Burr Medic	Tdr	F	L	Ex	Fabaceae (Faboideae)
Medicago laciniata	2918	Cut-leaved Medic	Tdr	F	L	Ex	Fabaceae (Faboideae)
Medicago minima	2920	Woolly Burr Medic	Tdr	F	L	Ex	Fabaceae (Faboideae)
Medicago polymorpha	2922	Burr Medic	Tdr	F	L	Ex	Fabaceae (Faboideae)
Medicago praecox	2923	Small-leaved Burr Medic	Tdr	F	L	Ex	Fabaceae (Faboideae)
Medicago spp.	MEDI	A Medic	Tdr	F	L	Ex	Fabaceae (Faboideae)
Medicago truncatula	2926	Barrel Medic	Tdr	F	L	Ex	Fabaceae (Faboideae)
Melilotus indicus	2928	Hexham Scent	Tdr	F	L	Ex	Fabaceae (Faboideae)
Mentha australis	3383	River Mint	ATe	F	L	N	Lamiaceae
Mentha pulegium	3386	Pennyroyal	ATe	F	L	N	Lamiaceae
Mentha satureioides	3387	Native Pennyroyal	Tda	F	L	N	Lamiaceae
Mentha spp.	MENT		Tda	F	L	N	Lamiaceae
Mimulus gracilis	5982	Slender Monkey-flower	Tda	F	L	N	Scrophulariaceae
Minuria integerrima	1573	Smooth Minuria	Tdr	F	L	N	Asteraceae
Minuria leptophylla	1574		Tda	F	L	N	Asteraceae
Minuria spp.	MINU		Tdr	F	L	N	Asteraceae
Myoporum montanum	3955	Western Boobialla	Tdr	S	M	N	Myoporaceae
Myoporum platycarpum	3957	Sugarwood	Tdr	T	M	N	Scrophulariaceae
Myosurus australis	13523	Mousetail	Tda	F	L	N	Ranunculaceae
Myriophyllum crispatum	6724	Green Water Milfoil	ARp	F	L	N	Haloragaceae
Myriophyllum papillosum	7738	Water Milfoil	ARp	F	L	N	Haloragaceae
Myriophyllum propinquum	3265	Common Water Milfoil	ARp	F	L	N	Haloragaceae
Myriophyllum simulans	6677	Water Milfoil	ARp	F	L	N	Haloragaceae
Myriophyllum spp.	MYRI	Water Milfoil	ARp	F	L	N	Haloragaceae

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Myriophyllum verrucosum	6546	Red Water-milfoil	ARp	F	L	N	Haloragaceae
Najas marina	4299	Prickly Waternymph	Sk	F	L	N	Najadaceae
Najas tenuifolia	6985	Waternymph	Sr	F	L	N	Najadaceae
Nasturtium officinale	1848	Water Cress	Tdr	F	L	Ex	Brassiaceae
Neptunia gracilis f. gracilis	10823	Sensitive Plant	Tdr	S	L	N	Fabaceae (Mimosoideae)
Nicotiana megalosiphon subsp. megalosiphon	7052	Long-flowered Tobacco-bush	Tdr	F	L	N	Solanaceae
Nitraria billardierei	6345	Dillon Bush	Tdr	S	M	N	Nitrariaceae
Nymphoides crenata	7725	Wavy Marshwort	ARf	F	L	N	Menyanthaceae
Oenothera speciosa	4346	White Evening Primrose	Tdr	F	L	Ex	Onagraceae
Onopordum acanthium subsp. acanthium	8884	Scotch Thistle	Tda	F	L	Ex	Asteraceae
Opuntia spp.	OPUN		Tdr	F	L	Ex	Cactaceae
Opuntia stricta	1875	Common Prickly Pear, Smooth Pest Pear	Tdr	F	L	Ex	Cactaceae
Osteocarpum acropterum	6919	Water Weed	Tdr	C	L	N	Chenopodiaceae
Osteocarpum acropterum var. deminuta	9665	Bonefruit	Tdr	C	L	N	Chenopodiaceae
Osteocarpum spp.	OSTE		Tdr	C	L	N	Chenopodiaceae
Ottelia ovalifolia subsp. ovalifolia	10855	Swamp Lily	ARf	F	L	N	Hydrocharitaceae
Ottelia spp.	OTTE		ARf	F	L	N	Hydrocharitaceae
Oxalis chnoodes	4612	Oxalis	Tdr	F	L	N	Oxalidaceae
Oxalis corniculata	4613	Creeping Oxalis	Tdr	F	L	Ex	Oxalidaceae
Oxalis perennans	4621	Oxalis	Tda	F	L	N	Oxalidaceae
Oxalis pes-caprae	4622	Soursob	Tdr	F	L	Ex	Oxalidaceae
Oxalis spp.	OXAL	Oxalis	Tda	F	L	N	Oxalidaceae
Oxalis thompsoniae	9292	Oxalis	Tda	F	L	N	Oxalidaceae
Panicum antidotale	5049	Giant Panic Grass	Tdr	G	L	Ex	Poaceae
Panicum coloratum var. makarikariense	9333	Coolah Grass	Tdr	G	L	Ex	Poaceae
Panicum decompositum	12036	Native Panic	Tdr	G	L	N	Poaceae
Panicum decompositum var. tenuius	12036	Native Panic	Tdr	G	L	N	Poaceae
Panicum effusum	5055	Hairy Panic	Tdr	G	L	N	Poaceae
Panicum queenslandicum	5064	Yadbila Grass	Tda	G	L	N	Poaceae
Panicum sp. A	14101		Tdr	G	L	N	Poaceae
Panicum spp.	PANI	Panicum	Tdr	G	L	N	Poaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Parietaria debilis	6231	Native Pellitory	Tdr	F	L	N	Urticaceae
Parsonsia eucalyptophylla	1178	Gargaloo	Tdr	V	L	N	Apocynaceae
Parsonsia spp.	PARS		Tdr	V	L	N	Apocynaceae
Paspalidium constrictum	5077	Knottybutt Grass	Tdr	G	L	N	Poaceae
Paspalidium distans	7172		Tdr	G	L	N	Poaceae
Paspalidium globoideum	5080	Shotgrass	Tdr	G	L	N	Poaceae
Paspalidium gracile	5081	Slender Panic	Tdr	G	L	N	Poaceae
Paspalidium jubiflorum	5082	Warrego Grass	Tda	G	L	N	Poaceae
Paspalidium spp.	PASA	Panic	Tda	G	L	N	Poaceae
Paspalum dilatatum	5086	Paspalum	Tda	G	L	Ex	Poaceae
Paspalum distichum	5087	Water Couch	ATe	G	L	N	Poaceae
Pelargonium spp.	PELA		Tdr	F	L	N	Geraniaceae
Persicaria attenuata	5277		ARp	F	L	N	Polygonaceae
Persicaria decipiens	7568	Slender Knotweed	ATe	F	L	N	Polygonaceae
Persicaria hydropiper	5281	Water Pepper	ATe	F	L	N	Polygonaceae
Persicaria lapathifolia	5282	Pale Knotweed	ATe	F	L	N	Polygonaceae
Persicaria orientalis	5284	Princes Feathers	ATe	F	L	N	Polygonaceae
Persicaria prostrata	5285	Creeping Knotweed	ATl	F	L	N	Polygonaceae
Persicaria spp.	PERC	Knotweed	ATe	F	L	N	Polygonaceae
Phalaris aquatica	5106	Phalaris	Tdr	G	L	Ex	Poaceae
Phalaris paradoxa	5111	Paradoxa Grass	Tda	G	L	Ex	Poaceae
Philydrum lanuginosum	7065	Frogsmouth	ATe	F	M	N	Philydraceae
Phragmites australis	5113	Common Reed	Se	G	M	N	Poaceae
Phyla canescens	11134	Lippia	ATl	F	L	Ex	Verbenaceae
Phyla nodiflora	6252	Carpet Weed	ATl	F	L	Ex	Verbenaceae
Phyllanthus fuernrohrii	2744		Tdr	F	L	N	Phyllanthaceae
Phyllanthus spp.	PHYL		Tdr	F	L	N	Phyllanthaceae
Phyllanthus virgatus	6751	Wiry Spurge	Tdr	F	L	N	Phyllanthaceae
Physalis ixocarpa	6056	Ground Cherry	Tdr	F	L	Ex	Solanaceae
Physalis lanceifolia	6057		Tda	F	L	Ex	Solanaceae
Physalis minima	7823	Wild Gooseberry	Tda	F	L	Ex	Solanaceae
Pimelea microcephala subsp. microcephala	6587	Shrubby Rice-flower	Tdr	F	L	N	Thymelaeaceae
Pimelea spp.	PIME		Tdr	F	L	N	Thymelaeaceae
Pittosporum angustifolium	11202	Butterbush	Tdr	S	M	N	Pittosporaceae
Plantago cunninghamii	4690	Sago-weed	Tdr	F	L	N	Plantaginaceae
Plantago gaudichaudii	4694	Narrow Plantain	Tdr	F	L	N	Plantaginaceae
Plantago lanceolata	4699	Lamb's Tongues	Tdr	F	L	Ex	Plantaginaceae
Plantago spp.	PLAA	Plantain	Tdr	F	L	Ex	Plantaginaceae
Poa fordeana	5129	Sweet Swamp-grass	Tda	G	M	N	Poaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Poa spp.	POA		Tdr	G	M	N	Poaceae
Poaceae indeterminate	POAC	Grass	Tdr	G	L	N	Poaceae
Polycarpon tetraphyllum	1979	Four-leaved Allseed	Tda	F	L	Ex	Caryophyllaceae
Polygonum arenastrum	5287	Wireweed	Tda	F	L	Ex	Polygonaceae
Polygonum aviculare	5288	Wireweed	Tdr	F	L	Ex	Polygonaceae
Polygonum plebeium	5291	Small Knotweed	Tda	F	L	N	Polygonaceae
Polygonum spp.	POLG	Polygonum sp.	Tda	F	L	Ex	Polygonaceae
Polymeria pusilla	9806		Tdr	L	L	N	Convolvulaceae
Polypogon monspeliensis	5145	Annual Beardgrass	ATe	G	L	Ex	Poaceae
Portulaca oleracea	5324	Pigweed	Tdr	F	L	N	Portulacaceae
Potamogeton spp.	POTA		Sk	F	L	N	Potamogetonaceae
Potamogeton tricarinatus	7023	Floating Pondweed	ARf	F	L	N	Potamogetonaceae
Pratia concolor	1922	Poison Pratia	ATe	F	L	N	Lobeliaceae
Pseudognaphalium luteoalbum	7780	Jersey Cudweed	Tdr	F	L	N	Asteraceae
Pseudoraphis spinescens	5148	Spiny Mudgrass	ARp	G	L	N	Poaceae
Psilocaulon tenue	1036	Wiry Noon-flower	Tdr	F	L	N	Aizoaceae
Ptilotus nobilis	1078	Yellowtails	Tdr	F	L	N	Amaranthaceae
Ptilotus semilanatus	8523	Lambs tails	Tdr	F	L	N	Amaranthaceae
Ptilotus spp.	PTIL		Tdr	F	L	N	Amaranthaceae
Ranunculus inundatus	5507	River Buttercup	ATl	F	L	N	Ranunculaceae
Ranunculus pentandrus var. platycarpus	12097		Tda	F	L	N	Ranunculaceae
Ranunculus pumilio	5520	Ferny Buttercup	ATe	F	L	N	Ranunculaceae
Ranunculus sceleratus	5524	Celery Buttercup	ATe	F	L	Ex	Ranunculaceae
Ranunculus sessiliflorus	5525	Small-flowered Buttercup	Tda	F	L	N	Ranunculaceae
Ranunculus sessiliflorus var. pilulifer	9640	Common Buttercup	Tda	F	L	N	Ranunculaceae
Ranunculus spp.	RANU	Buttervcup	ATe	F	L	N	Ranunculaceae
Ranunculus undosus	5528	Swamp Buttercup	ATe	F	L	N	Ranunculaceae
Rapistrum rugosum	1841	Turnip Weed	Tdr	F	L	Ex	Brassicaceae
Rhagodia spinescens	2161	Thorny Saltbush	Tdr	C	M	N	Chenopodiaceae
Rhodanthe corymbiflora	8919	Small White Sunray	Tdr	F	L	N	Asteraceae
Rhodanthe spp.	RHOA		Tdr	F	L	N	Asteraceae
Rhodanthe uniflora	9422		Tda	F	L	N	Asteraceae
Rhynchosia minima	7304		Tdr	F	L	N	Fabaceae (Faboideae)

Appendix 5 Species list for the Macquarie Marshes with Water Plant Functional Groups

Growth habit; C - Chenopod Shrub, E - Fern, Ep - Epiphyte, F - Forb, G - Tussock Grass, L - Vine, R - Rush, S - Shrub, T - Tree, V – Sedge. Strata type; L – Lower, M – Mid, T - Tallest. Species Code; Census of Australian Plant Species (CAPS) Number (OEH 2012). Tdr = Terrestrial dry, Tda = Terrestrial damp, ATw = Amphibious Tolerator (woody), ATe = Amp. Tol. (emergent), ARp = Amp. Responder (plastic), ARl = Amp. Resp. (low growing), ARf = Amp. Resp. (floating), Se and Sr = Semi- Aquatic

Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Romulea minutiflora	3304	Small-flowered Onion Grass	Tdr	F	L	Ex	Iridaceae
Rorippa eustylis	1843	River Cress	Tda	F	L	N	Brassicaceae
Rorippa laciniata	1846	Marsh Cress	Tda	F	L	N	Brassicaceae
Rorippa palustris	7382	Yellow Cress	Tda	F	L	Ex	Brassicaceae
Rorippa spp.	RORI	Marsh Cress	Tda	F	L	Ex	Brassicaceae
Rostellularia adscendens	9256	Pink Tongues	Tda	F	L	N	Acanthaceae
Rostraria pumila	7857	Roughtail	Tdr	G	L	Ex	Poaceae
Rumex brownii	5296	Swamp Dock	Tda	F	L	N	Polygonaceae
Rumex crispus	5298	Curled Dock	Tda	F	L	Ex	Polygonaceae
Rumex crystallinus	5299	Shiny Dock	ATe	F	L	N	Polygonaceae
Rumex spp.	RUME	Rumex spp.	Tda	F	L	N	Polygonaceae
Rumex tenax	5304	Shiny Dock	Tda	F	L	N	Polygonaceae
Rytidosperma caespitosum	14305	Ringed Wallaby Grass	Tdr	G	L	N	Poaceae
Rytidosperma erianthum	14308	Wallaby Grass	Tdr	G	L	N	Poaceae
Sagittaria montevidensis	1046	Arrowhead	ARp	F	L	N	Alismataceae
Salsola australis	14594	Buckbush	Tdr	C	L	N	Chenopodiaceae
Salsola kali var. kali	14594	Buckbush	Tdr	C	L	N	Chenopodiaceae
Salsola tragus	14594	Buckbush	Tdr	C	L	N	Chenopodiaceae
Salsola tragus subsp. tragus	14594	Buckbush	Tdr	C	L	N	Chenopodiaceae
Salvia reflexa	3445	Mintweed	Tda	F	L	Ex	Lamiaceae
Santalum acuminatum	5868	Sweet Quandong	Tdr	S	M	N	Santalaceae
Schenkia australis	14606	Spike Centaury	Tdr	F	L	N	Gentianaceae
Schoenus apogon	2491	Fluke Bogrush	ATe	V	L	N	Cyperaceae
Scleroblitum atriplicinum	2165	Purple Goosefoot	Tdr	C	L	N	Chenopodiaceae
Sclerolaena anisacanthoides	2167	Yellow Burr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena bicornis	2169	Goathead Burr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena bicornis var. horrida	7321	Goathead Burr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena birchii	2170	Galvinized Burr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena brachyptera	7676	Short-winged Copperburr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena calcarata	2172	Redburr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena decurrens	2176	Green Copperburr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena diacantha	2177	Grey Copperburr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena divaricata	2178	Tangled Copperburr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena lanicuspis	2182	Woolly Copperburr	Tdr	C	L	N	Chenopodiaceae
Sclerolaena muricata	2185	Black Rolypoly	Tdr	C	M	N	Chenopodiaceae
Sclerolaena muricata var. muricata	7570	Black Rolypoly	Tdr	C	M	N	Chenopodiaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Sclerolaena muricata var. villosa	7799	Black Rolypoly	Tdr	C	M	N	Chenopodiaceae
Sclerolaena patenticuspis	2190		Tdr	C	M	N	Chenopodiaceae
Sclerolaena spp.	SCLR	Copperburr, Poverty-bush	Tdr	C	M	N	Chenopodiaceae
Sclerolaena stelligera	6750	Star Copperburr	Tdr	C	M	N	Chenopodiaceae
Sclerolaena tricuspis	2192	Giant Redburr	Tdr	C	L	N	Chenopodiaceae
Seedlings	Seed	Seedlings	Tda	F	L	N	Seedlings
Senecio cunninghamii var. cunninghamii	8627	Bushy grounsel	Tda	F	L	N	Asteraceae
Senecio glossanthus	1661	Streaked Poverty Bush	Tdr	F	L	N	Asteraceae
Senecio hispidulus	1664	Hill Fireweed	Tdr	F	L	N	Asteraceae
Senecio madagascariensis	6465	Fireweed	Tdr	F	L	Ex	Asteraceae
Senecio pinnatifolius var. pinnatifolius	12811		Tdr	F	L	N	Asteraceae
Senecio quadridentatus	1675	Cotton Fireweed	Tdr	F	L	N	Asteraceae
Senecio runcinifolius	1676	Tall Groundsel	Tdr	F	L	N	Asteraceae
Senecio spp.	SENE	Groundsel, Fireweed	Tdr	F	L	N	Asteraceae
Senna artemisioides subsp. zygophylla	8494	Senna	Tdr	S	L	N	Fabaceae (Caesalpinioideae)
Senna circinnata	12080		Tdr	S	L	N	Fabaceae (Caesalpinioideae)
Sesbania cannabina	7462	Sesbania Pea	Tda	S	L	N	Fabaceae (Faboideae)
Sesbania cannabina var. cannabina	7462	Sesbania Pea	Tda	S	L	N	Fabaceae (Faboideae)
Sida ammophila	3663	Sand Sida	Tdr	F	L	N	Malvaceae
Sida corrugata	3664	Corrugated Sida	Tdr	F	L	N	Malvaceae
Sida cunninghamii	3666	Ridge Sida	Tdr	F	L	N	Malvaceae
Sida fibulifera	6711	Pin Sida	Tda	F	L	N	Malvaceae
Sida filiformis	3667		Tdr	F	L	N	Malvaceae
Sida rhombifolia	3673	Paddy's Lucerne	Tdr	F	L	N	Malvaceae
Sida sp. A	8283		Tdr	F	L	N	Malvaceae
Sida spp.	SIDA		Tdr	F	L	N	Malvaceae
Sida trichopoda	3674	High Sida	Tda	F	L	N	Malvaceae
Sigesbeckia orientalis subsp. orientalis	8789	Indian Weed	Tda	F	L	N	Asteraceae
Silene nocturna	1993		Tdr	F	L	Ex	Caryophyllaceae
Silybum marianum	1684	Variegated Thistle	Tdr	F	L	Ex	Asteraceae
Sisymbrium irio	1853	London Rocket	Tda	F	L	Ex	Brassicaceae
Solanum aviculare	6065	Kangaroo Apple	Tdr	S	M	N	Solanaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Solanum ellipticum	6079	Velvet Potato Bush	Tda	F	L	N	Solanaceae
Solanum esuriale	6081	Quena	Tda	F	L	N	Solanaceae
Solanum ferocissimum	6082	Spiny Potato-bush	Tdr	S	L	N	Solanaceae
Solanum nigrum	6091	Black-berry Nightshade	Tdr	F	L	Ex	Solanaceae
Soliva anthemifolia	1686	Dwarf Jo-jo	Tdr	F	L	N	Asteraceae
Sonchus asper subsp. asper	6513		Tdr	F	L	Ex	Asteraceae
Sonchus oleraceus	1690	Common Sowthistle	Tdr	F	L	Ex	Asteraceae
Sorghum halepense	5172	Johnson Grass	ATe	G	L	Ex	Poaceae
Spergularia diandra	1998	Lesser Sand-spurry	Tda	F	L	Ex	Caryophyllaceae
Spergularia rubra	2001	Sandspurry	Tdr	F	L	Ex	Caryophyllaceae
Sporobolus actinocladus	5175	Katoora Grass	Tdr	G	L	N	Poaceae
Sporobolus caroli	5177	Fairy Grass	Tdr	G	L	N	Poaceae
Sporobolus creber	5179	Slender Rat's Tail Grass	Tdr	G	L	N	Poaceae
Sporobolus mitchellii	5182	Rat's Tail Couch	Tda	G	L	N	Poaceae
Stellaria angustifolia	2002	Swamp Starwort	ATe	F	L	N	Caryophyllaceae
Stellaria angustifolia subsp. angusifolia	2002	Swamp Starwort	ATe	F	L	N	Caryophyllaceae
Stellaria spp.	STEL	Prickly Starwort	ATe	F	L	N	Caryophyllaceae
Swainsona spp.	SWAI		Tda	F	L	N	Fabaceae (Faboideae)
Taraxacum officinale	1698	Dandelion	Tdr	F	L	Ex	Asteraceae
Tetragonia tetragonioides	11185	New Zealand Spinach	Tdr	F	L	N	Aizoaceae
Teucrium racemosum	3453	Grey Germander	Tdr	F	L	N	Lamiaceae
Thellungia advena	5218	Coolibah Grass	Tdr	G	L	N	Poaceae
Tragus australianus	5224	Small Burrgrass	Tdr	G	L	N	Poaceae
Trianthema triquetra	7680	Small Hogweed	Tdr	F	L	N	Aizoaceae
Tribulus terrestris	7655	Cat-head	Tdr	F	L	Ex	Zygophyllaceae
Trifolium arvense	3073	Haresfoot Clover	Tdr	F	L	Ex	Fabaceae (Faboideae)
Trifolium spp.	TRIF	A Clover	Tdr	F	L	Ex	Fabaceae (Faboideae)
Triglochin dubia	3366		ATl	F	L	N	Juncaginaceae
Triglochin procera	3368	Water Ribbons	Se	F	L	N	Juncaginaceae
Triglochin spp.	TRIG		ATl	F	L	N	Juncaginaceae
Tripogon loliiformis	5229	Fiveminute Grass	Tdr	G	L	N	Poaceae
Typha domingensis	7224	Narrow-leaved Cumbungi	Se	R	M	N	Typhaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Typha orientalis	6217	Broad-leaved Cumbungi	Se	R	M	N	Typhaceae
Typha spp.	TYPH		Se	R	M	N	Typhaceae
Urochloa panicoides	5237	Urochloa Grass	Tdr	G	L	Ex	Poaceae
Vachellia farnesiana	12157	Mimosa Bush	Tdr	S	M	N	Fabaceae (Mimosoideae)
Vallisneria australis	14246	Eelweed	Sk	F	L	N	Hydrocharitaceae
Ventilago viminalis	6377	Supple Jack	Tdr	T	M	N	Rhamnaceae
Verbascum virgatum	5999	Twiggy Mullein	Tdr	F	M	Ex	Scrophulariaceae
Verbena bonariensis	6256	Purpletop	Tda	F	L	Ex	Verbenaceae
Verbena gaudichaudii	10717	Verbena	Tdr	F	L	N	Verbenaceae
Verbena officinalis	6259	Common Verbena	Tdr	F	L	Ex	Verbenaceae
Verbena supina	6261	Trailing Verbena	Tda	F	L	Ex	Verbenaceae
Verbesina encelioides subsp. encelioides	10164	Crownbeard	Tdr	F	L	Ex	Asteraceae
Veronica catenata	10221	Pink Water-speedwell	ATl	F	L	Ex	Plantaginaceae
Veronica peregrina	6007	Wandering Speedwell	Tdr	F	L	Ex	Plantaginaceae
Veronica persica	6008	Creeping Speedwell	Tda	F	L	Ex	Plantaginaceae
Veronica spp.	VERO		Tda	F	L	Ex	Plantaginaceae
Vittadinia cervicularis	1709		Tdr	F	L	N	Asteraceae
Vittadinia cuneata	1711	A Fuzzweed	Tdr	F	L	N	Asteraceae
Vittadinia cuneata var. cuneata	6737	A Fuzzweed	Tdr	F	L	N	Asteraceae
Vittadinia cuneata var. hirsuta	6992		Tdr	F	L	N	Asteraceae
Vittadinia pterochaeta	1717	Rough Fuzzweed	Tdr	F	L	N	Asteraceae
Vittadinia spp.	VITT	Fuzzweed	Tdr	F	L	N	Asteraceae
Vittadinia sulcata	1719		Tdr	F	L	N	Asteraceae
Vulpia muralis	8516	Wall Fescue	Tdr	G	L	Ex	Poaceae
Wahlenbergia fluminalis	1931	River Bluebell	Tda	F	L	N	Campanulaceae
Wahlenbergia spp.	WAHL	Bluebell	Tda	F	L	N	Campanulaceae
Xanthium occidentale	7130	Noogoora Burr	Tda	F	L	Ex	Asteraceae
Xanthium spinosum	1729	Bathurst Burr	Tdr	F	L	Ex	Asteraceae
Xerochrysum bracteatum	11377	Golden Everlasting	Tdr	F	L	N	Asteraceae
Zaleya galericulata	6504	Hogweed	Tdr	F	L	N	Aizoaceae
Zaleya galericulata subsp. australis	7094	Hogweed	Tdr	F	L	N	Aizoaceae
Zygophyllum apiculatum	6350	Common Twinleaf	Tdr	F	L	N	Zygophyllaceae
Zygophyllum glaucum	6354	Pale Twinleaf	Tdr	F	L	N	Zygophyllaceae

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Scientific name	Species code	Common Name	Wetland Plant Functional Group	Growth Habit	Strata Type	Exotic / Native	Family
Zygophyllum iodocarpum	6357	Violet Twinleaf	Tdr	F	L	N	Zygophyllaceae
Zygophyllum spp.	ZYGO	Twinleaf	Tdr	F	L	N	Zygophyllaceae

Appendix 6 Condition class ranges and scores for flood-dependent PCTs in the Macquarie Marshes

PCT No	PCT Name	Attribute	Attribute Decription	Percent Cover: Good	Percent Cover: Intermediate	Percent Cover: Poor	Percent Cover: Very Poor	Score: Good	Score: Intermediate	Score: Poor	Score: Very Poor
36	River red gum Forest	BareGd	Bare Ground	30	49.999	80	100	2	1.5	1	0
36	River red gum Forest	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0
36	River red gum Forest	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
36	River red gum Forest	RRGL	Indicator Species in Lower Stratum	1	0.5	0.0001	0	1.5	1	0.5	0
36	River red gum Forest	RRGM	Indicator Species in Mid Stratum	5	0.5	0.0001	0	1.5	1	0.5	0
36	River red gum Forest	RRGT	Indicator Species in Tallest Stratum	30	10	1	0	3	2.5	1.5	0
36	River red gum Forest	WetlandFG	Aquatic and Damp Functional Species	40	15	10	0	4	3	2.5	0
37	Black box Woodland	BareGd	Bare Ground	50	60	80	100	2	1	0.5	0
37	Black box Woodland	Chenopods	Invasive native terrestrial	20	50	80	100	3	2.5	1.75	0
37	Black box Woodland	BBoxL	Indicator Species in Lower Stratum	1	0.5	0.0001	0	1.5	1	0.5	0
37	Black box Woodland	BBoxM	Indicator Species in Mid Stratum	5	0.5	0.0001	0	1.5	1	0.5	0
37	Black box Woodland	BBoxT	Indicator Species in Tallest Stratum	10	3	1	0	3	2.5	2	0
37	Black box Woodland	ExCover	Exotic Species	10	50	80	100	3	2.5	1.75	0
37	Black box Woodland	NativeGrasses	Native Grasses	40	10	5	0	3	2.5	2	0
37	Black box Woodland	WetlandFG	Aquatic And Damp Functional Species	30	10	5	0	3	2	1	0
39	Coolibah - River Cooba - Lignum Woodland	BareGd	Bare Ground	40	59.999	80	100	2	1.5	1	0
39	Coolibah - River Cooba - Lignum Woodland	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0
39	Coolibah - River Cooba - Lignum Woodland	CoolL	Indicator Species in Lower Stratum	1	0.5	0.0001	0	1.5	1	0.5	0
39	Coolibah - River Cooba - Lignum Woodland	CoolM	Indicator Species in Mid Stratum	5	0.5	0.0001	0	1.5	1	0.5	0
39	Coolibah - River Cooba - Lignum Woodland	CoolT	Indicator Species in Tallest Stratum	10	3	1	0	3	2.5	1.5	0
39	Coolibah - River Cooba - Lignum Woodland	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0

Appendix 6 Condition class ranges and scores for flood-dependent PCTs in the Macquarie Marshes

PCT No	PCT Name	Attribute	Attribute Decription	Percent Cover: Good	Percent Cover: Intermediate	Percent Cover: Poor	Percent Cover: Very Poor	Score: Good	Score: Intermediate	Score: Poor	Score: Very Poor
39	Coolibah - River Cooba - Lignum Woodland	WetlandFG	Aquatic and Damp Functional Species	40	15	10	0	4	3	2.5	0
40	Coolibah grassy woodland	BareGd	Bare Ground	50	60	80	100	2	1	0.5	0
40	Coolibah grassy woodland	Chenopods	Invasive native terrestrial	20	50	80	100	3	2.5	1.75	0
40	Coolibah grassy woodland	CoolL	Indicator Species in Lower Stratum	1	0.5	0.0001	0	1.5	1	0.5	0
40	Coolibah grassy woodland	CoolM	Indicator Species in Mid Stratum	5	0.5	0.0001	0	1.5	1	0.5	0
40	Coolibah grassy woodland	CoolT	Indicator Species in Tallest Stratum	10	3	1	0	3	2.5	2	0
40	Coolibah grassy woodland	ExCover	Exotic Species	10	50	80	100	3	2.5	1.75	0
40	Coolibah grassy woodland	NativeGrasses	Native Grasses	40	10	5	0	3	2.5	2	0
40	Coolibah grassy woodland	WetlandFG	Aquatic and Damp Functional Species	30	10	5	0	3	2	1	0
53	Mixed Marsh	BareGd	Bare Ground	10	50	80	100	4	3	2	0
53	Mixed Marsh	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0
53	Mixed Marsh	WetlandFG	Aquatic and Damp Functional Species	80	40	10	0	8	6	4	0
53	Mixed Marsh	ExCover	Exotic Species	10	50	80	100	4	3	2	0
181	Phragmites	BareGd	Bare Ground	10	49.999	80	100	4	3	2	0
181	Phragmites	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0
181	Phragmites	Reeds	Indicator Species	80	40	10	0	8	6	4	0
181	Phragmites	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
182	Cumbungi	BareGd	Bare Ground	10	40	80	100	4	3	2	0
182	Cumbungi	Chenopods	Invasive native terrestrial	10	49.999	80	100	4	3	2	0
182	Cumbungi	Reeds	Indicator Species	80	40	10	0	8	6	4	0
182	Cumbungi	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
204	Water Couch Marsh Grassland	BareGd	Bare Ground	10	49.999	80	100	4	3	2	0
204	Water Couch Marsh Grassland	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0

Appendix 6 Condition class ranges and scores for flood-dependent PCTs in the Macquarie Marshes

PCT No	PCT Name	Attribute	Attribute Decription	Percent Cover: Good	Percent Cover: Intermediate	Percent Cover: Poor	Percent Cover: Very Poor	Score: Good	Score: Intermediate	Score: Poor	Score: Very Poor
204	Water Couch Marsh Grassland	WaterCouch	Indicator Species	80	40	10	0	8	6	4	0
204	Water Couch Marsh Grassland	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
204	Water Couch Marsh Grassland	WetlandFG	Aquatic and Damp Functional Species	0	0	0	0	0	0	0	0
205	Marsh Club-rush tall sedgeland	BareGd	Bare Ground	10	49.999	80	100	4	3	2	0
205	Marsh Club-rush tall sedgeland	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0
205	Marsh Club-rush tall sedgeland	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
205	Marsh Club-rush tall sedgeland	MCR	Indicator Species	80	40	10	0	8	6	4	0
214	Floodplain grassland	BareGd	Bare Ground	10	49.999	80	100	4	3	2	0
214	Floodplain grassland	Chenopods	Invasive native terrestrial	10	50	80	100	4	3	2	0
214	Floodplain grassland	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
214	Floodplain grassland	NativeGrasses	Native Grasses	40	20	10	0	4	3	2	0
214	Floodplain grassland	WetlandFG	Aquatic and Damp Functional Species	30	20	10	0	4	3	2	0
241	River Cooba/Lignum Shrubland	BareGd	Bare Ground	10	49.999	80	100	3	2	1	0
241	River Cooba/Lignum Shrubland	Chenopods	Invasive native terrestrial	10	50	80	100	3	2	1.5	0
241	River Cooba/Lignum Shrubland	CoobaML	Indicator Species in mid and lower Strata	5	0.5	0.001	0	2	1.5	1	0
241	River Cooba/Lignum Shrubland	CoobaT	Indicator Species in Tallest Stratum	10	3	1	0	2.5	2	1.5	0
241	River Cooba/Lignum Shrubland	ExCover	Exotic Species	10	49.999	80	100	3	2	1.5	0
241	River Cooba/Lignum Shrubland	Lignum	Indicator Species	30	10	5	0	3.5	3	1.5	0
241	River Cooba/Lignum Shrubland	WetlandFG	Aquatic and Damp Functional Species	30	10	5	0	3	2.5	2	0
247	Lignum Shrubland	BareGd	Bare Ground	10	49.999	80	100	4	3	2	0
247	Lignum Shrubland	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0
247	Lignum Shrubland	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
247	Lignum Shrubland	Lignum	Indicator Species	40	20	10	0	4	3	2	0

Appendix 6 Condition class ranges and scores for flood-dependent PCTs in the Macquarie Marshes

PCT No	PCT Name	Attribute	Attribute Decription	Percent Cover: Good	Percent Cover: Intermediate	Percent Cover: Poor	Percent Cover: Very Poor	Score: Good	Score: Intermediate	Score: Poor	Score: Very Poor
247	Lignum Shrubland	WetlandFG	Aquatic and Damp Functional Species	40	15	10	0	4	3	2	0
454	River red gum Grassy Woodland	BareGd	Bare Ground	40	59.999	80	100	2	1	0.5	0
454	River red gum Grassy Woodland	Chenopods	Invasive native terrestrial	10	40	80	100	3	2.5	1.75	0
454	River red gum Grassy Woodland	ExCover	Exotic Species	10	49.999	80	100	3	2.5	1.75	0
454	River red gum Grassy Woodland	NativeGrasses	Native Grasses	40	10	5	0	3	2.5	2	0
454	River red gum Grassy Woodland	RRGL	Indicator Species in Lower Stratum	1	0.5	0.0001	0	1.5	1	0.5	0
454	River red gum Grassy Woodland	RRGM	Indicator Species in Mid Stratum	4.999	0.5	0.0001	0	1.5	1	0.5	0
454	River red gum Grassy Woodland	RRGT	Indicator Species in Tallest Stratum	10	3	1	0	3	2.5	2	0
454	River red gum Grassy Woodland	WetlandFG	Aquatic and Damp Functional Species	30	10	5	0	3	2	1	0
36A	River red gum Woodland	BareGd	Bare Ground	40	59.999	80	100	2	1.5	1	0
36A	River red gum Woodland	Chenopods	Invasive native terrestrial	10	40	80	100	4	3	2	0
36A	River red gum Woodland	ExCover	Exotic Species	10	49.999	80	100	4	3	2	0
36A	River red gum Woodland	RRGL	Indicator Species in Lower Stratum	1	0.5	0.0001	0	1.5	1	0.5	0
36A	River red gum Woodland	RRGM	Indicator Species in Mid Stratum	5	0.5	0.0001	0	1.5	1	0.5	0
36A	River red gum Woodland	RRGT	Indicator Species in Tallest Stratum	10	3	1	0	3	2.5	1.5	0
36A	River red gum Woodland	WetlandFG	Aquatic and Damp Functional Species	40	15	10	0	4	3	2.5	0

Appendix 7a Water couch marsh grassland, inundation regimes

Analysis of Variance

Average annual duration Pre-Millennium Drought versus Inundation class PCT 204

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class 1	2	3339	1669.6	2.31	0.155
Error	9	6507	723		
Total	11	9846			

Average annual duration Millennium Drought versus Inundation class PCT 204

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class 1	2	4615	2307.5	8.2	0.009
Error	9	2532	281.3		
Total	11	7147			

Average annual duration Post-Millennium Drought versus Inundation class PCT 204

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class 1	2	20610	10305.2	31.51	0
Error	9	2943	327		
Total	11	23554			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Pre-Millennium Drought versus Inundation class PCT 204

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	14.4	18	(-36.0, 64.8)	0.8	0.713
Class 3 - Class 1	-29.4	19.6	(-84.2, 25.5)	-1.5	0.338
Class 3 - Class 2	-43.8	20.5	(-101.1, 13.6)	-2.13	0.138

Average annual duration Millennium Drought versus Inundation class PCT 204

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	-11.7	11.3	(-43.1, 19.7)	-1.04	0.573
Class 3 - Class 1	-49	12.2	(-83.2, -14.8)	-4	0.008
Class 3 - Class 2	-37.3	12.8	(-73.1, -1.5)	-2.91	0.042

Average annual duration Post-Millennium Drought versus Inundation class PCT 204

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	-49.3	12.1	(-83.2, -15.4)	-4.07	0.007
Class 3 - Class 1	-104.1	13.2	(-141.0, -67.2)	-7.88	0
Class 3 - Class 2	-54.8	13.8	(-93.4, -16.2)	-3.97	0.008

Kruskal-Wallis Test: years since last flood versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	0	30.1	-3.73	Not adjusted for ties	2	22.85	0
Class 2	28	0	41.7	0.35	Adjusted for ties	2	33.89	0
Class 3	15	4	64	4.34				
Overall	80		40.5					

Kruskal-Wallis Test: years since last flood versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	0	28.4	-2.27	Not adjusted for ties	1	5.16	0.023
Class 2	28	0	39.1	2.27	Adjusted for ties	1	10.59	0.001
Overall	65		33					

Appendix 7a Water couch marsh grassland, inundation regimes

Kruskal-Wallis Test: years since last flood versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	28	0	17.1	-3.49	Not adjusted for ties	1	12.19	0
Class 3	15	4	31.1	3.49	Adjusted for ties	1	13.62	0
Overall	43		22					

Kruskal-Wallis Test: years since last flood versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	0	20.7	-4.34	Not adjusted for ties	1	18.86	0
Class 3	15	4	40.8	4.34	Adjusted for ties	1	30.93	0
Overall	52		26.5					

Appendix 7b Water couch marsh grassland, floristic condition

Kruskal-Wallis Test: Water couch versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	58	47.8	2.6	Not adjusted for ties	2	33.92	0
Class 2	28	52.5	47.8	2.05	Adjusted for ties	2	34.27	0
Class 3	15	0	9	-5.82				
Overall	80		40.5					

Kruskal-Wallis Test: Water couch versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	58	32.8	-0.11	Not adjusted for ties	1	0.01	0.916
Class 2	28	52.5	33.3	0.11	Adjusted for ties	1	0.01	0.916
Overall	65		33					

Kruskal-Wallis Test: Water couch versus Inundation Duration Class 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	58	34	5.6	Not adjusted for ties	1	31.42	0
Class 3	15	0	8	-5.6	Adjusted for ties	1	32.19	0
Overall	52		26.5					

Kruskal-Wallis Test: Bare ground versus Inundation Duration Class 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	0.6	34.1	-2.3	Not adjusted for ties	2	6.43	0.04
Class 2	28	4.4	43.3	0.78	Adjusted for ties	2	6.47	0.039
Class 3	15	8	51.2	1.98				

Kruskal-Wallis Test: Exotic species versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	1	36.3	-1.52	Not adjusted for ties	2	5.49	0.064
Class 2	28	1.45	39.5	-0.28	Adjusted for ties	2	5.51	0.064
Class 3	15	8.1	52.8	2.27				
Overall	80		40.5					

Kruskal-Wallis Test: Invasive chenopods versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	0	24.6	-5.67	Not adjusted for ties	2	36.37	0
Class 2	28	0.2	48.9	2.37	Adjusted for ties	2	43.68	0
Class 3	15	4.1	64.1	4.36				
Overall	80		40.5					

Kruskal-Wallis Test: Invasive chenopods versus Inundation Duration Class PCT 204

Inundation	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	0	24	-4.4	Not adjusted for ties	1	19.34	0
Class 2	28	0.2	44.9	4.4	Adjusted for ties	1	27.27	0
Overall	65		33					

Kruskal-Wallis Test: Invasive chenopods versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	0	19.6	-5.17	Not adjusted for ties	1	26.74	0
Class 3	15	4.1	43.6	5.17	Adjusted for ties	1	38.48	0

Appendix 7b Water couch marsh grassland, floristic condition

Overall	52		26.5

Kruskal-Wallis Test: Invasive chenopods versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	28	0.2	18.5	-2.48	Not adjusted for ties	1	6.17	0.013
Class 3	15	4.1	28.5	2.48	Adjusted for ties	1	6.26	0.012
Overall	43		22					

Appendix 7c Water couch marsh grassland, floristic condition scores

Appendix 8c

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	17	47.6	2.53	Not adjusted for ties	2	24.39	0
Class 2	28	17.5	45.4	1.39	Adjusted for ties	2	24.97	0
Class 3	15	10	13.9	-4.92				

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	37	17	33.3	0.17				
Class 2	28	17.5	32.6	-0.17	Not adjusted for ties	1	0.03	0.868
Overall	65		33		Adjusted for ties	1	0.03	0.866

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	28	17.5	27.4	3.82	Not adjusted for ties	1	14.61	0
Class 3	15	10	12	-3.82	Adjusted for ties	1	15.09	0
Overall	43		22					

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 204

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
					Not adjusted for ties	1	25.4	0
Class 1	37	17	33.2	5.04	Adjusted for ties	1	26	0
Class 3	15	10	9.9	-5.04				
Overall	52		26.5					

Appendix 8a Mixed marsh sedgeland, inundation regimes

Analysis of Variance

Average annual duration Pre-Millennium Drought versus Inundation class PCT 53

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	8350	4174.9	18.91	0.001
Error	8	1766	220.7		
Total	10	10116			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Pre-Millennium Drought versus Inundation class PCT 53

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	-59.1	10.9	(-90.1, -28.1)	-5.45	0.002
Class 3 - Class 1	-65.7	12.1	(-100.3, -31.0)	-5.41	0.002
Class 3 - Class 2	-6.6	10.9	(-37.6, 24.4)	-0.61	0.821

Analysis of Variance

Average annual duration Millennium Drought versus Inundation class PCT 53

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	2163	1081.5	4.83	0.042
Error	8	1791	223.9		
Total	10	3954			

Average annual duration Pre-Millennium Drought versus Inundation class PCT 53

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	-26.5	10.9	(-57.7, 4.7)	-2.42	0.095
Class 3 - Class 1	-36.3	12.2	(-71.2, -1.4)	-2.97	0.042
Class 3 - Class 2	-9.8	10.9	(-41.0, 21.4)	-0.9	0.658

Analysis of Variance

Average annual duration Post-Millennium Drought versus Inundation class PCT 53

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	20817	10408.3	33.28	0
Error	8	2502	312.7		
Total	10	23318			

Average annual duration Pre-Millennium Drought versus Inundation class PCT 53

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	-82.1	12.9	(-119.0, -45.2)	-6.36	0.001
Class 3 - Class 1	-112.5	14.4	(-153.8, -71.3)	-7.79	0
Class 3 - Class 2	-30.5	12.9	(-67.3, 6.4)	-2.36	0.104

Kruskal-Wallis Test: Years since flood versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	0	17	-3.34	Not adjusted for ties	2	17.59	0
Class 2	27	0	28.6	0.02	Adjusted for ties	2	22.15	0
Class 3	13	17	42.5	3.54				
Overall	56		28.5					

Kruskal-Wallis Test: Years since flood versus Inundation Duration Class PCT 53

Appendix 8a Mixed marsh sedgeland, inundation regimes

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	0	15.5	-2.61	Not adjusted for ties	1	6.83	0.009
Class 2	27	0	25.9	2.61	Adjusted for ties	1	10.37	0.001
Overall	43		22					

Kruskal-Wallis Test: Years since flood versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	0	10	-3.51	Not adjusted for ties	1	12.31	0
Class 3	13	17	21.2	3.51	Adjusted for ties	1	17.11	0
Overall	29		15					

Kruskal-Wallis Test: Years since flood versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	27	0	16.7	-2.96	Not adjusted for ties	1	8.76	0.003
Class 3	13	17	28.4	2.96	Adjusted for ties	1	9.53	0.002
Overall	40		20.5					

Appendix 8b Mixed marsh sedgeland, floristic condition

Analysis of Variance
% FC Wetland plant Functional Species versus Inundation class PCT 53

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	24618	12309	14.15	0
Error	53	46113	870.1		
Total	55	70731			

Tukey Simultaneous Tests for Differences of Means
% FC Wetland plant Functional Species versus Inundation class PCT 53

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	-14.14	9.31	(-36.58, 8.30)	-1.52	0.29
Class 3 - Class 1	-56.5	11	(-83.0, -29.9)	-5.13	0
Class 3 - Class 2	-42.33	9.96	(-66.34, -18.32)	-4.25	0

Analysis of Variance
% cover Bare ground versus Inundation class PCT 53

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	285.8	142.9	0.33	0.723
Error	53	23234.9	438.4		
Total	55	23520.7			

Kruskal-Wallis Test: %FC Exotic species versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	0.9	17.3	-1.91	Not adjusted for ties	1	3.65	0.056
Class 2	27	3.05	24.8	1.91	Adjusted for ties	1	3.65	0.056
Overall	43		22					

Kruskal-Wallis Test: %FC Exotic species versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	27	3.05	17.6	-2.28	Method	DF	H-Value	P-Value
Class 3	13	25	26.6	2.28	Not adjusted for ties	1	5.2	0.023
Overall	40		20.5		Adjusted for ties	1	5.21	0.023

Kruskal-Wallis Test: %FC Exotic species versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	0.9	10.9	-2.85	Method	DF	H-Value	P-Value
Class 3	13	25	20	2.85	Not adjusted for ties	1	8.13	0.004
Overall	29		15		Adjusted for ties	1	8.15	0.004

Kruskal-Wallis Test: %FC Invasive native chenopods versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	0	14	-3.22	Not adjusted for ties	1	10.34	0.001

Appendix 8b Mixed marsh sedgeland, floristic condition

Class 2	27	0.1	26.7	3.22	Adjusted for ties	1	12.94	0
Overall	43		22					

Kruskal-Wallis Test: %FC Invasive native chenopods versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	27	0.1	16.4	-3.23	Not adjusted for ties	1	10.46	0.001
Class 3	13	3	29.1	3.23	Adjusted for ties	1	10.71	0.001
Overall	40		20.5					

Kruskal-Wallis Test: %FC Invasive native chenopods versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	0	8.6	-4.52	Method	DF	H-Value	P-Value
Class 3	13	3	22.9	4.52	Not adjusted for ties	1	20.4	0
Overall	29		15		Adjusted for ties	1	23.7	0

Appendix 8c Mixed marsh sedgeland, floristic condition scores

Kruskal-Wallis Test: %Floristic condition score versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	18	33.4	1.43	Not adjusted for ties	2	14.26	0.001
Class 2	27	17	32.8	1.89	Adjusted for ties	2	14.88	0.001
Class 3	13	10	13.5	-3.77				
Overall	56		28.5					

Kruskal-Wallis Test: %Floristic condition score versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	18	22.5	0.21	Not adjusted for ties	1	0.05	0.831
Class 2	27	17	21.7	-0.21	Adjusted for ties	1	0.05	0.824
Overall	43		22					

Kruskal-Wallis Test: %Floristic condition score versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	27	17	25.1	3.58	Not adjusted for ties	1	12.82	0
Class 3	13	10	11	-3.58	Adjusted for ties	1	13.28	0
Overall	40		20.5					

Kruskal-Wallis Test: %Floristic condition score versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	16	18	19.4	3.09	Not adjusted for ties	1	9.56	0.002
Class 3	13	10	9.6	-3.09	Adjusted for ties	1	9.79	0.002
Overall	29		15					

Appendix 8d Mixed marsh sedgeland, floristic composition

Kruskal-Wallis Test: %FC Water couch versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	17	35	36.3	4.33	Not adjusted for ties	2	18.93	0
Class 2	30	0	18.2	-4.02	Adjusted for ties	2	21.64	0
Class 3	1	0	12.5	-0.87				
Overall	48		24.5					

Kruskal-Wallis Test: %FC Water couch versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	17	35	35.4	4.28	Not adjusted for ties	1	18.35	0
Class 2	30	0	17.6	-4.28	Adjusted for ties	1	20.79	0
Overall	47		24					

Kruskal-Wallis Test: %FC Water couch versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	30	0	24.2	1.27	Not adjusted for ties	1	1.62	0.203
Class 3	14	0	18.9	-1.27	Adjusted for ties	1	3.01	0.083
Overall	44		22.5					

Kruskal-Wallis Test: %FC Water couch versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	17	35	22.1	4.09	Not adjusted for ties	1	16.72	0
Class 3	14	0	8.6	-4.09	Adjusted for ties	1	18.84	0
Overall	31		16					

Kruskal-Wallis Test: %FC Sedges and Rushes versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	17	3.4	27.2	-1.04	Not adjusted for ties	2	12.77	0.002
Class 2	30	44.4	38.7	3.34	Adjusted for ties	2	12.84	0.002
Class 3	14	0.15	19.1	-2.86				
Overall	61		31					

Kruskal-Wallis Test: %FC Sedges and Rushes versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	17	3.4	17.7	-2.38	Not adjusted for ties	1	5.66	0.017
Class 2	30	44.4	27.6	2.38	Adjusted for ties	1	5.69	0.017
Overall	47		24					

Kruskal-Wallis Test: %FC Sedges and Rushes versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value				
Class 2	30	44.4	26.6	3.12	Not adjusted for ties	1	9.76	0.002
Class 3	14	0.15	13.6	-3.12	Adjusted for ties	1	9.83	0.002
Overall	44		22.5					

Kruskal-Wallis Test: %FC Sedges and Rushes versus Inundation Duration Class PCT 53

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	17	3.4	18.5	1.71	Not adjusted for ties	1	9.76	0.002
Class 3	14	0.15	12.9	-1.71	Adjusted for ties	1	9.83	0.002
Overall	31		16					

Appendix 9a Floodplain grassland, inundation regimes

Kruskal-Wallis Test: Average annual duration Pre-Millennium Drought versus Inundation class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	2	0.2	2	-0.77	Not adjusted for ties	1	0.6	0.439
Class 3	2	4.25	3	0.77	Adjusted for ties	1	1	0.317
Overall	4		2.5					

Kruskal-Wallis Test: Average annual duration Millennium Drought versus Inundation class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	2	0	2	-0.77	Not adjusted for ties	1	0.6	0.439
Class 3	2	0.4	3	0.77	Adjusted for ties	1	1	0.317
Overall	4		2.5					

Kruskal-Wallis Test: Average annual duration Post-Millennium Drought versus Inundation class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	2	8.056	3.5	1.55		1	2.4	0.121
Class 3	2	2.778	1.5	-1.55				
Overall	4		2.5					

Kruskal-Wallis Test: Years since last flood versus Inundation class PCT 214

Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	8	1.5	6.1	-2	Not adjusted for ties	1	3.98	0.046
Class 3	8	22	10.9	2	Adjusted for ties	1	4.02	0.045
Overall	16		8.5					

Appendix 9b Floodplain grassland, floristic condition

Kruskal-Wallis Test: % FC Native grasses versus Inundation Duration Class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	8	11.4	9.5	0.84	Not adjusted for ties	1	0.71	0.401
Class 3	8	2.25	7.5	-0.84	Adjusted for ties	1	0.71	0.399
Overall	16		8.5					

Kruskal-Wallis Test: % FC Wetland Plant functional species versus Inundation Duration Class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	8	0.55	9.2	0.58	Not adjusted for ties	1	0.33	0.564
Class 3	8	0.25	7.8	-0.58	Adjusted for ties	1	0.34	0.562
Overall	16		8.5					

Kruskal-Wallis Test: % cover bare ground versus Inundation Duration Class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	8	39	9.4	0.74	Not adjusted for ties	1	0.54	0.462
Class 3	8	23.5	7.6	-0.74	Adjusted for ties	1	0.54	0.462
Overall	16		8.5					

Kruskal-Wallis Test: % FC Exotic species versus Inundation Duration Class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	8	1.1	7.8	-0.58	Not adjusted for ties	1	0.33	0.564
Class 3	8	1.95	9.2	0.58	Adjusted for ties	1	0.34	0.562
Overall	16		8.5					

Kruskal-Wallis Test: % FC Invasive native chenopods versus Inundation Duration Class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	8	0.6	6.3	-1.89	Not adjusted for ties	1	3.57	0.059
Class 3	8	3.75	10.8	1.89	Adjusted for ties	1	3.59	0.058
Overall	16		8.5					

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Appendix 9c Floodplain grassland, floristic condition scores

Kruskal-Wallis Test: Floristic condition scores versus Inundation Duration Class PCT 214

Inundation Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	8	12	8.6	0.05	Not adjusted for ties	1	0	0.958
Class 3	8	12	8.4	-0.05	Adjusted for ties	1	0	0.958
Overall	16		8.5					

Appendix 10a Lignum shrubland, inundation regimes

Analysis of Variance

Average annual duration Pre-Millennium Drought versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	3906	3906	10.62	0.031
Error	4	1472	367.9		
Total	5	5378			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Pre-Millennium Drought versus Inundation class PCT 247

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 2 - Class 1	-54.1	16.6	(-100.2, -8.0)	-3.26	0.031

Average annual duration Millennium Drought versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	1134.9	1134.9	4.71	0.096
Error	4	963.5	240.9		
Total	5	2098.4			

Average annual duration Millennium Drought versus Inundation class PCT 247

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 2 - Class 1	-29.2	13.4	(-66.5, 8.1)	-2.17	0.096

Analysis of Variance

Average annual duration Post-Millennium Drought versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	1643.7	1643.72	16.52	0.015
Error	4	398.1	99.52		
Total	5	2041.8			

Average annual duration Post-Millennium Drought versus Inundation class PCT 247

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 2 - Class 1	-35.11	8.64	(-59.10, -11.12)	-4.06	0.015

Analysis of Variance

Years since last flood versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	0.0417	0.04167	0.03	0.874
Error	10	15.625	1.5625		
Total	11	15.6667			

Years since last flood versus Inundation class PCT 247

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 2 - Class 1	0.125	0.765	(-1.581, 1.831)	0.16	0.874

Appendix 10b Lignum shrubland, floristic condition

Analysis of Variance

% FC Lignum versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	6.84	6.843	0.04	0.855
Error	10	1936.07	193.607		
Total	11	1942.92			

Analysis of Variance

% FC Wetland plant Functional Species versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	493.1	493.1	0.6	0.456
Error	10	8189.9	819		
Total	11	8683			

Analysis of Variance

% cover Bare ground versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	17.89	17.89	0.14	0.714
Error	10	1256.53	125.65		
Total	11	1274.41			

Analysis of Variance

% FC Exotic species versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	40.27	40.27	0.35	0.569
Error	10	1159.55	115.96		
Total	11	1199.82			

Analysis of Variance

% FC Invasive native chenopods versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	0.8172	0.8172	0.14	0.716
Error	10	58.3916	5.8392		
Total	11	59.2088			

Appendix 10c Lignum shrubland, floristic condition scores

Analysis of Variance

% Floristic condition score versus Inundation class PCT 247

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	1.042	1.042	0.29	0.604
Error	10	36.375	3.638		
Total	11	37.417			

Appendix 11a River red gum forest and woodland, inundation regimes

Analysis of Variance
Average annual duration Pre-Millennium Drought versus Inundation class PCT 36 and 36A

Source	DF	Adj SS	Adj MS	F-Value	P-Value
In Class	2	4441	2220.5	5.52	0.011
Error	23	9244	401.9		
Total	25	13685			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Pre-Millennium Drought versus Inundation class PCT 36 and 36A

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 1 (Woo - Class 1 (For	-30.2	17.4	(-73.6, 13.3)	-1.74	0.213
Class 2 (Woo - Class 1 (For	-36.5	11	(-64.0, -9.0)	-3.32	0.008
Class 2 (Woo - Class 1 (Woo	-6.4	14.9	(-43.6, 30.9)	-0.43	0.905

Analysis of Variance
Average annual duration Millennium Drought versus Inundation class PCT 36 and 36A

Source	DF	Adj SS	Adj MS	F-Value	P-Value
In Class	2	2536	1268	6.85	0.005
Error	23	4255	185		
Total	25	6791			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Millennium Drought versus Inundation class PCT 36 and 36A

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 1 (Woo - Class 1 (For	-12	11.8	(-41.5, 17.5)	-1.02	0.572
Class 2 (Woo - Class 1 (For	-26.54	7.45	(-45.19, -7.89)	-3.56	0.005
Class 2 (Woo - Class 1 (Woo	-14.5	10.1	(-39.8, 10.7)	-1.44	0.338

Analysis of Variance
Average annual duration Post-Millennium Drought versus Inundation class PCT 36 and 36A

Source	DF	Adj SS	Adj MS	F-Value	P-Value
In Class	2	13518	6759.1	19.58	0
Error	23	7941	345.3		
Total	25	21459			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Post-Millennium Drought versus Inundation class PCT 36 and 36A

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 1 (W) - Class 1 (F)	-25.5	16.1	(-65.8, 14.8)	-1.58	0.273
Class 2 (W) - Class 1 (F)	-60.9	10.2	(-86.3, -35.4)	-5.98	0
Class 2 (W) - Class 1 (W)	-35.4	13.8	(-69.9, -0.9)	-2.57	0.044

Kruskal-Wallis Test: Years since last flood versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0	46.3	-2.84	Not adjusted for ties	2	9.07	0.011
Class 1 (Woodland)	12	0	60.8	-0.59	Adjusted for ties	2	12.67	0.002
Class 2 (woodland)	98	0	72.6	2.82				
Overall	133		67					

Appendix 11a River red gum forest and woodland, inundation regimes

Kruskal-Wallis Test: Years since last flood versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0	16.7	-1.03	Not adjusted for ties	1	1.05	0.305
Class 1 (Woodland)	12	0	20.5	1.03	Adjusted for ties	1	3.44	0.063
Overall	35		18					

Kruskal-Wallis Test: Years since last flood versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0	41.5	-2.96	Not adjusted for ties	1	8.74	0.003
Class 2 (woodland)	98	0	65.6	2.96	Adjusted for ties	1	12.01	0.001
Overall	121		61					

Kruskal-Wallis Test: Years since last flood versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Woodland)	12	0	46.8	-1	Not adjusted for ties	1	1	0.316
Class 2 (woodland)	98	0	56.6	1	Adjusted for ties	1	1.28	0.259
Overall	110		55.5					

Appendix 11b River red gum forest and woodland, floristic condition

Analysis of Variance

% FC RRG Tallest Stratum versus Inundation class PCT 36 and 36A

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Lower Stratum Classes	2	17219	8609.5	30.17	0
Error	105	29967	285.4		
Total	107	47186			

Tukey Simultaneous Tests for Differences of Means

% FC RRG Tallest Stratum versus Inundation class PCT 36 and 36A

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 1 (W) - Class 1 (F)	-34.78	7.24	(-51.99, -17.57)	-4.8	0
Class 2 (W) - Class 1 (F)	-34.66	4.5	(-45.35, -23.98)	-7.71	0
Class 2 (W) - Class 1 (W)	0.12	6.25	(-14.74, 14.98)	0.02	1

Kruskal-Wallis Test: %FC RRG Middle Stratum versus Inundation Duration Class PCT 36 and 36 A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0.5	91.2	3.32	Not adjusted for ties	2	11.72	0.003
Class 1 (Woodland)	12	0	53	-1.32	Adjusted for ties	2	14.2	0.001
Class 2 (woodland)	98	0	63	-1.99				
Overall	133		67					

Kruskal-Wallis Test: %FC RRG Middle Stratum versus Inundation Duration Class PCT 36 and 36 A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0.5	21.2	2.54	Not adjusted for ties	1	6.44	0.011
Class 1 (Woodland)	12	0	11.9	-2.54	Adjusted for ties	1	7.15	0.007
Overall	35		18					

Kruskal-Wallis Test: %FC RRG Middle Stratum versus Inundation Duration Class PCT 36 and 36 A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0.5	82.1	3.2	Not adjusted for ties	1	10.24	0.001
Class 2 (Woodland)	98	0	56.1	-3.2	Adjusted for ties	1	12.16	0
Overall	121		61					

Kruskal-Wallis Test: %FC RRG Middle Stratum versus Inundation Duration Class PCT 36 and 36 A

Appendix 11b River red gum forest and woodland, floristic condition

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Woodland)	12	0	47.6	-0.91	Not adjusted for ties	1	0.82	0.365
Class 2 (Woodland)	98	0	56.5	0.91	Adjusted for ties	1	1.07	0.302
Overall	110		55.5					

Kruskal-Wallis Test: %FC RRG Lower Stratum versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0	67.3	0.04	Not adjusted for ties	2	2.91	0.234
Class 1 (Woodland)	12	0	49	-1.69	Adjusted for ties	2	3.38	0.185
Class 2 (woodland)	98	0.1	69.1	1.07				
Overall	133		67					

Kruskal-Wallis Test: %FC Wetland Functional Species versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	62.9	82.5	2.12	Not adjusted for ties	2	5.13	0.077
Class 1 (Woodland)	12	29.8	55.3	-1.1	Adjusted for ties	2	5.13	0.077
Class 2 (woodland)	98	42.85	64.8	-1.1				
Overall	133		67					

Kruskal-Wallis Test: % cover Bare ground versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	6	62.7	-0.59	Not adjusted for ties	2	9.77	0.008
Class 1 (Woodland)	12	33.5	100.1	3.12	Adjusted for ties	2	9.79	0.007
Class 2 (woodland)	98	5	64	-1.52				
Overall	133		67					

Kruskal-Wallis Test: % cover Bare ground versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	6	14	-3.2	Not adjusted for ties	1	10.22	0.001
Class 1 (Woodland)	12	33.5	25.7	3.2	Adjusted for ties	1	10.26	0.001
Overall	35		18					

Kruskal-Wallis Test: % cover Bare ground versus Inundation Duration Class PCT 36 and PCT 36A

Appendix 11b River red gum forest and woodland, floristic condition

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	6	60.7	-0.05	Not adjusted for ties	1	0	0.958
Class 2 (woodland)	98	5	61.1	0.05	Adjusted for ties	1	0	0.958
Overall	121		61					

Kruskal-Wallis Test: % cover Bare ground versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Woodland)	12	33.5	81	2.93	Not adjusted for ties	1	8.58	0.003
Class 2 (woodland)	98	5	52.4	-2.93	Adjusted for ties	1	8.6	0.003
Overall	110		55.5					

Analysis of Variance

% FC Exotic species versus Inundation class PCT 36 and 36A

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	0.4332	0.2166	0.42	0.656
Error	124	63.5152	0.5122		
Total	126	63.9484			

Tukey Simultaneous Tests for Differences of Means

% FC Exotic species versus Inundation class PCT 36 and 36A

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P-value
Class 1 (W) - Class 1 (F)	-0.099	0.255	(-0.703, 0.505)	-0.39	0.921
Class 2 (W) - Class 1 (F)	-0.152	0.167	(-0.548, 0.243)	-0.91	0.633
Class 2 (W) - Class 1 (W)	-0.054	0.22	(-0.574, 0.467)	-0.24	0.968

Kruskal-Wallis Test: % FC Invasive native chenopods versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0	34	-4.52	Not adjusted for ties	2	28.52	0
Class 1 (Woodland)	12	0	44	-2.17	Adjusted for ties	2	32.78	0
Class 2 (woodland)	98	0.15	77.6	5.29				
Overall	133		67					

Kruskal-Wallis Test: % FC Invasive native chenopods versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0	17	-0.8	Not adjusted for ties	1	0.64	0.424
Class 1 (Woodland)	12	0	19.9	0.8	Adjusted for ties	1	3.95	0.047

Appendix 11b River red gum forest and woodland, floristic condition

Overall	35		18					

Kruskal-Wallis Test: % FC Invasive native chenopods versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	0	29	-4.86	Not adjusted for ties	1	23.64	0
Class 2 (woodland)	98	0.15	68.5	4.86	Adjusted for ties	1	26.46	0
Overall	121		61					

Kruskal-Wallis Test: % FC Invasive native chenopods versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Woodland)	12	0	30.5	-2.87	Not adjusted for ties	1	8.25	0.004
Class 2 (woodland)	98	0.15	58.6	2.87	Adjusted for ties	1	8.84	0.003
Overall	110		55.5					

Appendix 11c River red gum forest and woodland, floristic condition scores

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	17.5	93.4	3.61	Not adjusted for ties	2	13.11	0.001
Class 1 (Woodland)	12	15.5	58.7	-0.78	Adjusted for ties	2	13.2	0.001
Class 2 (woodland)	98	16	61.8	-2.59				
Overall	133		67					

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	17.5	21.3	2.62	Not adjusted for ties	1	6.88	0.009
Class 1 (Woodland)	12	15.5	11.7	-2.62	Adjusted for ties	1	6.96	0.008
Overall	35		18					

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	23	17.5	84.1	3.51	Not adjusted for ties	1	12.33	0
Class 2 (woodland)	98	16	55.6	-3.51	Adjusted for ties	1	12.41	0
Overall	121		61					

Kruskal-Wallis Test: Floristic condition score versus Inundation Duration Class PCT 36 and PCT 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Woodland)	12	15.5	53.5	-0.23	Not adjusted for ties	1	0.05	0.818
Class 2 (woodland)	98	16	55.7	0.23	Adjusted for ties	1	0.05	0.817
Overall	110		55.5					

Appendix 12a River red gum grassy woodland, inundation regimes

Analysis of Variance

Average annual duration Pre-Millennium Drought versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	148.4	148.4	4.51	0.101
Error	4	131.6	32.91		

Tukey Simultaneous Tests for Differences of Means

Average annual duration Pre-Millennium Drought versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-10.55	4.97	(-24.34, 3.24)	-2.12	0.101

Analysis of Variance

Average annual duration Millennium Drought versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	670.51	670.508	165.84	0
Error	4	16.17	4.043		

Tukey Simultaneous Tests for Differences of Means

Average annual duration Millennium Drought versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-22.42	1.74	(-27.26, -17.59)	-12.88	0

Analysis of Variance

Average annual duration Post-Millennium Drought versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	2013.6	2013.58	25.05	0.007
Error	4	321.5	80.37		
Total	5	2335			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Post- Millennium Drought versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-38.86	7.76	(-60.42, -17.31)	-5.01	0.007

Kruskal-Wallis Test: Years since flood versus Inundation Duration Class PCT 454

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	9	1	13.9	-1.13	Not adjusted for ties	1	1.28	0.258
Class 3	24	2.5	18.2	1.13	Adjusted for ties	1	1.34	0.246
Overall	33		17					

Appendix 12b River red gum grassy woodland, floristic condition

Analysis of Variance
% FC RRG Tallest Stratum versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
LS Class	1	467.7	467.7	0.82	0.374
Error	25	14252.5	570.1		
Total	26	14720.3			

Tukey Simultaneous Tests for Differences of Means
% FC RRG Tallest Stratum versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	9.5	10.5	(-12.1, 31.1)	0.91	0.374

Analysis of Variance
% FC RRG Middle Stratum versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class LS	1	0.00365	0.003649	0.09	0.761
Error	31	1.20181	0.038768		
Total	32	1.20545			

Tukey Simultaneous Tests for Differences of Means
% FC RRG Middle Stratum versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	0.0236	0.077	(-0.1334, 0.1806)	0.31	0.761

Analysis of Variance
% FC RRG Lower Stratum versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class LS	1	0.009899	0.009899	0.32	0.578
Error	31	0.968889	0.031254		
Total	32	0.978788			

Tukey Simultaneous Tests for Differences of Means
% FC RRG Lower Stratum versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	0.0389	0.0691	(-0.1020, 0.1798)	0.56	0.578

Analysis of Variance
% FC Wetland Functional Species versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class LS	1	682.6	682.6	1.17	0.288
Error	31	18139.3	585.1		
Total	32	18821.9			

Tukey Simultaneous Tests for Differences of Means
% FC Wetland Functional Species versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-10.21	9.45	(-29.50, 9.07)	-1.08	0.288

Kruskal-Wallis Test: %FC Native grasses versus Inundation Duration Class PCT 454

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value

Appendix 12b River red gum grassy woodland, floristic condition

Class LS	N	Median	Mean Rank	Z-Value	Not adjusted for ties	1	2.88	0.09
Class 2	9	0	12.3	-1.7	Adjusted for ties	1	3.3	0.069
Class 3	24	0.1	18.8	1.7				

Kruskal-Wallis Test: %FC Exotic species versus Inundation Duration Class PCT 454

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	9	15.5	22.3	1.94	Not adjusted for ties	1	3.76	0.052
Class 3	24	3.06	15	-1.94	Adjusted for ties	1	3.77	0.052
Overall	33		17					

Analysis of Variance

% FC Invasive native chenopods versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class LS	1	28.18	28.18	1.4	0.246
Error	31	623.58	20.12		
Total	32	651.76			

Tukey Simultaneous Tests for Differences of Means

% FC Invasive native chenopods versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	2.07	1.75	(-1.50, 5.65)	1.18	0.246

Appendix 12c River red gum grassy woodland, floristic condition scores

Analysis of Variance

% Floristic condition score versus Inundation class PCT 454

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class LS	1	2.672	2.672	0.84	0.367
Error	31	98.639	3.182		
Total	32	101.311			

Tukey Simultaneous Tests for Differences of Means

% FC Invasive native chenopods versus Inundation class PCT 454

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-0.639	0.697	(-2.061, 0.783)	-0.92	0.367

Appendix 13a Coolibah woodland, inundation regimes

Analysis of Variance

Average annual duration Pre-Millennium Drought versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
LS Class	1	405.54	405.54	19.52	0.022
Error	3	62.33	20.78		
Total	4	467.87			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Pre-Millennium Drought versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-18.38	4.16	(-31.63, -5.14)	-4.42	0.022

Analysis of Variance

Average annual duration Millennium Drought versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
LS Class	1	209.1	209.09	3.58	0.155
Error	3	175.3	58.43		
Total	4	384.4			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Millennium Drought versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-13.2	6.98	(-35.41, 9.01)	-1.89	0.155

Analysis of Variance

Average annual duration Post-Millennium Drought versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
LS Class	1	2042.79	2042.79	70.11	0.004
Error	3	87.42	29.14		
Total	4	2130.21			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Post-Millennium Drought versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-41.26	4.93	(-56.94, -25.58)	-8.37	0.004

Kruskal-Wallis Test: Years since last flood versus Inundation Duration Class PCT 40

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	12	0.5	7.6	-3.41	Not adjusted for ties	1	11.6	0.001
Class 3	12	8	17.4	3.41	Adjusted for ties	1	11.94	0.001
Overall	24		12.5					

Appendix 13b Coolibah woodland, floristic condition

Analysis of Variance

% FC Coolibah in Tallest Stratum versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class LS	1	0.796	0.796	3.96	0.067
Error	14	2.8146	0.201		
Total	15	3.6107			

Kruskal-Wallis Test: %FC Coolibah Middle Stratum versus Inundation Duration Class PCT 40

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	12	0	13	0.38	Not adjusted for ties	1	0.14	0.707
Class 3	12	0	12	-0.38	Adjusted for ties	1	0.43	0.514
Overall	24		12.5					

Analysis of Variance

% FC Coolibah in Lowest Stratum versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	0	0	0	1
Error	22	0.065	0.002955		
Total	23	0.065			

Tukey Simultaneous Tests for Differences of Means

Average annual duration Post-Millennium Drought versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	0	0.0222	(-0.0460, 0.0460)	0	1

Kruskal-Wallis Test: %FC Wetland functional species versus Inundation Duration Class PCT 40

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	12	19.3	16.6	2.86	Not adjusted for ties	1	8.17	0.004
Class 3	12	0.65	8.4	-2.86	Adjusted for ties	1	8.18	0.004
Overall	24		12.5					

Kruskal-Wallis Test: %FC Native grasses versus Inundation Duration Class PCT 40

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	12	1.55	8.4	-2.83	Not adjusted for ties	1	8	0.005
Class 3	12	22.5	16.6	2.83	Adjusted for ties	1	8.01	0.005
Overall	24		12.5					

Appendix 13b Coolibah woodland, floristic condition

Test

Analysis of Variance

% cover bare ground versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	3358	3358.3	9.23	0.006
Error	22	8002	363.7		
Total	23	11360			

Tukey Simultaneous Tests for Differences of Means

% cover bare ground versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	23.66	7.79	(7.51, 39.81)	3.04	0.006

Analysis of Variance

% FC Invasive native chenopds versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	0.0094	0.009355	0.01	0.904
Error	19	12.0088	0.632042		
Total	20	12.0181			

Tukey Simultaneous Tests for Differences of Means

% FC Invasive native chenopds versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	0.043	0.351	(-0.691, 0.776)	0.12	0.904

Appendix 13c Coolibah woodland, floristic condition scores

Analysis of Variance

% Floristic condition score versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	1	0.0234	0.02344	0.01	0.921
Error	22	51.0365	2.31984		
Total	23	51.0599			

Tukey Simultaneous Tests for Differences of Means

% FC Invasive native chenopds versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 2	-0.063	0.622	(-1.352, 1.227)	-0.1	0.921

Appendix 14a River red gum forest and woodland, inundation regimes (tree stand condition)

Analysis of Variance
Average annual duration Pre-Millennium Drought versus Inundation class PCT 36 and 36A (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeClass	2	7580	3790.2	15.4	0
Error	21	5169	246.2		
Total	23	12750			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Pre-Millennium Drought versus Inundation class PCT 36 and 36A (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 1 (W) - Class 1 (F)	-29.83	8.97	(-52.41, -7.25)	-3.33	0.009
Class 2 (W) - Class 1 (F)	-54.11	9.83	(-78.87, -29.36)	-5.5	0
Class 2 (W) - Class 1 (W)	-24.28	7.36	(-42.80, -5.77)	-3.3	0.009

Analysis of Variance
Average annual duration Millennium Drought versus Inundation class PCT 36 and 36A (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeClass	2	0.4517	0.22585	18.02	0
Error	21	0.2632	0.01253		
Total	23	0.7149			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Millennium Drought versus Inundation class PCT 36 and 36A (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 1 (W) - Class 1 (F)	-0.2082	0.064	(-0.3693, -0.0470)	-3.25	0.01
Class 2 (W) - Class 1 (F)	-0.4129	0.0702	(-0.5895, -0.2363)	-5.88	0
Class 2 (W) - Class 1 (W)	-0.2047	0.0525	(-0.3368, -0.0726)	-3.9	0.002

Analysis of Variance
Average annual duration Post-Millennium Drought versus Inundation class PCT 36 and 36A (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeClass	2	14005	7002.7	20.53	0
Error	21	7163	341.1		
Total	23	21169			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Post-Millennium Drought versus Inundation class PCT 36 and 36A (Tree)

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 1 (W) - Class 1 (F)	-51.9	10.6	(-78.5, -25.4)	-4.92	0
Class 2 (W) - Class 1 (F)	-73.8	11.6	(-102.9, -44.6)	-6.37	0
Class 2 (W) - Class 1 (W)	-21.84	8.66	(-43.63, -0.04)	-2.52	0.05

Analysis of Variance

Tukey Simultaneous Tests for Differences of Means

Kruskal-Wallis Test: Slope_92 versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	4	-0.0357843	14.8	0.7	Not adjusted for ties	2	11.32	0.003
Class 1 (Woodland)	13	-0.0539216	8.2	-3.22	Adjusted for ties	2	11.33	0.003
Class 2 (Woodland)	7	-0.025	19.1	2.95				
Overall	24		12.5					

Kruskal-Wallis Test: Slope_92 versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value

Appendix 14a River red gum forest and woodland, inundation regimes (tree stand condition)

Class 1 (Forest)	4	-0.0357843	13.3	1.92		1	3.71	0.054
Class 1 (Woodland)	13	-0.0539216	7.7	-1.92				
Overall	17		9					

Kruskal-Wallis Test: Slope_92 versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	4	-0.0357843	4	-1.51	Not adjusted for ties	1	2.29	0.131
Class 2 (Woodland)	7	-0.025	7.1	1.51	Adjusted for ties	1	2.3	0.13
Overall	11		6					

Kruskal-Wallis Test: Slope_92 versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Woodland)	13	-0.0539216	7.5	-3.05	Not adjusted for ties	1	9.31	0.002
Class 2 (Woodland)	7	-0.025	16	3.05	Adjusted for ties	1	9.31	0.002
Overall	20		10.5					

Appendix 14b River red gum forest and woodland, tree stand condition

Analysis of Variance
PAI versus Inundation class PCT 36 and 36A (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tree Class	2	4.733	2.36669	30.24	0
Error	104	8.139	0.07826		
Total	106	12.873			

Tukey Simultaneous Tests for Differences of Means
PAI versus Inundation class PCT 36 and 36A (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 1 (W) - Class 1 (F)	-0.4227	0.0775	(-0.6067, -0.2386)	-5.46	0
Class 2 (W) - Class 1 (F)	-0.6461	0.0831	(-0.8436, -0.4487)	-7.78	0
Class 2 (W) - Class 1 (W)	-0.2235	0.0608	(-0.3680, -0.0790)	-3.67	0.001

Analysis of Variance
%FC versus Inundation class PCT 36 and 36A (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	4.732	2.36601	30.31	0
Error	105	8.197	0.07807		
Total	107	12.929			

Tukey Simultaneous Tests for Differences of Means
%FC versus Inundation class PCT 36 and 36A (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 1 (W) - Class 1 (F)	-0.4269	0.0772	(-0.6104, -0.2435)	-5.53	0
Class 2 (W) - Class 1 (F)	-0.6461	0.083	(-0.8433, -0.4490)	-7.79	0
Class 2 (W) - Class 1 (W)	-0.2192	0.0605	(-0.3631, -0.0754)	-3.62	0.001

Kruskal-Wallis Test: % LBA versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	17	100	64.8	1.48	Not adjusted for ties	2	2.21	0.331
Class 1 (Woodland)	57	100	52.2	-0.8	Adjusted for ties	2	2.76	0.252
Class 2 (Woodland)	34	100	53.1	-0.3				
Overall	108		54.5					

Kruskal-Wallis Test: % DC versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	17	16.0909	42.1	-1.78	Not adjusted for ties	2	5.19	0.075
Class 1 (Woodland)	57	25.8333	60.4	2.08	Adjusted for ties	2	5.19	0.075
Class 2 (Woodland)	34	14.4375	50.8	-0.84				
Overall	108		54.5					

Kruskal-Wallis Test: % DL versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	17	0	43.5	-1.58	Not adjusted for ties	2	3.05	0.218
Class 1 (Woodland)	57	6.25	54.7	0.06	Adjusted for ties	2	3.36	0.186
Class 2 (Woodland)	34	8.63333	59.7	1.17				
Overall	108		54.5					

Appendix 14c River red gum forest and woodland, tree stand condition scores

Kruskal-Wallis Test: Tree stand condition score versus Inundation Duration Class PCT 36 and 36A

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1 (Forest)	17	17	64.8	1.47	Not adjusted for ties	2	2.18	0.336
Class 1 (Woodland)	57	16	52.3	-0.77	Adjusted for ties	2	2.24	0.327
Class 2 (Woodland)	34	17	53.1	-0.32				
Overall	108		54.5					

Appendix 15a River red gum grassy woodland, inundation regimes (tree stand condition)

Analysis of Variance
Average annual duration Pre-Millennium Drought versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeClass	2	121	60.51	1.14	0.428
Error	3	159	53.01		
Total	5	280			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Pre-Millennium Drought versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	7.85	8.92	(-29.41, 45.11)	0.88	0.687
Class 3 - Class 1	-4.68	6.65	(-32.46, 23.09)	-0.7	0.778
Class 3 - Class 2	-12.53	8.41	(-47.67, 22.60)	-1.49	0.409

Analysis of Variance
Average annual duration Millennium Drought versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeClass	2	1.0876	0.5438	1.73	0.317
Error	3	0.9435	0.3145		
Total	5	2.0311			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Millennium Drought versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	0.629	0.687	(-2.241, 3.499)	0.92	0.669
Class 3 - Class 1	-0.531	0.512	(-2.671, 1.608)	-1.04	0.607
Class 3 - Class 2	-1.16	0.648	(-3.867, 1.546)	-1.79	0.312

Analysis of Variance
Average annual duration Post-Millennium Drought versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeClass	2	0.5661	0.283	0.48	0.658
Error	3	1.7617	0.5872		
Total	5	2.3277			

Tukey Simultaneous Tests for Differences of Means
Average annual duration Post-Millennium Drought versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	0.47	0.939	(-3.452, 4.392)	0.5	0.876
Class 3 - Class 1	-0.372	0.7	(-3.295, 2.552)	-0.53	0.862
Class 3 - Class 2	-0.842	0.885	(-4.540, 2.856)	-0.95	0.651

Analysis of Variance
Slope_92 Post-Millennium Drought versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeClass	2	0.000755	0.000377	6.06	0.088
Error	3	0.000187	0.000062		
Total	5	0.000942			

Tukey Simultaneous Tests for Differences of Means
Slope_92 Post-Millennium Drought versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	0.00833	0.00967	(-0.03207, 0.04874)	0.86	0.697
Class 3 - Class 1	0.02451	0.00721	(-0.00561, 0.05462)	3.4	0.084
Class 3 - Class 2	0.01618	0.00912	(-0.02192, 0.05427)	1.77	0.317

Appendix 15b River red gum grassy woodland, tree stand condition

Analysis of Variance

PAI versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	2.638	1.3189	3.66	0.042
Error	23	8.297	0.3607		
Total	25	10.935			

Tukey Simultaneous Tests for Differences of Means

PAI versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	0.109	0.4	(-0.893, 1.111)	0.27	0.96
Class 3 - Class 1	-0.608	0.257	(-1.251, 0.034)	-2.37	0.066
Class 3 - Class 2	-0.717	0.382	(-1.674, 0.239)	-1.88	0.168

Analysis of Variance

%FC versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	2.638	1.3189	3.66	0.042
Error	23	8.297	0.3607		
Total	25	10.935			

Tukey Simultaneous Tests for Differences of Means

%FC versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	0.109	0.4	(-0.893, 1.111)	0.27	0.96
Class 3 - Class 1	-0.608	0.257	(-1.251, 0.034)	-2.37	0.066
Class 3 - Class 2	-0.717	0.382	(-1.674, 0.239)	-1.88	0.168

Kruskal-Wallis Test: %LBA versus Inundation Duration Class PCT 454

Class Tree	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	9	100	19	2.31	Not adjusted for ties	2	8.57	0.014
Class 2	3	100	19	1.16	Adjusted for ties	2	11.42	0.003
Class 3	15	92.091	10	-2.93				

Kruskal-Wallis Test: %LBA versus Inundation Duration Class PCT 454

Class Tree	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	9	100	6.5	0	Not adjusted for ties	1	0	1
Class 2	3	100	6.5	0				
Overall	12		6.5					

Kruskal-Wallis Test: %LBA versus Inundation Duration Class PCT 454

Class Tree	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	9	100	17.5	2.68	Not adjusted for ties	1	7.2	0.007
Class 3	15	92.091	9.5	-2.68	Adjusted for ties	1	8.99	0.003
Overall	24		12.5					

Kruskal-Wallis Test: %LBA versus Inundation Duration Class PCT 454

Class Tree	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 2	3	100	14.5	1.78	Not adjusted for ties	1	3.16	0.076
Class 3	15	92.091	8.5	-1.78	Adjusted for ties	1	3.47	0.063

Appendix 15b River red gum grassy woodland, tree stand condition

Overall	18		9.5		

Analysis of Variance

%DC versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class Tree	2	2.131	1.06546	15.79	0
Error	24	1.62	0.06748		
Total	26	3.75			

Tukey Simultaneous Tests for Differences of Means

%DC versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	0.232	0.173	(-0.200, 0.664)	1.34	0.387
Class 3 - Class 1	0.607	0.11	(0.334, 0.880)	5.54	0
Class 3 - Class 2	0.375	0.164	(-0.035, 0.785)	2.28	0.078

Analysis of Variance

%DL versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	4.272	2.1361	14.14	0.001
Error	13	1.964	0.1511		
Total	15	6.236			

Tukey Simultaneous Tests for Differences of Means

%DL versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	0.893	0.426	(-0.230, 2.016)	2.1	0.129
Class 3 - Class 1	1.13	0.213	(0.568, 1.691)	5.31	0
Class 3 - Class 2	0.236	0.408	(-0.839, 1.312)	0.58	0.833

Appendix 15c River red gum grassy woodland, tree stand condition scores

Analysis of Variance

Tree stand condition score versus Inundation class PCT 454 (Tree)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Class	2	0.3244	0.1622	4.69	0.02
Error	23	0.7949	0.03456		
Total	25	1.1193			

Tukey Simultaneous Tests for Differences of Means

%DC versus Inundation class PCT 454 (Tree)

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 2 - Class 1	-0.022	0.124	(-0.332, 0.288)	-0.18	0.982
Class 3 - Class 1	-0.2292	0.0794	(-0.4281, -0.0304)	-2.89	0.022
Class 3 - Class 2	-0.207	0.118	(-0.503, 0.089)	-1.75	0.209

Appendix 16a Coolibah woodland, inundation regimes (tree stand condition)

Kruskal-Wallis Test: Pre-Millenniun Drought versus Inundation Duration Class PCT 40 (Tree)

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	2	18	3.5	1.55		1	2.4	0.121
Class 3	2	2.25	1.5	-1.55				
Overall	4		2.5					

Kruskal-Wallis Test: Millenniun Drought versus Inundation Duration Class PCT 40 (Tree)

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	2	16.4	3.5	1.55		1	2.4	0.121
Class 3	2	0.5	1.5	-1.55				
Overall	4		2.5					

Kruskal-Wallis Test: Post-Millenniun Drought versus Inundation Duration Class PCT 40 (Tree)

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
Class 1	2	43.1556	3.5	1.55		1	2.4	0.121
Class 3	2	0.5444	1.5	-1.55				
Overall	4		2.5					

Analysis of Variance
Slope_92 versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TreeCluster	1	0.000035	0.000035	1.66	0.326
Error	2	0.000042	0.000021		
Total	3	0.000076			

Tukey Simultaneous Tests for Differences of Means
Slope_92 versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 1	0.00588	0.00456	(-0.01373, 0.02550)	1.29	0.326

Appendix 16c Coolibah woodland, tree stand condition scores

Analysis of Variance
PAI Coolibah versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tree Class	1	0.5082	0.5082	1.8	0.216
Error	8	2.2537	0.2817		
Total	9	2.7619			

Tukey Simultaneous Tests for Differences of Means
PAI Coolibah versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
43134	-0.451	0.336	(-1.225, 0.323)	-1.34	0.216

Analysis of Variance
% FC Coolibah versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tree Class	1	0.5082	0.5082	1.8	0.216
Error	8	2.2537	0.2817		
Total	9	2.7619			

Tukey Simultaneous Tests for Differences of Means
% FC Coolibah versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 1	-0.451	0.336	(-1.225, 0.323)	-1.34	0.216

Kruskal-Wallis Test: % LBA versus Inundation Duration Class PCT 40 (Tree)

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
2	5	100	4.5	-1.04	Not adjusted for ties	1	1.09	0.296
3	5	100	6.5	1.04	Adjusted for ties	1	2.25	0.134
Overall	10		5.5					

Analysis of Variance
% DC versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tree Class	1	0.2661	0.2661	2.23	0.179
Error	7	0.834	0.1191		
Total	8	1.1001			

Tukey Simultaneous Tests for Differences of Means
% DC versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 1	-0.346	0.232	(-0.894, 0.201)	-1.49	0.179

Kruskal-Wallis Test: % DL versus Inundation Duration Class PCT 40 (Tree)

In Class	N	Median	Mean Rank	Z-Value	Method	DF	H-Value	P-Value
2	5	0	6.5	1.04	Not adjusted for ties	1	1.09	0.296
3	5	0	4.5	-1.04	Adjusted for ties	1	2.25	0.134
Overall	10		5.5					

Appendix 16c Coolibah woodland, tree stand condition scores

Analysis of Variance
% Tree stand condition score versus Inundation class PCT 40

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tree Class	1	0.1	0.1	0.05	0.831
Error	8	16.4	2.05		
Total	9	16.5			

Tukey Simultaneous Tests for Differences of Means
% Tree stand condition score versus Inundation class PCT 40

Difference of Levels	Difference of means	SE of Difference	95% CI	T-Value	Adjusted P- value
Class 3 - Class 1	-0.2	0.906	(-2.288, 1.888)	-0.22	0.831

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

Tree stand condition River red gum forest and woodland, PCT 36/36A

PCT No.	Mapped Condition 2008	Site Name	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
36	Intermediate	MM1	16	ns	ns	17	ns	20	17	18	16	17
36	Intermediate	MM1	Intermediate	ns	ns	Intermediate	ns	Excellent	Intermediate	Good	Intermediate	Intermediate
36	Good	HallsRRGF	ns	17	ns	17	ns	19.5	18.5	18.5	16.5	15
36	Good	HallsRRGF	ns	Intermediate	ns	Int	ns	Good	Good	Good	Intermediate	Int
36	Intermediate	UBlock3	ns	ns	ns	ns	15	15	13	ns	10	6
36	Intermediate	UBlock3	ns	ns	ns	ns	Intermediate	Intermediate	Intermediate/ poor	ns	ns	ns
36A	Intermediate	BluLgtWest	ns	ns	ns	ns	ns	ns	ns	16	16	16
36A	Intermediate	BluLgtWest	ns	ns	ns	ns	ns	ns	ns	Intermediate	Intermediate	Intermediate
36A	Poor	HuntsRRG	ns	ns	ns	16	ns	16	ns	ns	16	15
36A	Poor	HuntsRRG	ns	ns	ns	ns	ns	Intermediate	ns	ns	Intermediate	Intermediate
36A	Intermediate	PiliRRGW	ns	ns	ns	ns	18	18	19	19	19	19
36A	Intermediate	PiliRRGW	ns	ns	ns	ns	Good	Good	Good	Good	Good	Good
36A	Intermediate	NortNR8	ns	14	ns	18	18	18	19	19	17	19
36A	Intermediate	NortNR8	ns	Intermediate/ poor	ns	Good	Good	Good	Good	Good	Intermediate	Good
36A	Intermediate	Nov_12	ns	ns	ns	ns	ns	17	18	17	17	17
36A	Intermediate	Nov_12	ns	ns	ns	ns	ns	Intermediate	Good	Intermediate	Intermediate	Intermediate
36A	Intermediate	Nov_16	ns	ns	ns	16	16	18	ns	ns	ns	17

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

Tree stand condition River red gum forest and woodland, PCT 36/36A

PCT No.	Mapped Condition 2008	Site Name	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
36A	Intermediate	Nov_16	ns	ns	ns	Intermediate	Intermediate	Good	ns	ns	ns	Int
36A	Intermediate	Nov_5	ns	17	ns	17	ns	17	17	17	14	16
36A	Intermediate	Nov_5	ns	Intermediate	ns	Intermediate	ns	Intermediate	Intermediate	Intermediate	Intermediate/ poor	Int
36A	Intermediate	BluLgtEast	ns	14	ns	ns	ns	17	ns	17	17	17
36A	Intermediate	BluLgtEast	ns	Intermediate/ poor	ns	ns	ns	Intermediate	ns	Intermediate	Intermediate	Intermediate
36A	Poor	Oxley1	ns	ns	ns	16	16	16	17	16	15	14
36A	Poor	Oxley1	ns	ns	ns	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate/ poor
36A	Poor	OxleyRRGW	ns	ns	ns	9	9	9	10	10	16	10
36A	Poor	OxleyRRGW	ns	ns	ns	Poor	Poor	Poor	Poor	Poor	Intermediate	Poor
36A	Poor	UBlockRRGW	ns	ns	ns	ns	19	17	17	17	17	16
36A	Poor	UBlockRRGW	ns	ns	ns	ns	Good	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
36A	Intermediate	WilgaraRRG	ns	ns	ns	ns	16	17	17	17	17	14
36A	Intermediate	WilgaraRRG	ns	ns	ns	ns	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate/ poor

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

Community and tree stand condition, River red gum grassy woodland PCT 454

PCT No.	Mapped Condition 2008	Site Name	Condition Measure	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
454	Intermediate	BarLgn1	Community score	ns	ns	ns	ns	ns	ns	15.5	10.5	9.8	ns
454	Intermediate	BarLgn1	Community category	ns	ns	ns	ns	ns	ns	Intermediate	Poor	Poor	ns
454	Intermediate	BarLgn1	Tree stand score	ns	ns	ns	ns	ns	ns	17	16	17	ns
454	Intermediate	BarLgn1	Tree stand condition	ns	ns	ns	ns	ns	ns	Intermediate	Intermediate	Intermediate	ns
454	Intermediate	ExpLgn	Community score	ns	ns	ns	13.0	ns	12.5	12.5	12.0	10.0	13.5
454	Intermediate	ExpLgn	Community category	ns	ns	ns	Intermediate/ poor	ns	Intermediate/ poor	Intermediate/ poor	Intermediate/ poor	Poor	Intermediate/ poor
454	Intermediate	ExpLgn	Tree stand score	ns	ns	ns	18	ns	18	18	18	16	16
454	Intermediate	ExpLgn	Tree stand condition	ns	ns	ns	Good	ns	Good	Good	Good	Intermediate	Intermediate
454	Intermediate	MMI	Community score	13	ns	ns	13	ns	11	12.5	10.5	14.5	11
454	Intermediate	MMI	Community category	Intermediate/ poor	ns	ns	Intermediate/ poor	ns	Poor	Intermediate/ poor	Poor	Intermediate/ poor	Poor
454	Intermediate	MMI	Tree stand score	ns	ns	ns	ns	ns	18	17	17	14	14
454	Intermediate	MMI	Tree stand condition	ns	ns	ns	ns	ns	Good	Intermediate	Intermediate	Intermediate/ poor	Intermediate/ poor
454	Poor	PoorRRG1	Community score	ns	ns	ns	12.5	13	15	10.5	10.5	11	12
454	Poor	PoorRRG1	Community category	ns	ns	ns	Intermediate/ poor	Intermediate/ poor	Intermediate	Poor	Poor	Poor	Intermediate/ poor
454	Poor	PoorRRG1	Tree stand score	ns	ns	ns	4	4	4	0	4	8	8
454	Poor	PoorRRG1	Tree stand condition	ns	ns	ns	Very poor	Very poor	Very poor	Very poor	Very poor	Very poor	Very poor
454	Poor	PoorRRG2	Community score	ns	ns	ns	11.0	ns	ns	13.0	ns	9.5	10.0
454	Poor	PoorRRG2	Community category	ns	ns	ns	Poor	ns	ns	Intermediate/ poor	ns	Poor	Poor

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

Community and tree stand condition, River red gum grassy woodland PCT 454

PCT No.	Mapped Condition 2008	Site Name	Condition Measure	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
454	Poor	PoorRRG2	Tree stand score	ns	ns	ns	14	ns	ns	14	ns	14	14
454	Poor	PoorRRG2	Tree stand condition	ns	ns	ns	Intermediate/ poor	ns	ns	Intermediate/ poor	ns	Intermediate/ poor	Intermediate/ poor
454	Intermediate	UBlock6	Condition score	10.5	ns	ns	16.5	ns	ns	11	11	11	13
454	Intermediate	UBlock6	Condition category	Poor	ns	ns	Intermediate	ns	ns	Poor	Poor	Poor	Intermediate/ poor
454	Intermediate	UBlock6	Tree stand score	ns	ns	ns	ns	ns	18	18	18	18	18
454	Intermediate	UBlock6	Tree stand condition	ns	ns	ns	ns	ns	Good	Good	Good	Good	Good

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

Community and tree stand condition, Coolibah woodland PCT 40

PCT No.	Mapped Condition 2008	SiteName	Condition Measure	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
40	Intermediate	MM6	Community score	ns	ns	ns	11.5	ns	ns	11.8	ns	ns	ns
40	Intermediate	MM6	Community category	ns	ns	ns	Poor	ns	ns	Poor	ns	ns	ns
40	Intermediate	MM6	Tree stand score	ns	ns	ns	14	ns	ns	14	ns	ns	ns
40	Intermediate	MM6	Tree Condition category	ns	ns	ns	Intermediate/ poor	ns	ns	Intermediate/ poor	ns	ns	ns
40	Intermediate	MM16	Community score	9.25	ns	ns	14	ns	15	13.5	10	10	7.5
40	Intermediate	MM16	Community category	Poor	ns	ns	Intermediate/ poor	ns	Intermediate	Intermediate/ poor	Intermediate/ poor	Intermediate/ poor	Very poor
40	Intermediate	MM16	Tree stand Score	16	ns	ns	16	ns	16	16	16	16	18
40	Intermediate	MM16	Tree stand condition	Intermediate	ns	ns	Intermediate	ns	Intermediate	Intermediate	Intermediate	Intermediate	Good
40	Intermediate	Nov_1	Community score	ns	14.5	ns	13.5	ns	13	11	10.5	12	13.5
40	Intermediate	Nov_1	Community category	ns	Intermediate/ poor	ns	Intermediate/ poor	ns	Intermediate/ poor	Poor	Poor	Intermediate/ poor	Intermediate/ poor
40	Intermediate	Nov_1	Tree stand score	16	ns	ns	17	ns	19	19	16	17	16
40	Intermediate	Nov_1	Tree stand condition	Intermediate	ns	ns	Intermediate	ns	Good	Good	Intermediate	Intermediate	Intermediate
40	Intermediate	MM11	Community score	12.5	ns	ns	13.5	ns	13.5	12.5	11.0	14.0	14.0
40	Intermediate	MM11	Community category	Intermediate/ poor	ns	ns	Intermediate/ poor	ns	Intermediate/ poor	Intermediate/ poor	Poor	Intermediate/ poor	Intermediate/ poor
40	Intermediate	MM11	Tree stand score	17	ns	ns	17	ns	19	19	19	17	17
40	Intermediate	MM11	Tree stand condition	Intermediate	ns	ns	Intermediate	ns	Good	Good	Good	Intermediate	Intermediate
40	Very Poor	BarLgn2	Community score	ns	ns	ns	ns	ns	ns	16	15	14	ns
40	Very Poor	BarLgn2	Community category	ns	ns	ns	ns	ns	ns	Intermediate	Intermediate	Intermediate/ poor	ns
40	Very Poor	BarLgn2	Tree stand score	ns	ns	ns	ns	ns	ns	17	17	17	ns
40	Very Poor	BarLgn2	Tree stand condition	ns	ns	ns	ns	ns	ns	Intermediate	Intermediate	Intermediate	ns

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

Community condition, Mixed marsh sedgeland, PCT 53

PCT No.	Mapped Condition 2008	Site Name	Condition Measure	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
53	Poor	DustyMM	Community score	ns	10	ns	18	ns	ns	15	ns	ns	ns
53	Poor	DustyMM	Community category	ns	Poor	ns	Good	ns	ns	Intermediate	ns	ns	ns
53	Very Poor	MM12A	Community score	ns	ns	ns	10	9	9	9	10	8	10
53	Very Poor	MM12A	Community category	ns	ns	ns	Poor	Poor	Poor	Poor	Poor	Very poor	Poor
53	Intermediate	MM14	Community score	17	ns	ns	20	ns	20	17	10	14	20
53	Intermediate	MM14	Community category	Intermediate/poor	ns	ns	Excellent	ns	Excellent	Intermediate	Poor	Intermediate/poor	Excellent
53	Very Poor	MM15	Community score	8	ns	ns	18	ns	19	20	20	17	17
53	Very Poor	MM15	Community category	Very poor	ns	ns	Good	ns	Good	Excellent	Excellent	Intermediate	Intermediate
53	Poor	MM19	Community score	9	ns	ns	16	ns	17	ns	ns	16	17
53	Poor	MM19	Community category	Poor	ns	ns	Intermediate	ns	Intermediate	ns	ns	Intermediate	Intermediate
53	Poor	MMA	Community score	9	ns	ns	16	ns	20	ns	20	17	20
53	Poor	MMA	Community category	Poor	ns	ns	Intermediate	ns	Excellent	ns	Excellent	Intermediate	Excellent
53	Poor	MMH	Community score	9	ns	ns	ns	20	20	20	15	14	17
53	Poor	MMH	Community category	Poor	ns	ns	ns	Excellent	Excellent	Excellent	Intermediate	Intermediate/poor	Intermediate
53	Intermediate	MoEfloA	Community score	ns	ns	20	ns	ns	ns	ns	17	17	19
53	Intermediate	MoEfloA	Community category	ns	ns	Excellent	ns	ns	ns	ns	Intermediate	Intermediate	Good
53	Intermediate	Oxley3	Community score	ns	ns	ns	17	16	19	20	20	14	8
53	Intermediate	Oxley3	Community category	ns	ns	ns	Intermediate	Intermediate	Good	Excellent	Excellent	Intermediate/poor	Very poor
53	Very Poor	UBlock5	Community score	ns	ns	ns	ns	20	17	17	17	14	20
53	Very Poor	UBlock5	Community category	ns	ns	ns	ns	Excellent	Intermediate	Intermediate	Intermediate	Intermediate/poor	Excellent

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

Community condition, Water couch marsh grassland, PCT 204

PCT No.	Mapped Condition 2008	SiteName	Condition Measure	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
204	Intermediate	BuEfloB	Community score	ns	ns	15	20	ns	10	17	17	18	15
204	Intermediate	BuEfloB	Community category	ns	ns	Intermediate	Excellent	ns	Poor	Intermediate	Intermediate	Good	Intermediate
204	Intermediate	BuEfloC	Community score	ns	ns	17	20	18	18	18	18	18	18
204	Intermediate	BuEfloC	Community category	ns	ns	Intermediate	Excellent	Good	Good	Good	Good	Good	Good
204	Very Poor	MM10	Community score	8	ns	ns	17	ns	18	10	11	10	12
204	Very Poor	MM10	Community category	Very poor	ns	ns	Intermediate	ns	Good	Poor	Poor	Poor	Intermediate/poor
204	Very Poor	MM24	Community score	20	ns	ns	20	20	20	20	20	17	17
204	Very Poor	MM24	Community category	Excellent	ns	ns	Excellent	Excellent	Excellent	Excellent	Excellent	Intermediate	Intermediate
204	Very Poor	SthNRWC	Community score	9	ns	ns	11	ns	10	10	10	10	11
204	Very Poor	SthNRWC	Community category	Poor	ns	ns	Poor	ns	Poor	Poor	Poor	Poor	Poor
204	Intermediate	Nov_13	Community score	ns	15	ns	16	ns	ns	17	9	14	15
204	Intermediate	Nov_13	Community category	ns	Intermediate	ns	Intermediate	ns	ns	Intermediate	Poor	Intermediate/poor	Intermediate
204	Intermediate	Nov_4	Community score	ns	20	ns	20	ns	18	17	12	8	12
204	Intermediate	Nov_4	Community category	ns	Excellent	ns	Excellent	ns	Good	Intermediate	Intermediate/poor	Very poor	Intermediate/poor
204	Very Poor	Oxley2	Community score	ns	ns	ns	10	14	20	20	8	10	8
204	Very Poor	Oxley2	Community category	ns	ns	ns	Poor	Intermediate/poor	Excellent	Excellent	Very poor	Poor	Very poor
204	Intermediate	UBlock1	Community score	ns	ns	ns	18	ns	20	18	20	15	16
204	Intermediate	UBlock1	Community category	ns	ns	ns	Good	ns	Excellent	Good	Excellent	Intermediate	Intermediate
204	Intermediate	WiEfloA	Community score	ns	20	17	20	19	17	15	17	17	11
204	Intermediate	WiEfloA	Community category	ns	Excellent	Intermediate	Excellent	Good	Intermediate	Intermediate	Intermediate	Intermediate	Poor
204	Intermediate	WiEfloB	Community score	ns	ns	18	18	15	18	18	17	20	18
204	Intermediate	WiEfloB	Community category	ns	ns	Good	Good	Intermediate	Good	Good	Intermediate	Excellent	Good

Appendix 17 Results of condition class assessment at all sites by year 2008/09 to 2016/17

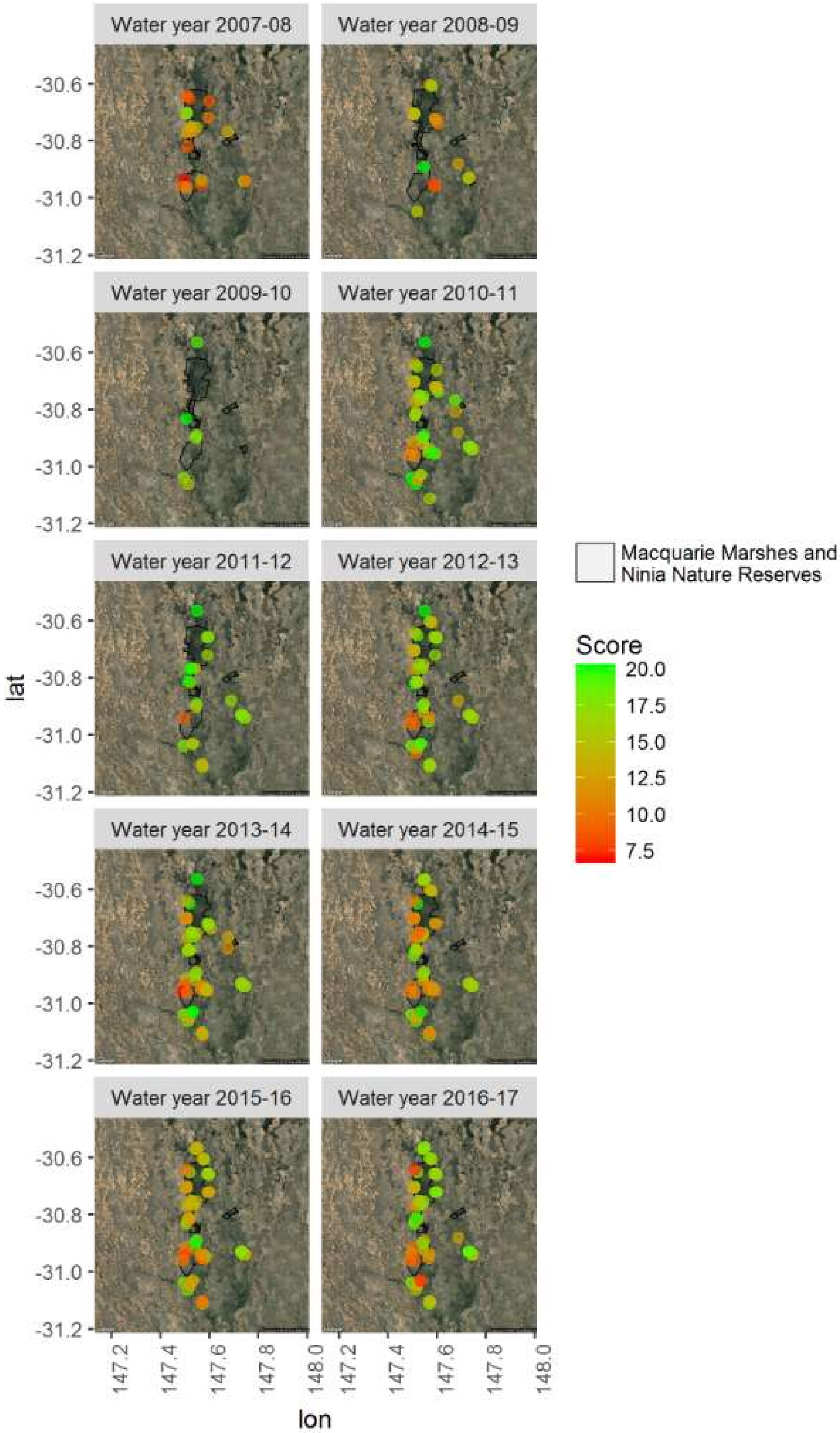
Community condition, Floodplain grassland, PCT 214

PCT No.	Mapped Condition 2008	SiteName	Condition Measure	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
214	Poor	Cutbus12	Community score	ns	13	ns	19	ns	ns	13	ns	ns	ns
214	Poor	Cutbus12	Community category	ns	Intermediate/poor	ns	Good	ns	ns	Intermediate/poor	ns	ns	ns
214	Poor	MM9	Community score	11	ns	ns	11	ns	9	10	14	ns	9
214	Poor	MM9	Community category	Poor	ns	ns	Poor	ns	Poor	Poor	Intermediate/poor	ns	Poor
214	Very Poor	Willan GL	Community score	ns	9	ns	16	ns	ns	13	10	ns	ns
214	Very Poor	Willan GL	Community category	ns	Poor	ns	Intermediate	ns	ns	Intermediate/poor	Poor	ns	ns

Community condition, Lignum Shrubland, PCT 247

PCT No.	Mapped Condition 2008	Site Name	Condition Measure	2007_08	2008_09	2009_10	2010_11	2011_12	2012_13	2013_14	2014_15	2015_16	2016_17
247	Intermediate	HallsLig	Community score	15	ns	ns	18	ns	18	16	19	19	19
247	Intermediate	HallsLig	Community category	Intermediate	ns	ns	Good	ns	Good	Intermediate	Good	Good	Good
247	Poor	MM20	Community score	10.5	ns	ns	15	ns	ns	16.5	10	13.5	15
247	Poor	MM20	Community category	Poor	ns	ns	Intermediate	ns	ns	Intermediate	Poor	Intermediate/poor	Intermediate
247	Intermediate	StanLigA	Community score	ns	ns	ns	ns	ns	ns	ns	ns	19.5	20
247	Intermediate	StanLigA	Community category	ns	ns	ns	ns	ns	ns	ns	ns	Good	Excellent
247	Poor	ZooligA	Community score	ns	ns	ns	ns	ns	ns	ns	ns	14.5	20
247	Poor	ZooligA	Community category	ns	ns	ns	ns	ns	ns	ns	ns	Intermediate/poor	Excellent

Appendix18 Map of Community condition scores Macquarie Marshes 2007/08-2016/17 The colour ramp indicates the condition score



Appendix18 Map of Tree condition scores Macquarie Marshes 2007/08-2016/17 The colour ramp indicates the condition score