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Pike Floodplain Vegetation Condition Monitoring 2015 Report

Jason Nicol, Susan Gehrig, Kate Frahn and Josh Fredberg

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SARDI Aquatics Sciences
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PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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ACKNOWLEDGEMENTS

The authors thank Arron Strawbridge for field assistance. Brad Hollis, Andy Harrison, Todd Wallace and Chris Bice for comments on early drafts of this report. Funding for condition monitoring has been provided by the South Australian Riverland Floodplain Integrated Infrastructure Program. SARFIIP has been initiated to improve the flexibility of managing the system via new infrastructure and operational solutions. The purpose of SARFIIP is to improve the ecological condition of Riverland floodplains, including the Pike and Katarapko Floodplains, using environmental regulators to deliver environmental water. SARFIIP seeks to introduce variability in patterns of flooding and to mimic aspects of the natural water regime. The intent is to improve the condition of floodplain biotic communities and to improve biological connectivity between the main River Murray channel and its floodplain environments. The infrastructure proposed to be constructed on the Pike and Katarapko Floodplains will have a similar function to the Chowilla environmental regulator. SARFIIP, in conjunction with the Riverine Recovery Program (RRP), aims to create an interconnected mosaic of manageable floodplains between Lock 3 and the South Australian Borders with New South Wales and Victoria. This is to be achieved through the integrated operation of River Murray locks 4, 5 and 6, and purpose-built infrastructure on Katarapko, Pike and Chowilla Floodplains.

EXECUTIVE SUMMARY

Floodplain ecosystem degradation, as a result of river regulation and water abstraction, is widespread throughout the lower River Murray in South Australia. Most native floodplain understorey species are adapted to periodic floodplain inundation, but the frequency, duration and magnitude of such events are now greatly reduced compared to pre-regulation (Maheshwari *et al.* 1995). In the absence of regular inundation, floodplain species are initially replaced by terrestrial species and secondly, salt tolerant species, or conditions may become so hostile that plants cannot survive and are replaced by bare soil. This can have serious implications for riverine and terrestrial trophodynamics as a source of carbon that is produced at regular intervals is now only available periodically.

Environmental regulators that enable inundation under flows that would not normally inundate floodplain habitats have been constructed (e.g. Chowilla) or are proposed at several sites in the lower River Murray. These regulators may reinstate aspects of the inundation regime and provide conditions suitable for the recruitment of native floodplain species. Such an environmental regulator has been proposed for the Pike Anabranch system under the *South Australian Riverland Floodplain Integrated Infrastructure Project* (SARFIIP). The Pike Anabranch system bypasses Lock and Weir Number 5, resulting in a 3 m head differential between its upstream inlets and the downstream confluence of the Pike River and River Murray. This head differential provides the opportunity to undertake engineered floodplain inundation events through the use of an environmental regulator. Information regarding the plant community prior to construction of the proposed regulator is required to evaluate vegetation response to engineered floodplain inundation.

The objective of the current study was to monitor the vegetation of the Pike Floodplain in 2015, to provide baseline/reference data against which to evaluate vegetation response to future regulator operation. Secondly, we aimed to compare data collected in 2015, with similar data collected in 2010 and 2011, to provide insight on recent natural floodplain vegetation dynamics. A total of 65 condition monitoring sites were established on the Pike Floodplain and surveyed in February 2010, during the Millennium Drought, and again in August 2011, immediately following extensive flooding. Each site consists of three 1 x 15 m quadrats running parallel to elevation contours that are divided into 1 x 1 m cells and the presence of species in each cell recorded to give a score between zero and 15 for each species. An additional 25 sites were established in 2015 and most sites established in 2010 were resurveyed to provide baseline data. Sites established in 2010 were used to compare the change in plant communities between 2010 and 2015.

A total of 35 taxa (including five exotics), from 14 families, were recorded across the 80 sites, in April 2015. The five most frequently encountered taxa (accounting for 66% of quadrat presences) were *Sclerolaena stelligera*, *Atriplex* spp., *Sporobolus mitchelli*, *Calotis hispidula* and *Sclerolaena brachyptera*. Multivariate analysis of quadrat data classified sites into six groups using Cluster Analysis (at 30% similarity). Indicator Species Analysis produced a list of representative taxa for each grouping and was used to name each of the groups:

1. "Dryland" characterised by the terrestrial species *Enchylaena tomentosa* and *Disphyma crassifolium* with the floodplain species *Brachyscome dentata* (2.5% of sites).

2. "Dryland/Sporobolus" characterised by high abundances of the terrestrial taxa *Atriplex* spp., *Sclerolaena brachyptera, Sclerolaena divaricata* and *Sclerolaena stelligera* and the floodplain species *Sporobolus mitchelli* and *Calotis hispidula* (72% of sites).

3. "Tecticornia pergranulata" characterised by the halophyte *Tecticornia pergranulata* (12% of sites).

4. "Bare soil" characterised by quadrats devoid of vegetation (10% of sites).

5. "Open water" sites that were inundated (2.5% of sites).

6. "Annuals" sites characterised by the annual taxa *Sonchus oleraceus, Bulbine bulbosa* and *Medicago* spp. and the amphibious grass *Eragrostis australasica* (1% of sites).

The Pike Floodplain plant community was spatially and temporally variable. A total of 24 taxa (predominantly terrestrial and salt tolerant taxa) were recorded during drought in 2010, but following flood, species richness increased to 68 species in 2011, with an increase in the abundance of amphibious and floodplain species, and a decrease in terrestrial and salt tolerant taxa. The plant community of 2015, was intermediate between 2010 and 2011; species richness had declined to 28 species, but both floodplain and salt tolerant taxa were present in high proportions.

The plant community present on the Pike Floodplain in 2015 was typical of floodplain plant communities that have not been inundated for three to five years. Terrestrial and salt tolerant taxa are typically dominant in the absence of flooding; nevertheless, drought tolerant floodplain species (which probably recruited after the recession of the 2010-11 flood) remained abundant. The change in plant community between 2010 and 2015 was similar to changes observed at the Chowilla Floodplain.

The monitoring program established in 2010 and continued in 2015, will provide a baseline to evaluate temporal variability in vegetation communities and responses to both natural flooding, and management interventions. The dispersion of sites among areas that will be inundated by the proposed regulator and areas that will not be inundated, will enable causative relationships to be determined because of the provision of reference sites. Collection of several years of pre-regulator data will enable assessment of changes in the plant community through time (or in response to natural flooding) to be investigated to gain a multi-year baseline. Floodplain plant communities are naturally dynamic and an understanding of this natural dynamism is fundamental to elucidate potential responses to regulator operation. Furthermore, the recent removal of grazing from the Pike Floodplain appears to have benefited the plant community, which could confound the response to engineered inundation and a multi-year baseline will provide information to quantify the response to the removal of grazing.

1. INTRODUCTION

The combination of river regulation and water abstraction has resulted in reduced frequency, duration and magnitude of floodplain inundation in the lower River Murray compared to pre regulation (e.g. Maheshwari *et al.* 1995). The biota of river systems are adapted to the natural flow regime and alteration of the flow regime typically results in substantial changes to biotic patterns and processes (e.g. Poff *et al.* 1997; Poff and Zimmerman 2010). This includes the spatio-temporal dynamics of floodplain and littoral vegetation communities. In the lower River Murray, reduced floodplain inundation has resulted in rising saline water tables and soil salinisation (e.g. Eldridge *et al.* 1993; Akeroyd *et al.* 2003; Holland *et al.* 2006; Overton *et al.* 2006a) and a reduction in the width of the littoral zone to a narrow band around permanent water bodies (Nicol *et al.* 2010a). This has resulted in species adapted to stable water levels colonising river banks (Blanch and Walker 1997; Blanch *et al.* 1999; 2000), the decline in condition of long-lived species such as river red gums (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*) (e.g. Eldridge *et al.* 1993; Murray-Darling Basin Commission 2003; Overton *et al.* 2006a) and reduced opportunities for colonisation of floodplain understorey species (Nicol *et al.* 2010a).

The floodplain understorey plant community of the lower River Murray is dominated by species that are adapted to regular disturbance (Grime's (1979) r-selected species) and are physiologically and ecologically more similar to desert annuals than aquatic plants (Nicol 2004). Most species are intolerant of flooding as adult or juvenile plants but require high soil moisture to germinate, which in the arid environment of the lower River Murray Floodplain is usually only provided by inundation with rainfall often not providing sufficient water for germination (Nicol 2004; Nicol *et al.* 2010a). Most floodplain species germinate as flood waters recede and have flexible life history strategies that enable them to grow, flower and set seed before conditions become unfavourable (Nicol 2004). Whilst conditions are unfavourable they persist in the seed bank and often have long-lived persistent seed banks (e.g. Thompson 1992; Leck and Brock 2000; Nicol 2004; Brock 2011). Whilst the majority of understorey species are intolerant of flooding and germinate as water levels recede (herein referred to as floodplain species), amphibious species, those that either tolerate or respond to fluctuating water levels as adult or juvenile plants (Brock and Casanova 1997), are also often present on floodplains, particularly in areas close to permanent water or in temporary wetlands (Gehrig *et al.* 2014).

Management actions to deliver environmental water, reinstate water level variability and inundate floodplain in the absence of hydrological flooding have been undertaken throughout the lower River Murray. Management actions that have been implemented include: pumping water to temporary wetlands, weir pool manipulations, injection of freshwater into shallow aquifers and the construction of the Chowilla Environmental Regulator. Pumping temporary wetlands has been successful in improving tree condition (Holland *et al.* 2009; 2013) and providing suitable conditions for recruitment of floodplain and amphibious understorey species (Nicol *et al.* 2010b; Nicol 2012). However, the areas influenced are usually small, not hydrologically connected to the main river channel and typically require large pumps to move water from the main channel and the construction of banks or levees to retain water in the wetland basin. Weir pool manipulations maintain the hydrological connection to the main river channel but operational constraints mean the maximum water level is typically only 50 cm above normal operating level. Therefore, the area inundated is usually small and the effect of the weir pool raising diminishes as the distance from the weir increases (Overton *et al.* 2006b). The small area inundated by raising weirs is often occupied by emergent species, and the opportunities for floodplain and amphibious plant recruitment is limited (Gehrig *et al.* 2015). Injection of freshwater into shallow aquifers at the Bookpurnong Floodplain proved effective in creating localised freshwater lenses and improving tree condition but the areas that benefited were small and provided no surface water for the recruitment of floodplain and amphibious taxa (Berens *et al.* 2009a; 2009b; Alaghmand *et al.* 2015).

The Chowilla Environmental Regulator was completed and operated for the first time in spring 2014. The 3 m head differential between the upper and lower pool levels of Lock and Weir 6 meant that water levels could be raised up to 3 m by the regulator and significant areas of floodplain and temporary wetlands inundated. This significantly increased the littoral zone and provided large areas with conditions suitable for the recruitment of floodplain and amphibious species. Monitoring results showed that there was significant recruitment of floodplain and amphibious species, although not to the extent as expected (unpublished data).

The Chowilla Environmental Regulator was commissioned in spring 2014. The 3 m head differential between the upper and lower pool levels of Lock and Weir 6 meant that water levels could be raised up to 3 m by the regulator and significant areas of temporary wetlands and floodplain inundated. This significantly increased the littoral zone and provided large areas with conditions suitable for the recruitment of floodplain and amphibious species. Monitoring results showed that there was significant recruitment of floodplain and amphibious species, although not to the extent as expected (Gehrig *et al.* in prep.).

Similar to the Chowilla Floodplain, the Pike and Katarapko anabranch systems bypass a weir and there is potential to construct environmental regulators on these systems to inundate temporary wetlands and floodplain in the absence of overbank flows. The *South*

Australian Riverland Floodplain Integrated Infrastructure Project (SARFIIP) was established to fund the construction of regulators on the Pike and Katarapko systems with the objective of improving floodplain condition. The collection of data prior to regulator construction is important to provide a baseline to compare plant communities before and after the regulator has been constructed and operated to determine vegetation responses, and potential benefits of regulator operation. A baseline vegetation survey was undertaken on the Pike Floodplain in 2010 during the Millennium Drought (Marsland 2010) and sites were resurveyed in August 2011, immediately following flooding in 2010-11 (Holland *et al.* 2013). Nonetheless, there is a need to collect further 'contemporary' data on the vegetation community prior to regulator construction and operation.

1.1. Objectives

The objective of the current study was to quantitatively monitor the vegetation community of the Pike Floodplain in 2015 and provide contemporary data to assist in evaluating future responses to regulator operation. This builds upon data collected in 2010 and 2011, providing the opportunity to evaluate recent spatio-temporal variability in floodplain plant communities. The survey period (2010–2015) included record low inflows, a large unregulated flow and several smaller flow pulses and therefore, the influence of inundation history on floodplain understorey vegetation community responses can be investigated (Appendix 1). Three specific objectives were:

- Establish a monitoring program to evaluate the benefits of regulated inundation (and other interventions) and natural flooding.
- Gain a snapshot of the plant community on the Pike Floodplain in autumn 2015.
- Investigate changes in the plant community on the Pike Floodplain between 2010 and 2015.

2. METHODS

2.1. Study site

The Pike Floodplain, located between the townships of Paringa and Lyrup (Figure 1) and is one of three large anabranch–floodplain habitats in the lower Murray system in South Australia. Covering >4,000 ha, the Pike Floodplain consists of a variety of aquatic environments including a series of creeks, temporary billabongs and permanent backwaters (Ecological Associates 2008) (Figure 2). Water enters the Pike system through two inlet creeks (Margaret Dowling Creek and Deep Creek) immediately upstream Lock 5, traversing Mundic Creek, then flowing through to the Upper Pike which then diverges to the River Murray and the Lower Pike (Ecological Associates 2008) (Figure 2). A series of creeks and billabongs connect to these major creeks, and at high river levels water also spreads into low-lying woodlands and wetlands (Figure 2). Both outlets reach the River Murray below lock 5, hence the head difference between the Lock 4 and 5 weir pools results in a diversity of aquatic habitats throughout the Pike Anabranch system (Beyer *et al.* 2011). The area supports a range of species and is listed in the Directory of Important Wetlands in Australia (Australian Nature Conservation Agency 1996).

The Pike Floodplain is characterised by a range of vegetation types including *Eucalyptus largiflorens* (black box) woodlands, *Eucalyptus camaldulensis* var. *camaldulensis* (river red gum) woodlands, *Atriplex* spp. (saltbush) shrublands and a range of aquatic and riparian vegetation types associated with the various temporary and permanent wetlands (Ecological Associates 2008). However, the Millennium drought (van Dijk *et al.* 2013), river regulation (e.g. Maheshwari *et al.* 1995) and the regulation of the Pike Anabranch system through a series of banks and flow-control structures has reduced the occurrence of overbank flooding (Ecological Associates 2008). This has resulted in the water requirements of floodplain flora not being met and an overall decline in the condition of floodplain vegetation has been observed. The Pike Floodplain was subjected to grazing by domestic stock (sheep and cattle); however, a program to buy grazing licenses commenced in 2009 and by 2013 domestic stock were removed from the floodplain.

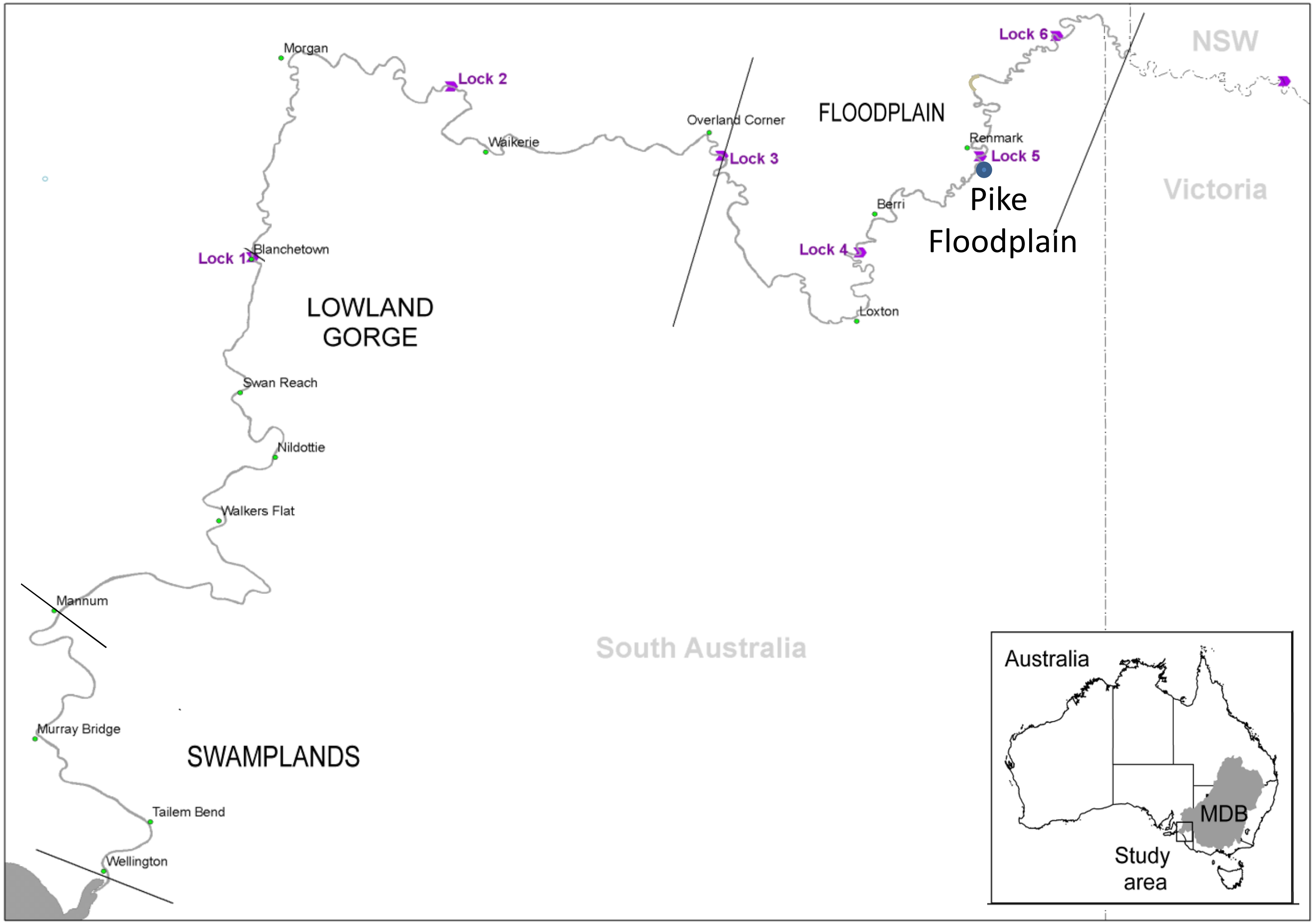

Figure 1: The Lower River Murray and geomorphic regions in South Australia (modified from Holland *et al.* 2013); inset shows extent and position of the Murray-Darling Basin in Australia. The Pike Floodplain is represented by the blue circle.

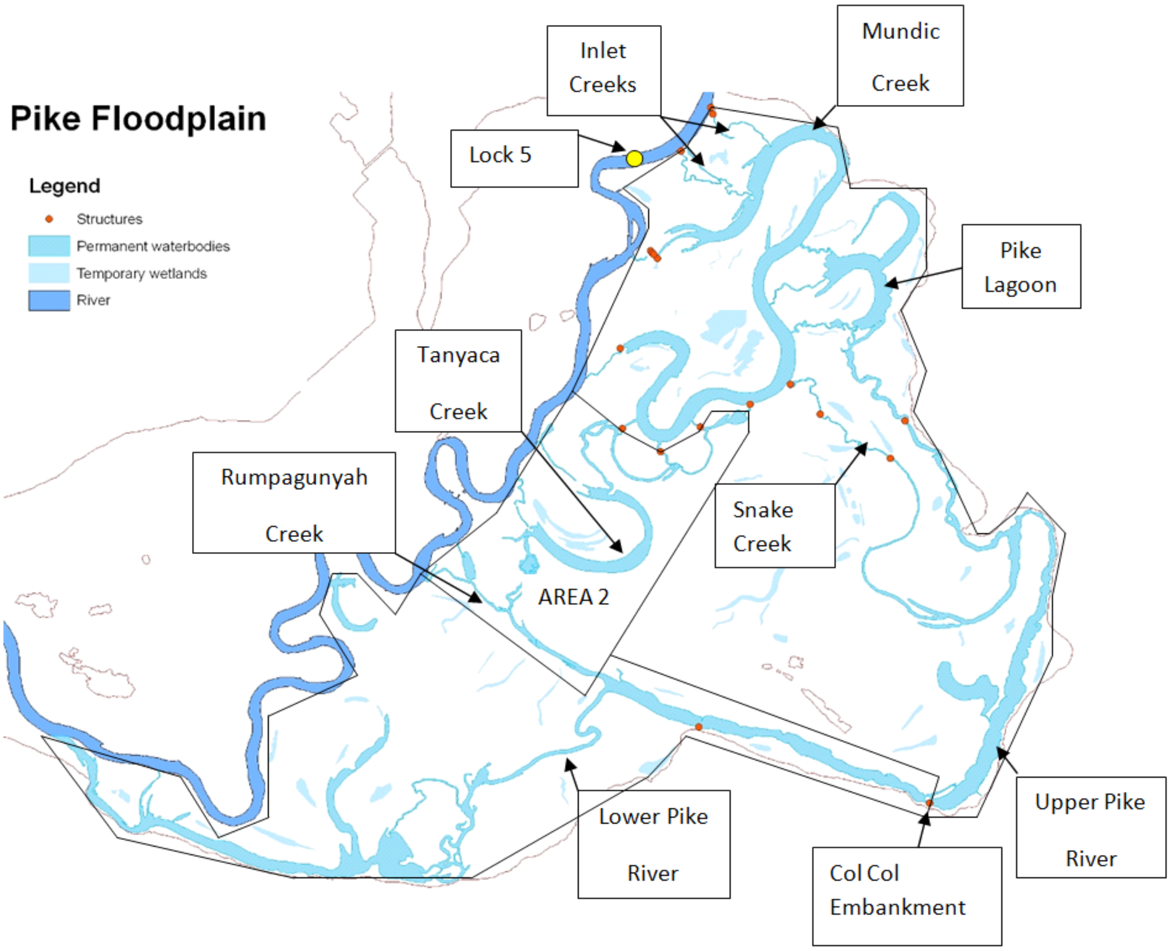

Figure 2: Map of the Pike Anabranch and Floodplain system (modified from Beyer *et al.* 2011).

<u>Recent flows to the Pike Floodplain</u>

From 1996 to 2010, the Murray-Darling Basin experienced the most severe drought in recorded history (van Dijk *et al.* 2013). Below average stream flows, coupled with upstream water extraction and river regulation, resulted in reduced inflows to South Australia (van Dijk *et al.* 2013), which prior to August 2010 were insufficient to inundate the floodplain (Murray-Darling Basin Authority 2011) (Figure 3). However, from June 2010 to May 2011 total inflow volumes were among the highest on record and the patterns of inflows were atypical compared to historical flows (Murray-Darling Basin Authority 2011) (Figure 3). Until the end of November 2010, inflows were the highest since 2000, but not unusual compared to historical flows. However, inflows during summer 2010-11 were the highest on record (~6,700 GL); more than double the previous highest record of ~2,980 GL in the summer of 1992-93 (Murray-Darling Basin Authority 2011).

The increase in inflows in the spring and summer of 2010-11 resulted in widespread flooding across the Murray-Darling Basin. By the end of May 2011, the total annual flow into South Australia was ~14,000 GL, which was the highest total since 1975-76. During this period, flow into South Australia peaked at 93,000 ML/day, in February 2011 (Figure 3). Flows of this magnitude were estimated to inundate around 70% of the Pike Floodplain area (Overton *et al.* 2006b), where the delineation between floodplain and highland is based upon the extent of the 1956 flood (Overton and Doody 2010). Hence, for the first time in ten years, flows not only watered red gum (*Eucalyptus camaldulensis*) woodland and wetland areas, but also reached some black box (*Eucalyptus largiflorens*) woodlands (Murray-Darling Basin Authority 2011).

Large flows with maximums of ~100,000 ML/day typically last for around three months as unregulated events (Sharley and Huggan 1995), but the 2010-11 high flows and floodplain inundation persisted for ~11 months (Figure 3). Flows remained high throughout winter and spring 2011 peaking at 41,000 ML/day in August 2011 and remained above 15,000 ML/day throughout the summer and another two flow pulses peaking at 60,000 ML day^{-1} and 50,000 ML/day (flow into South Australia) occurred in April and October 2012 (Figure 3). Flow declined and from January 2013 flow into South Australia was maintained at entitlement flows until August 2013, when there was a small unregulated flow peaking at 23,500 ML/day in October (Figure 3). Flow then declined and from December 2013 to June 2014 flow to South Australia was at entitlement levels (Figure 3). There was a small flow peaking at 16,000 ML/day in July after which flows decreased to 5,000 ML/day in September 2014 and increased to between 7,000 and 11,000 ML/day between October 2014 and March 2015 after which flows returned to entitlement levels (Figure 3). These flows were confined to the channel and were insufficient to inundate large areas of floodplain; nevertheless, some low lying temporary wetlands were flooded between 2011 and 2015.

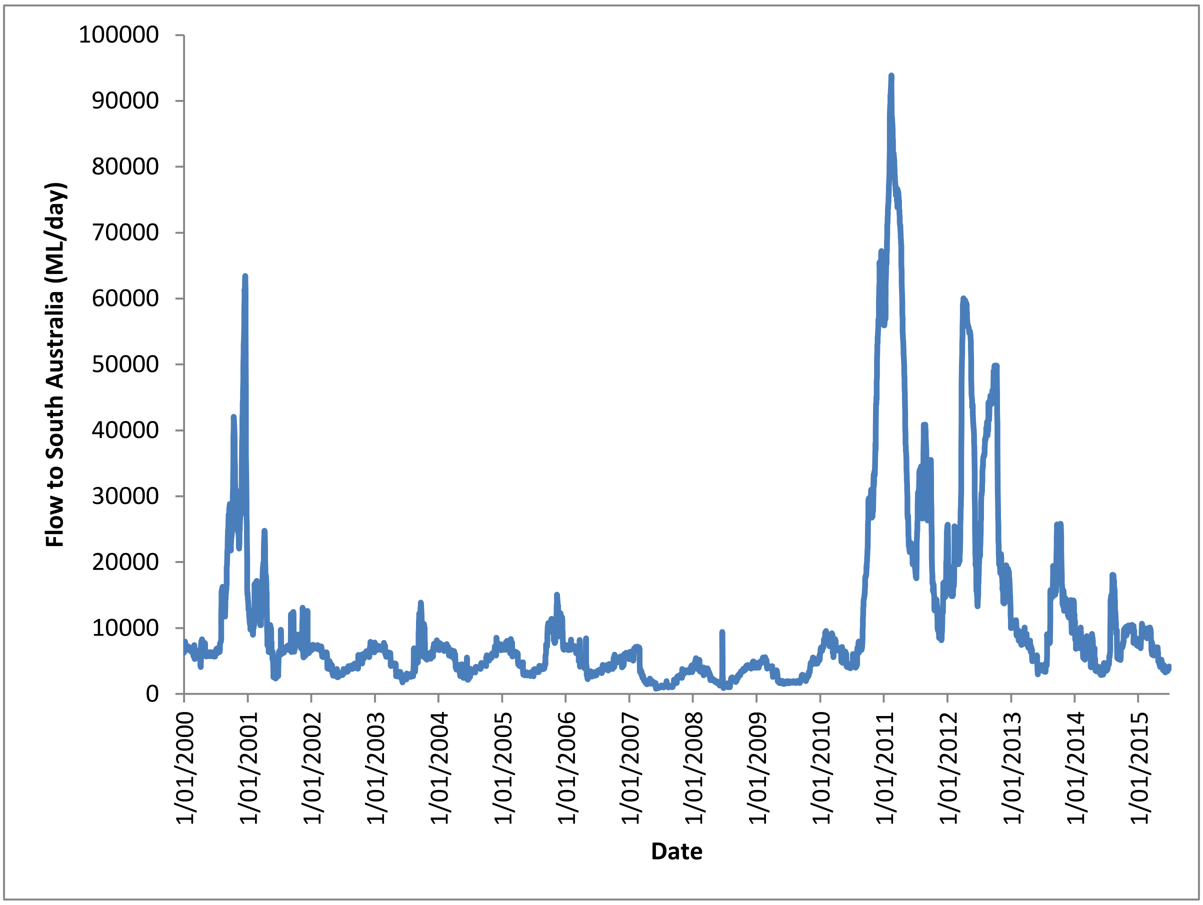

Figure 3: River Murray flow to South Australia from January 2000 to June 2015.

2.2. Vegetation surveying protocol

Vegetation survey methods followed those used for other vegetation monitoring projects in the South Australian River Murray Corridor upstream of Wellington; including the Chowilla condition (Gehrig *et al.* 2014) and intervention (Nicol *et al.* 2010b; Nicol 2012) monitoring programs, Chowilla works and measures understorey vegetation surveys (Zampatti *et al.* 2011), Lock 1 draw down (Nicol 2010) and refill (Nicol *et al.* 2013), weir pool raising (Gehrig *et al.* 2015) and Katarapko Floodplain condition monitoring (Nicol et al. in prep.). The use of consistent methods and ongoing monitoring will allow comparison of data across studies and enable a greater understanding of vegetation dynamics in the lower River Murray.

In February 2010, a baseline vegetation survey was undertaken and 65 sites located in low-lying open areas across the Pike Floodplain were established (Figure 4, Appendix 1) (Marsland 2010). Sites were chosen such that they:

- were located in areas that would be inundated by natural overbank flows;
- some sites were located in areas that would be inundated by the proposed regulator and others in areas that would not be inundated to act as reference sites;

- had no tree overstorey, although some sites were adjacent to tree condition sites;
- were accessible by 4WD vehicle during dry conditions or by boat; and
- covered a range of vegetation types and grazing histories.

Sites were re-surveyed in July 2011 (high river levels prevented access to the floodplain in February) as part of the Goyder Institute's Murray Flood Ecology project. In 2015, as part of the current project, the sites established by Marsland (2010) were resurveyed (except sites 51 to 55, which were deemed as surplus (based on spatial coverage, access and plant community) and sites 59 to 64, which were inaccessible) and an additional 25 sites were established in areas where there was previously limited spatial coverage, resulting in a total number of 80 sites (Figure 4, Appendix 1).

At each site, three 15 m x 1 m quadrats were surveyed. Quadrats were arranged in a straight line parallel to elevation contours (i.e. quadrats were at the same elevation) 50 m apart. Each quadrat was divided into 15, 1 m x 1 m cells. The presence of each species that had live plants rooted within each cell was recorded to give a total score out of 15 for each quadrat. Cells containing no live plants were recorded as bare ground.

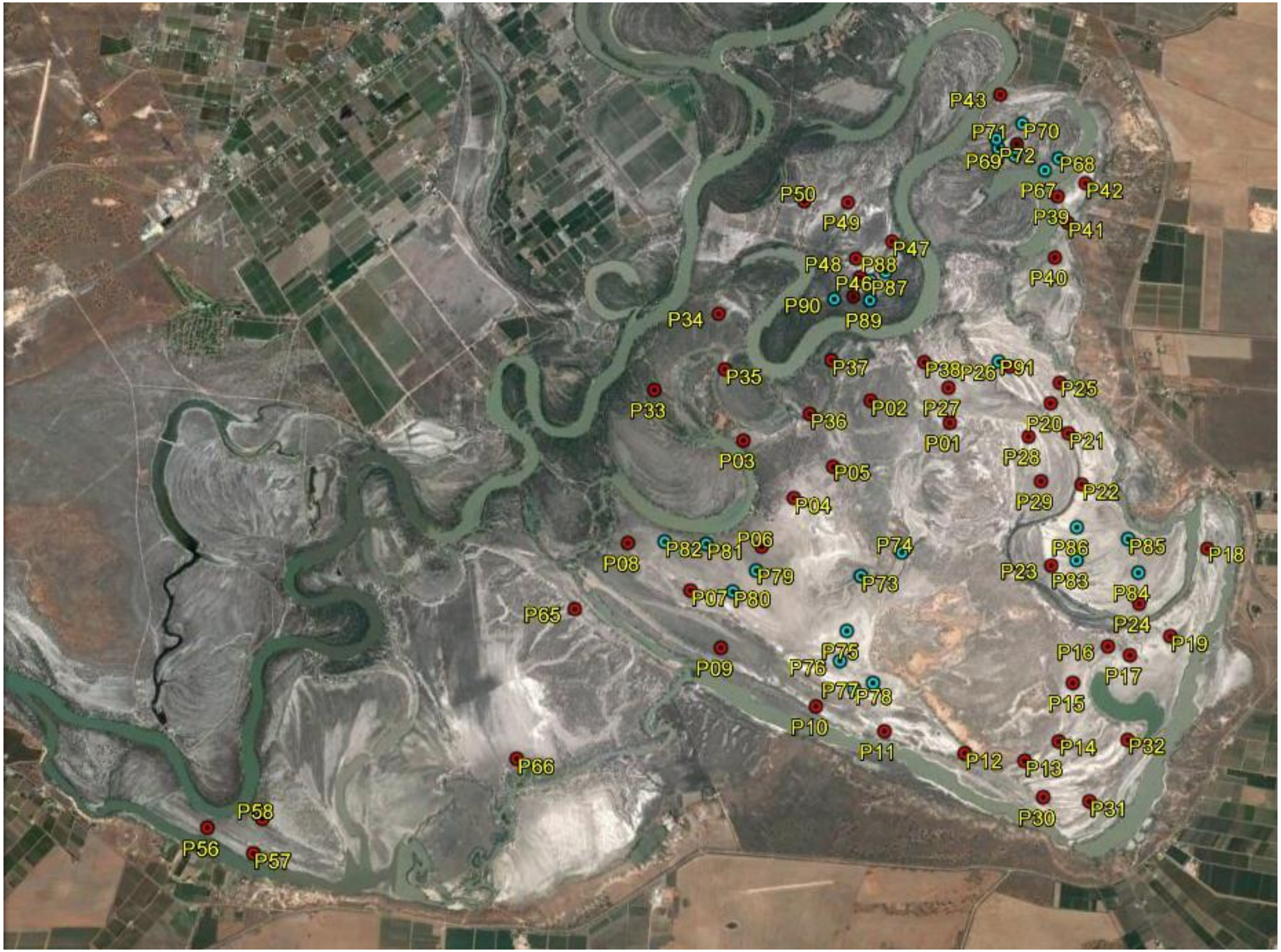

Figure 4: Satellite image of the Pike Floodplain showing floodplain the current vegetation monitoring sites (red circles indicate sites established in 2010 and blue circles sites established in 2015).

2.3. Plant identification and nomenclature

Plants were identified using keys in Jessop and Toelken (1986), Cunningham *et al.* (1992), and Jessop *et al.* (2006). In some cases, due to immature individuals or lack of floral structures, plants were identified to genus only. Nomenclature follows the Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria (2015). A comprehensive list of all species surveyed from 2010 to the present, plus their functional classification, life history strategy and conservation status is presented in Appendix 2.

2.4. Data analysis

For the 2015 survey, plant communities present were compared using Group Average Clustering (McCune *et al.* 2002) performed on pooled data (species scores were averaged from the three quadrats at each site). A cut-off score of 30% similarity was used to determine the cluster groups based on species presence and their abundances. To identify the representative species for each group, Indicator Species Analysis (Dufrene and Legendre 1997) was performed on the unpooled data using the groupings of sites derived from the cluster analysis. All multivariate analyses used Bray-Curtis (1957) distances to construct the similarity matrices and were undertaken using the multivariate statistical package PCOrd 5.12 (McCune and Mefford 2006). Finally, the locations of the quadrats were mapped to allow presentation of the spatial distribution of the vegetation groups.

The changes in floristic composition at sites 1–66 from 2010 to 2015 were analysed using NMS ordination using the package PRIMER version 6.1.12 (Clarke and Gorley 2006) with species (with a Pearson Correlation Coefficient of greater than 0.5) overlaid as vectors on the ordination plot. In addition, plants were classified into functional groups based on the framework developed by Nicol *et al.* (2010b) and the proportion of broad functional groups (terrestrial, salt tolerant, floodplain, amphibious and bare soil) present at each survey were plotted.

3. RESULTS

3.1. 2015 plant communities

A total of 35 taxa (including five exotics) from 14 families were observed across the 80 sites. The five most frequently encountered taxa (accounting for 66% of quadrat presences) were *Sclerolaena stelligera*, *Atriplex* spp., *Sporobolus mitchelli*, *Calotis hispidula* and *Sclerolaena brachyptera*. All but *Sporobolus mitchelli* (Poaceae) and *Calotis hispidula* (Asteraceae) are members of the Chenopodiaceae.

Cluster analysis separated the sites into six groups at 30% similarity (Figure 5). This produced a manageable number of groups and reflected the major differences between sites. The spatial distribution of plant communities based on the groups identified by cluster analysis is presented in Figure 6. Indicator Species Analysis produced a list of representative taxa for each grouping (Table 1). These species lists were used to name the five groups according to their characteristic taxa:

1. "Dryland" characterised by the terrestrial species *Enchylaena tomentosa* and *Disphyma crassifolium* with the floodplain species *Brachyscome dentata* (2.5% of sites) (Table 1).

2. "Dryland/Sporobolus" characterised by high abundances of the terrestrial taxa *Atriplex* spp., *Sclerolaena brachyptera, Sclerolaena divaricata* and *Sclerolaena stelligera* and the floodplain species *Sporobolus mitchelli* and *Calotis hispidula* (72% of sites) (Table 1).

3. "Tecticornia pergranulata" characterised by the halophyte *Tecticornia pergranulata* (12% of sites) (Table 1).

4. "Bare soil" characterised by quadrats devoid of vegetation (10% of sites) (Table 1).

5. "Open water" sites that were inundated (2.5% of sites) (Table 1).

6. "Annuals" sites characterised by the annual taxa *Sonchus oleraceus, Bulbine bulbosa* and *Medicago* spp. and the amphibious grass *Eragrostis australasica* (1% of sites) (Table 1).

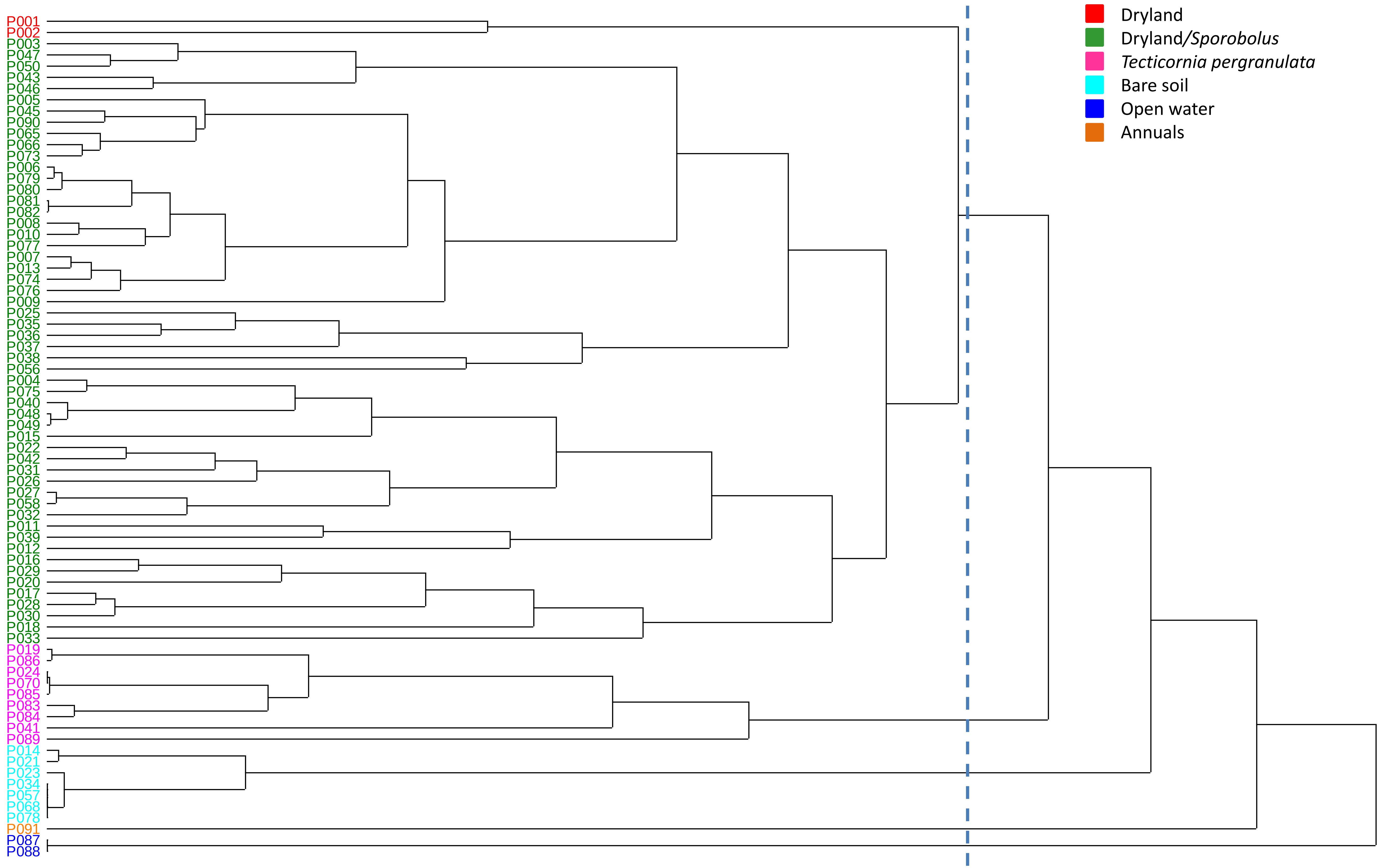

Figure 5: Dendrogram showing clustering of vegetation survey sites using Bray-Curtis similarity from the 2015 survey. Dashed line shows division of sites into vegetation groups at 30% similarity.

Table 1: Indicator Species Analysis (Dufrene and Legendre 1997) based on unpooled data (*n* = 240) from the 2015 vegetation survey. Max. Group indicates group in which taxon had highest indicator value. *P*-value derived from Monte-Carlo test of significance (permutations = 10,000). Significant (p<0.05) taxa are highlighted (*denotes exotic species).

Taxon	Max. Group	*P*-value
Eragrostis australasica	Annuals	0.0002
Medicago spp.*	Annuals	0.0002
Bulbine bulbosa	Annuals	0.0006
Sonchus oleraceus	Annuals	0.0196
Bare soil	Bare soil	0.0002
Disphyma crassifolium ssp. *clavellatum*	Dryland	0.0002
Brachyscome dentata	Dryland	0.0134
Enchylaena tomentosa	Dryland	0.0204
Einadia nutans	Dryland	0.0938
Maireana spp.	Dryland	0.3645
Atriplex spp.	Dryland/*Sporobolus*	0.0002
Sclerolaena stelligera	Dryland/*Sporobolus*	0.0002
Sclerolaena brachyptera	Dryland/*Sporobolus*	0.0020
Calotis hispidula	Dryland/*Sporobolus*	0.0074
Sporobolus mitchellii	Dryland/*Sporobolus*	0.0236
Sclerolaena divaricata	Dryland/*Sporobolus*	0.0392
Frankenia pauciflora var. *gunnii*	Dryland/*Sporobolus*	0.4641
Duma florulenta	Dryland/*Sporobolus*	0.6707
Solanum lacunarium	Dryland/*Sporobolus*	0.8158
*Mesembryanthemum crystallinum**	Dryland/*Sporobolus*	0.9296
Chamaesyce drummondii	Dryland/*Sporobolus*	1.0000
Craspedia chrysantha	Dryland/*Sporobolus*	1.0000
Dysphania pumilio	Dryland/*Sporobolus*	1.0000
Eucalyptus largiflorens	Dryland/*Sporobolus*	1.0000
Osteocarpum acropterum	Dryland/*Sporobolus*	1.0000
*Phyla canescens**	Dryland/*Sporobolus*	1.0000
Salsola australis	Dryland/*Sporobolus*	1.0000
*Spergularia marina**	Dryland/*Sporobolus*	1.0000
Tecticornia triandra	Dryland/*Sporobolus*	1.0000
Teucrium racemosum	Dryland/*Sporobolus*	1.0000
Open water	Open water	0.0002
Tecticornia pergranulata	*Tecticornia pergranulata*	0.0002
Mimulus repens	*Tecticornia pergranulata*	0.1484
*Heliotropium curassavicum**	*Tecticornia pergranulata*	0.1838
Atriplex suberecta	*Tecticornia pergranulata*	0.2859
Rumex bidens	*Tecticornia pergranulata*	0.2859
Tetragonia tetragonioides	*Tecticornia pergranulata*	0.4751

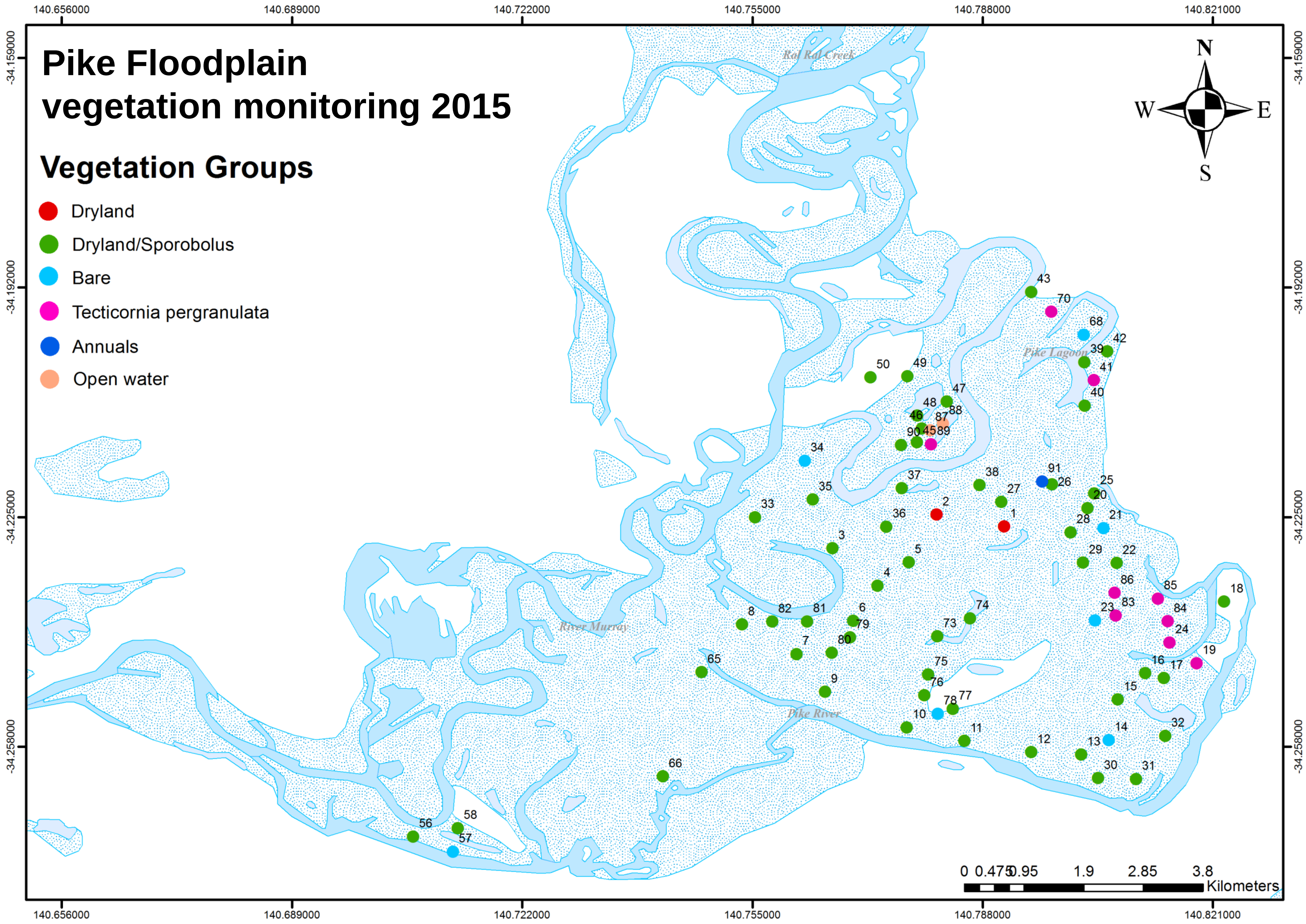

Figure 6: Spatial distribution and vegetation communities of the 80 sites surveyed on the Pike Floodplain for the 2015 survey. Numbers refer to site IDs. Legend colours reflect dendrogram groupings (Figure 5).

3.2 Change in floristic composition between 2010 and 2015

A total of 24 taxa were recorded on the Pike Floodplain in 2010 (Marsland 2010) (Figure 7), and the community was dominated by terrestrial and salt tolerant species (Figure 8). In addition, there were a large number of quadrat cells characterised by bare soil (i.e. no live plants were present) (Figure 8). In 2011 there was a nearly threefold increase in species richness (Figure 7), an increase in the abundance of floodplain and amphibious species and a corresponding decrease in abundance of bare soil, salt tolerant and terrestrial species (Figure 8). Between 2011 and 2015, there was a decrease in species richness (Figure 7), decreased abundance of floodplain and amphibious species and a corresponding increase in terrestrial and salt tolerant taxa (Figure 8). The number of quadrat cells devoid of living plants increased between 2011 and 2015 from 2.5% to 4%, but was much lower than the number observed in 2010 (24%) (Figure 8).

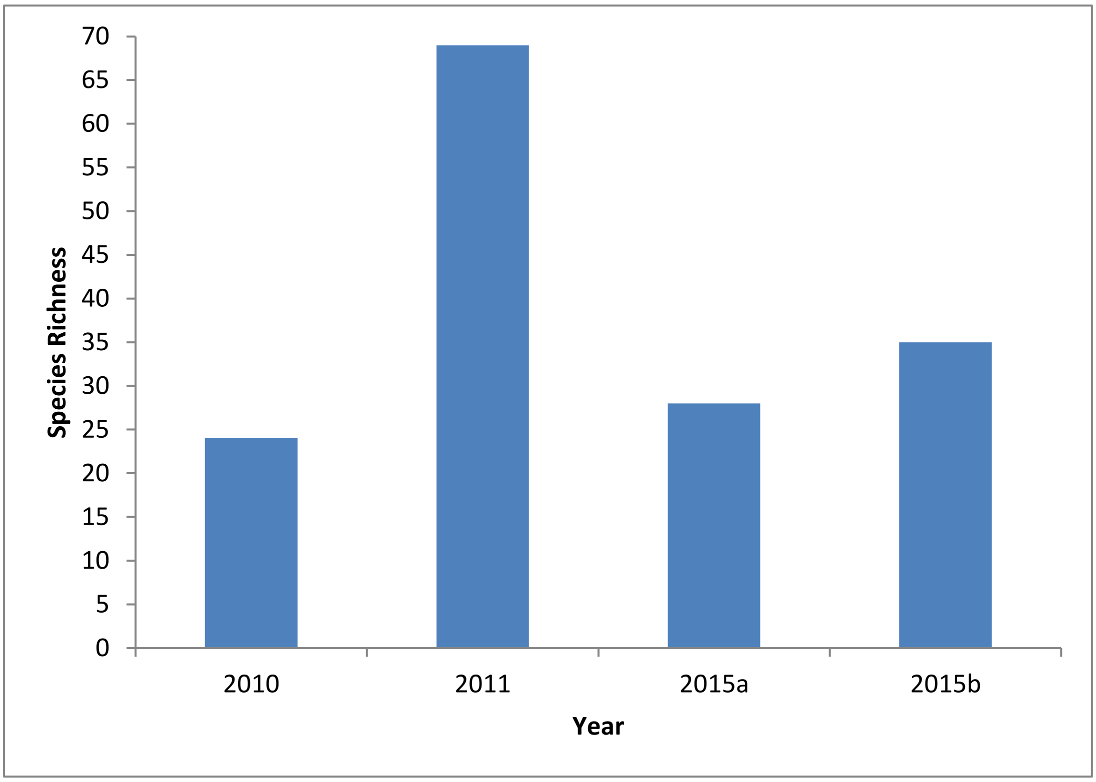

Figure 7: Changes through time in species richness (number of taxa) of the Pike Floodplain from 2010 to 2015 (2015a denotes sites 1–66 and 2015b denotes all sites 1–90).

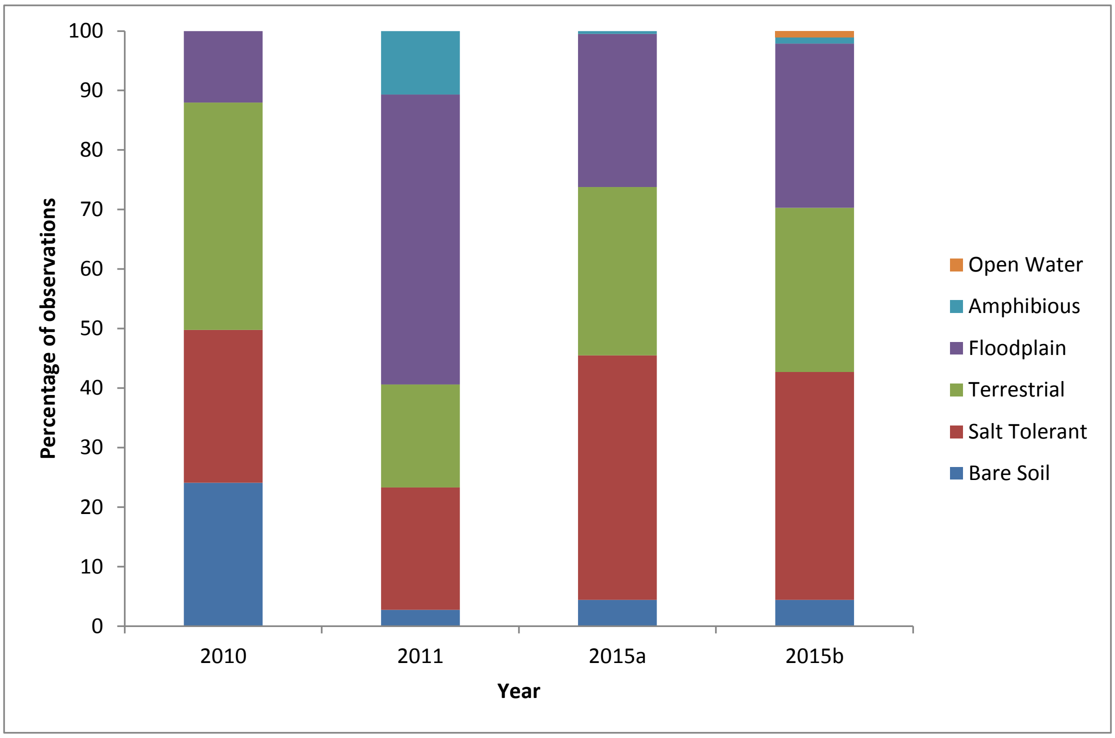

Figure 8: Changes in the percentage of observations of vegetation functional groups of the Pike Floodplain from 2010 to 2015 (2015a denotes sites 1–66 and 2015b denotes all sites, 1–90).

NMS ordination showed that the plant community on the Pike Floodplain was spatio-temporally variable between 2010 and 2015 (Figure 9) and reflected the variable hydrology. The quadrats from the 2011 survey were generally located on the right-hand side of the ordination and overlaid vectors suggested dominance of the amphibious species *Mimulus repens* and floodplain species *Centipeda minima*, *Sporobolus mitchelli* and *Plantago cunninghamii* (Figure 9). The quadrats surveyed in 2010 and 2015 were generally located closer to the left hand side and at the bottom of the ordination (along with the quadrats surveyed in 2011 that were not inundated by the 2010-11 flood) (Figure 9). The sites located to the left hand side of the ordination were dominated by bare soil and the terrestrial taxa *Atriplex* spp. and *Sclerolaena divaricata* were abundant in the quadrats located towards the bottom of the ordination (Figure 9).

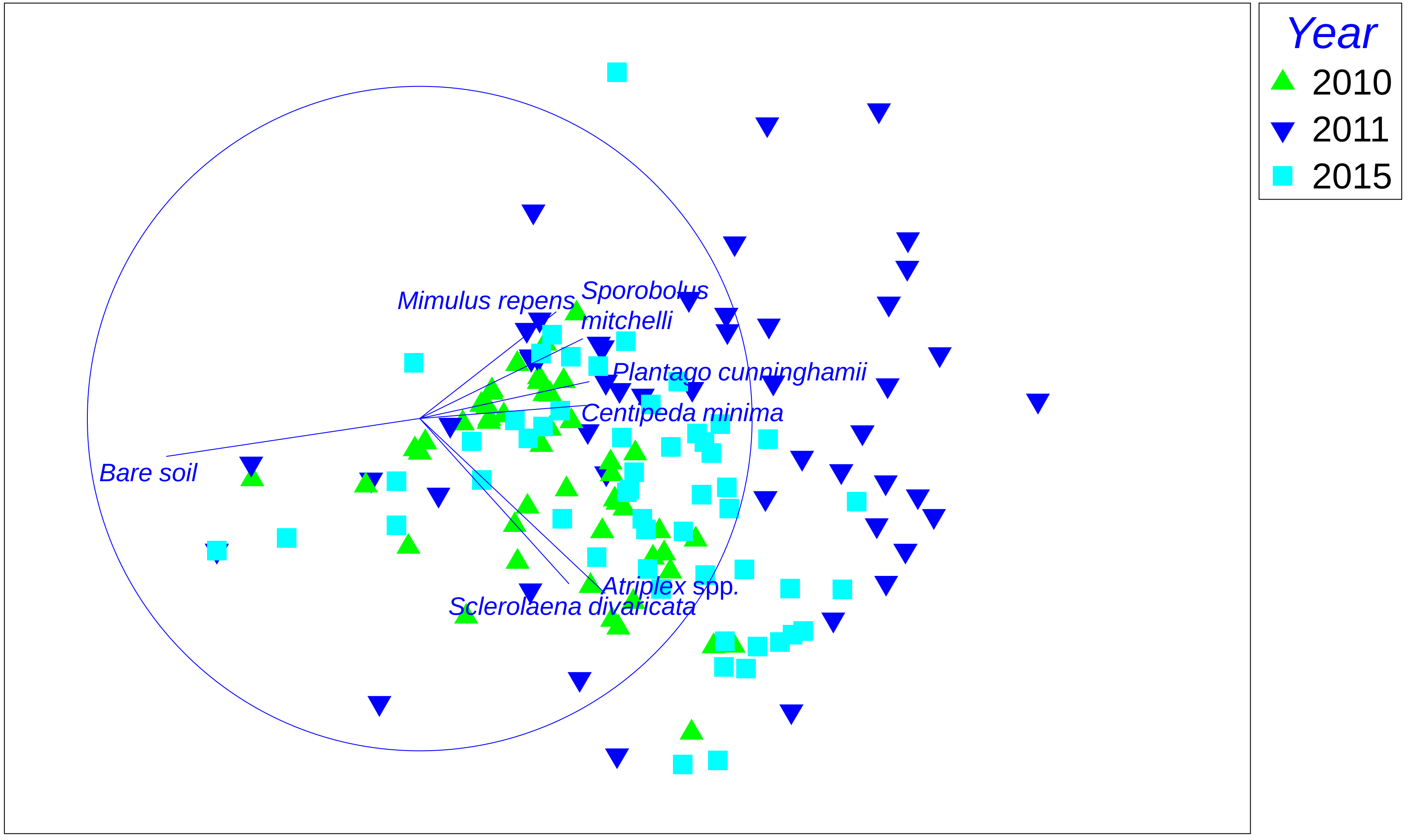

Figure 9: NMS ordination comparing the plant communities of Pike Floodplain at sites 1–66 from 2010 to 2015 (Stress = 18%).

4. DISCUSSION

The plant community present on the Pike Floodplain in 2015 was typical of floodplain plant communities that have not been inundated for three to five years (Gehrig *et al.* 2014). Terrestrial (*Atriplex* spp., *Sclerolaena divaricata*), and salt tolerant (*Sclerolaena brachyptera, Sclerolaena stelligera, Tecticornia pergranulata, Disphyma crassifolium*) taxa are typically dominant in the absence of flooding (Gehrig *et al.* 2014); nevertheless, drought tolerant floodplain species, such as *Sporobolus mitchelli, Brachyscome* spp. and *Calotis* spp. (Cunningham *et al.* 1992), which probably recruited after the recession of the 2010-11 flood, were also abundant. The presence of floodplain species in areas that had not been inundated for over three years suggested there was sufficient soil moisture for these species to persist and soil salinity had not risen past their physiological tolerances. With increasing time since flooding the abundance of salt tolerant taxa and bare soil would be expected to increase, with concurrent decreases in floodplain and terrestrial taxa (Gehrig *et al.* 2014).

The occurrence of bare soil on the Pike Floodplain in 2015 (4% of observations) was low compared to the Chowilla Floodplain (8% of observations) (*Gehrig et al.* in prep.) in 2015 and the Pike Floodplain in 2010 (24% of occurrences) (Figure 8). This is potentially due to the removal of grazing from the Pike Floodplain, which (in combination with flooding in 2010-11) has allowed the recruitment of grazing sensitive species in areas where they would have historically been eliminated (Fensham 1998; Crossle and Brock 2002; ID&A 2002; Marty 2005; Lunt *et al.* 2007).

The change in plant community between 2010 and 2015 was similar to changes observed at the Chowilla Floodplain over the same period (Gehrig *et al.* 2014). In 2010, both floodplains exhibited low species richness, were dominated by bare soil and salt tolerant taxa, and generally devoid of amphibious and floodplain species (Marsland 2010; Gehrig *et al.* 2014). There was a large increase in species richness after the 2010-11 flood, which was driven by increased prevalence of amphibious and floodplain species (Holland *et al.* 2013). No monitoring was undertaken on the Pike Floodplain between 2011 and 2015, but at Chowilla, the response was short-lived with almost all amphibious and floodplain species present in 2011, absent by 2013 (Gehrig *et al.* 2014). Direct comparisons between Chowilla and Pike were unable to be undertaken in 2015 due to regulator operation at Chowilla; however, there was a higher proportion of bare soil at sites at Chowilla (*Gehrig et al.* in prep.) that were not inundated by the regulator compared to Pike. The lower abundance of bare soil at Pike compared to Chowilla was probably due to the removal of grazing at Pike. The removal of grazing from the Pike Floodplain may have also resulted in the recruitment of a substantial area of cane grass (*Eragrostis australasica*) in a shallow depression. This is one of the most extensive stands of *Eragrostis australasica* on the South Australian River Murray Floodplain (J. Nicol pers. obs.) and site 91 (Figure 4) was established to monitor survivorship.

This survey and future monitoring will provide a robust baseline to evaluate the benefits of the proposed environmental regulator. Sites were selected to provide adequate coverage of floodplain and temporary wetland habitats that will be inundated by regulator operation but also covers areas that will not be inundated, which will serve as reference sites (*sensu* Underwood 1992). The collection of several years of pre-operation data will enable investigation of temporal variability in the vegetation community and gain information regarding decline or recovery depending on natural conditions prior to regulator construction. These data, in conjunction with data from the Katarapko and Chowilla monitoring programs, could provide the basis for the development of a predictive floodplain vegetation model that could inform management decisions.

4.1 Future studies

Future studies of the vegetation of the Pike Floodplain that would contribute to a greater understanding of plant community dynamics and inform management of the system include:

- Continuation of the monitoring program established in 2015 to gain further baseline information to assess responses to interventions.
- Undertake soil sampling at monitoring sites to investigate the relationship between vegetation and soil properties such as texture, water potential, organic matter and salinity.
- Assess soil seed banks across the flooding frequency and condition (e.g. salinised areas, heavily grazed areas and areas in good condition) gradient to gain information regarding species resilience and water requirements to maintain resilience (*sensu* Boulton and Lloyd 1992).
- Investigate regeneration niches of key native and exotic species (*sensu* Nicol and Ganf 2000) to provide data to develop a predictive floodplain vegetation model.
- Investigate inundation tolerances of key native and exotic species to provide data to develop a predictive floodplain vegetation model.

4.2 Conclusions

Data collected in this survey will serve as part of a multi-year baseline dataset to evaluate the effects of interventions and natural flooding on floodplain vegetation. Future surveys before the proposed regulator is constructed and operated will give a better understanding of the medium-term variability to then better elucidate intervention-driven vegetation responses.

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APPENDICES

Appendix 1: Monitoring site GPS coordinates (map datum WGS 84) and year the site was established.

Site	Latitude	Longitude	Year established	Site	Latitude	Longitude	Year established
P01	-34.22633725	140.7910692	2010	P41	-34.20532717	140.8039405	2010
P02	-34.22463392	140.7813996	2010	P42	-34.20118165	140.8058496	2010
P03	-34.2294674	140.7664684	2010	P43	-34.19262331	140.7949618	2010
P04	-34.23485463	140.7729469	2010	P44	-34.19760549	140.7973159	2010
P05	-34.23149889	140.7774078	2010	P45	-34.21424851	140.778593	2010
P06	-34.23988046	140.7694585	2010	P46	-34.21224763	140.7792821	2010
P07	-34.24468084	140.761344	2010	P47	-34.20840306	140.7828527	2010
P08	-34.24040858	140.7535048	2010	P48	-34.21040665	140.7786248	2010
P09	-34.25009978	140.7654013	2010	P49	-34.20473143	140.7772285	2010
P10	-34.25520807	140.7771064	2010	P50	-34.20492013	140.7719417	2010
P11	-34.25717083	140.7853776	2010	P56	-34.27089556	140.7063891	2010
P12	-34.25877454	140.7949861	2010	P57	-34.27307343	140.7120522	2010
P13	-34.25912898	140.8021322	2010	P58	-34.26970215	140.7127481	2010
P14	-34.25702492	140.8060581	2010	P65	-34.24726895	140.7477289	2010
P15	-34.25121907	140.8073747	2010	P66	-34.26224617	140.7421771	2010
P16	-34.24741939	140.8113257	2010	P67	-34.20010158	140.800885	2015
P17	-34.24814494	140.8139848	2010	P68	-34.19880832	140.8024782	2015
P18	-34.23713705	140.8226092	2010	P69	-34.19883216	140.7971588	2015
P19	-34.24599653	140.8186702	2010	P70	-34.19547678	140.7978529	2015
P20	-34.22369656	140.8030294	2010	P71	-34.19722333	140.7947827	2015
P21	-34.22659517	140.8053136	2010	P72	-34.19814331	140.7950908	2015
P22	-34.23159449	140.8072349	2010	P73	-34.24213899	140.7815073	2015
P23	-34.23984152	140.8041103	2010	P74	-34.23953737	140.7862152	2015
P24	-34.24300562	140.8148106	2010	P75	-34.24762133	140.7802196	2015
P25	-34.22158776	140.8039897	2010	P76	-34.25060879	140.7796338	2015
P26	-34.22028827	140.7979347	2010	P77	-34.25254029	140.7837043	2015
P27	-34.22281932	140.7906653	2010	P78	-34.25326077	140.7815328	2015
P28	-34.22718282	140.8006001	2010	P79	-34.24228102	140.7690148	2015
P29	-34.23155066	140.8023596	2010	P80	-34.24450585	140.7663828	2015
P30	-34.2625148	140.8045466	2010	P81	-34.23997672	140.7628485	2015
P31	-34.26262261	140.8100208	2010	P82	-34.2400207	140.7578667	2015
P32	-34.25642425	140.8141838	2010	P83	-34.23913909	140.807091	2015
P33	-34.22500864	140.7553736	2010	P84	-34.23996387	140.8145228	2015
P34	-34.21690591	140.7624862	2010	P85	-34.23670189	140.8131033	2015
P35	-34.22246365	140.7636757	2010	P86	-34.23588408	140.806925	2015
P36	-34.22637051	140.7742183	2010	P87	-34.21253009	140.7805207	2015
P37	-34.22084618	140.7764261	2010	P88	-34.21155112	140.782299	2015
P38	-34.22040605	140.7875771	2010	P89	-34.21453373	140.7806219	2015
P39	-34.20271862	140.8025898	2010	P90	-34.21465402	140.7763073	2015
P40	-34.20896859	140.8026403	2010	P91	-34.21986	140.79654	2015

Appendix 2: Species list, years when species was present, functional classification, life history strategy, conservation status (state conservation status from listings in Barker et al. 2005 (*denotes exotic species, **denotes proclaimed pest plant in South Australia, ***denotes weed of national significance, # denotes listed as rare in South Australia, ^ denotes listed as vulnerable in South Australia, ^^denotes listed as endangered in South Australia).

Species	Common name	Family	Status	Life history strategy	Functional group	2010	2011	2015
Alternanthera denticulata	lesser joyweed	Amaranthaceae	Native	Annual herb	Floodplain		*	
Ammannia multiflora	jerry-jerry	Lythraceae	Native	Annual herb	Amphibious		*	
*Asphodelus fistulosus***	onion weed	Liliaceae	Exotic, Proclaimed SA Plant	Annual/Perennial	Terrestrial	*		
Atriplex nummularia	old man saltbush	Chenopodiaceae	Native	Perennial	Terrestrial	*		
*Atriplex prostrata**	mat saltbush	Chenopodiaceae	Exotic, Naturlaised	Annual herb	Terrestrial		*	
Atriplex spp.	saltbush	Chenopodiaceae	Native	Perennial	Terrestrial	*	*	*
Atriplex suberecta	lagoon saltbush	Chenopodiaceae	Native	Perennial	Floodplain		*	
Brachyscome dentata	swamp daisy	Asteraceae	Native	Perennial herb	Floodplain	*	*	*
Bulbine bulbosa	bulbine lily	Alliaceae	Native	Perennial herb	Floodplain			*
Calotis cuneifolia	purple (or blue) burr-daisy	Asteraceae	Native	Perennial herb	Floodplain		*	
Calotis hispidula	bogan flea, hairy burr-daisy, bindyi	Asteraceae	Native	Annual herb	Floodplain		*	*
*Carrichtera annua**	Wards weed	Brassicaceae	Exotic, Naturalised	Annual	Terrestrial		*	
Centipeda minima	speading sneezeweed	Asteraceae	Native	Annual herb	Floodplain	*	*	
Chamaesyce drummondii	caustic weed	Euphorbiaceae	Native	Annual herb	Floodplain		*	*
*Conyza bonariensis**	flaxleaf fleabane, tall fleabane	Asteraceae	Exotic, Naturalised	Annual herb	Terrestrial		*	
Cotula australis	common cotula	Asteraceae	Native	Annual/Perennial herb	Amphibious		*	
Craspedia chrysantha	bachelors buttons, common billybuttons	Asteraceae	Native	Annual herb, sometimes Biennial	Terrestrial			*
Crassula helmsii	swamp crassula	Crassulaceae	Native	Annual	Amphibious		*	
Crassula sieberana^^	Australian stonecrop	Crassulaceae	Native, Endangered in South Australia	Annual/Perennial	Amphibious		*	
Cyperus gymnocaulos	spiny flat-sedge, spiny sedge	Cyperaceae	Native	Perennial	Amphibious		*	
Disphyma crassifolium ssp. *clavellatum*	round pigface	Aizoaceae	Native	Annual	Terrestrial	*	*	*
Duma florulenta	lignum	Polygonaceae	Native	Perennial shrub	Amphibious		*	*
Duma horrida#	spiny lignum	Polygonaceae	Native	Perennial shrub	Amphibious		*	

Species	Common name	Family	Status	Life history strategy	Functional group	2010	2011	2015
Dysphania pumilio	clammy goosefoot, small crumbweed	Chenopodiaceae	Native	Annual/Perennial	Floodplain		*	*
Einadia nutans	climbing saltbush	Chenopodiaceae	Native	Perennial shrub	Terrestrial		*	*
Enchylaena tomentosa	ruby saltbush, barrier saltbush	Chenopodiaceae	Native	Perennial shrub	Terrestrial	*		*
Enneapogon nigricans	black-heads, niggerheads	Poaceae	Native	Perennial	Floodplain		*	
Epaltes australis	spreading nut-heads	Compositae	Native	Annual/Perennial herb	Floodplain	*	*	
Eragrostis australasica	cane-grass, bamboo-grass	Poaceae	Native	Perennial	Amphibious			*
*Erodium cicutrium**	common storks bill	Geraniaceae	Exotic, Naturalised	Annual/Biennial herb	Floodplain		*	
Eucalyptus camaldulensis var. *camaldulensis*	red gum, river red gum	Myrtaceae	Native	Tree	Amphibious		*	
Euchiton involucratus	common cud-weed	Asteraceae	Native	Perennial herb	Floodplain		*	
Frankenia pauciflora var. *gunnii*	common (or southern) sea-heath	Frankeniaceae	Native	Perennial herb	Salt tolerant	*	*	*
Goodenia gracilis^	slender goodenia	Goodeniaceae	Native, Vulnerable in South Australia	Annual/Perennial herb	Floodplain		*	
Gunniopsis septifraga	round leaf pig face	Aizoaceae	Native	Annual herb	Terrestrial		*	
Helichrysum luteoalbum	Jersey cud weed	Asteraceae	Native	Annual	Floodplain		*	
*Heliotropium amplexicaule**	blue heliotrope	Boraginaceae	Exotic, Naturalised	Perennial herb	Floodplain		*	
*Heliotropium curassavicum**	smooth heliotrope	Boraginaceae	Exotic, Naturalised	Annual/Perennial herb	Floodplain	*	*	
*Heliotropium europaeum**	potato weed, heliotrope, common heliotrope	Boraginaceae	Exotic, Naturalised	Annual herb	Floodplain		*	
*Hordeum vulgare**	barley grass	Poaceae	Exotic, Naturalised	Annual grass	Terrestrial		*	
*Hypochaeris glabra**	smooth cats ear, glabrous cats ear	Asteraceae	Exotic, Naturalised	Annual herb	Terrestrial		*	
Isoetopsis graminifolia	grass cushions, grass buttons	Asteraceae	Native	Annual herb	Floodplain		*	
Lachnagrostis filiformis	blown grass, fairy grass	Gramineae	Native	Perennial	Floodplain		*	
*Lactuca saligna**	prickly lettuce	Asteraceae	Exotic, Naturalised	Annual herb	Terrestrial		*	
Ludwigia peploides	Water primrose, clove-strip	Onagraceae	Native	Perrennial	Amphibious		*	

Species	Common name	Family	Status	Life history strategy	Functional group	2010	2011	2015
Maireana spp.	bluebush	Chenopodiaceae	Native	Perennial shrub	Terrestrial	*	*	*
Marsilea costulifera	nardoo	Marsileaceae	Native	Annual	Amphibious		*	
Medicago spp.*	burr-medic	Fabaceae	Exotic, Naturalised	Annual herb	Terrestrial			*
*Mesembryanthemum crystallinum**	Common iceplant	Aizoaceae	Exotic, Naturalised	Annual/biennial herb	Terrestrial	*		*
Mimulus repens	creeping monkey flower, Maori musk	Scrophulariaceae	Native	Perennial herb	Amphibious		*	
Mollugo cerviana	wire-stem chickweed	Aizoaceae	Native	Ephemeral/Annual herb	Floodplain		*	
Myosurus minimus	tiny mouse tail	Ranunculaceae	Native	Annual herb	Floodplain		*	
Myriophyllum verrucosum	red milfoil	Haloragaceae	Native	Perennial herb	Amphibious		*	
*Nothoscordum borbonicum**	fragrant false garlic	Alliaceae	Exotic, Naturalised	Perennial herb	Terrestrial		*	
Osteocarpum acropterum	water weed, babbagia	Chenopodiaceae	Native	Perennial herb	Floodplain		*	*
*Phyla canescens**	lippia, fog fruit	Verbenaceae	Exotic, Naturalised	Perennial herb	Terrestrial		*	*
Phyllanthus lacunaris	lagoon spurge, Caraweena clover	Euphorbiaceae	Native	Annual/Perennial herb	Floodplain		*	
Plantago cunninghamii	sago weed	Plantaginaceae	Native	Annual herb	Floodplain		*	
Polygonum plebium	small knotweed	Polygonaceae	Native	Annual	Floodplain		*	
*Riechardia tingitana**	false sow thistle	Asteraceae	Exotic, Naturalised	Annual herb	Terrestrial		*	
*Rorippa palustris**	yellow cress, marsh watercress	Brassicaceae	Exotic, Naturalised	Annual/Biennial herb	Floodplain		*	
Rumex bidens	mud dock	Polygonaceae	Native	Perennial	Amphibious		*	
Salsola australis	buckbush, rolypoly, soft roly-poly, prickly saltwort	Chenopodiaceae	Native	Annual	Salt tolerant	*		*
Sclerolaena brachyptera	short-winged copperburr, hairy bassia,	Chenopodiaceae	Native	Annual	Salt tolerant	*	*	*
Sclerolaena divaricata	tangled copperburr, pale poverty bush	Chenopodiaceae	Native	Perennial	Terrestrial	*	*	*
Sclerolaena stelligera	star-fruit bassia, star copperburr, starred bluebush	Chenopodiaceae	Native	Perennial	Salt tolerant	*	*	*
Senecio cunninghamii	bushy groundsel	Asteraceae	Native	Perennial shrub	Floodplain			*
Senecio runcinifolius	tall groundsel	Asteraceae	Native	Perennial herb	Floodplain		*	
Sida ammophila	sand sida	Malvaceae	Native	Perennial shrub	Terrestrial		*	
Solanum lacunarium	lagoon Nightshade	Solanaceae	Native	Perennial herb	Floodplain		*	

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*Sonchus oleraceus**	sow thistle	Asteraceae	Exotic, Naturalised	Annual herb	Terrestrial		*	
*Spergularia marina**	salt sand-spurrey	Caryophyllaceae	Exotic, Naturalised	Annual/Biennial/Perennial herb	Salt tolerant	*	*	*
Sporobolus mitchellii	rats-tail couch, short rats-tail grass	Poaceae	Native	Perennial	Floodplain	*	*	*
Tecticornia pergranulata	N/A	Chenopodiaceae	Native	Perennial herb/shrub	Amphibious	*	*	*
Tecticornia triandra	desert glasswort	Chenopodiaceae	Native	Perennial shrub	Salt tolerant	*	*	
Tetragonia tetragonioides	New Zealand spinach, Warragul cabbage	Aizoaceae	Native	Annual/Perennial herb	Floodplain		*	*
Teucrium racemosum	grey germander	Lamiaceae	Native	Perennial herb	Floodplain			*
Trachymene cyanopetala	purple trachymene, purple parsnip	Apiaceae	Native	Annual herb	Floodplain		*	*
Wahlenbergia fluminalis	river bluebell	Campanulaceae	Native	Perennial	Floodplain		*	