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DEVELOPMENT OF A WETLAND PLANT INDICATOR LIST TO INFORM THE DELINEATION OF WETLANDS IN NEW SOUTH WALES

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Abstract

Wetlands experience fluctuating water levels, and so their extent varies spatially and temporally. This characteristic is widespread and likely to increase as global temperatures and evaporation rates increase. The temporary nature of wetlands can confound where a wetland begins and ends, resulting in unreliable mapping and determination of wetland areas for inventory, planning or monitoring purposes. The occurrence of plants that rely on the presence of water for part-or-all of their life-history can be a reliable way to determine the extent of water-affected ecosystems. A wetland plant indicator list (WPIL) could enable more accurate mapping, and provide a tool for on-ground validation of wetland boundaries. However, this introduces the problem of the definition of 'wetland plant', especially with species that can tolerate, or require, water-level fluctuations, and that respond to flooding or drought by adjustment of their morphology or phenology (i.e 'amphibious' plants, and those that grow only during drawdown). In this study we developed a WPIL through a process of expert elicitation. The expert decisions were compared and standardised for each species. It is envisaged that this work will lead to a comprehensive listing of wetland plants for Australia for the purposes of planning, mapping and management.

Introduction

Wetlands provide key ecological services (Gibbs 2000, Mitch and Gosselink 2007, Georgiou and Turner 2012), the scale of which is dependent on the area of wetland and its characteristics. However, determination of wetland boundaries can be difficult due to the dynamic nature of these systems in a variable climate. Determination of boundaries of wetlands for regulatory purposes is increasingly important. It is necessary to know the limits of wetlands because many activities that require government approval or assessments prior to commencing work occur in or near wetlands. Further, as plant community assemblages are used as descriptors within biodiversity legislation (e.g., NSW Biodiversity Conservation Act, Threatened / Endangered Ecological Communities) there is a need to develop a comprehensive listing of wetland plants, as it relates to wetland identification and delineation. The contributions of plants to wetland functioning have been extensively reviewed (Mitsch and Gosselink 2000, Sainty and Jacobs 2003, Boulton *et al.* 2014), and while plants exist in sufficient richness to give clear and robust signals of many ecological factors as well as human disturbance, the definition of ‘wetland vegetation’ (Tiner 1999) is problematic as there is no single suite of species that defines all wetlands.

The term ‘wetland’ has been defined in numerous ways, in general based on the presence of water affected soils and water-dependent flora and fauna (Adam 1995, Tiner 1999, Winning and Duncan 2001). In this study we use the definition of wetland used in the NSW Wetland Policy (2010) because of the legislative authority it provides. It also focuses on species adaptations as indicators of wetland (and non-wetland) status. That is, ‘wetlands’ are defined as *“areas of land that are wet by surface water or groundwater, or both, for long enough periods that the plants and animals in them are adapted to, and depend on, moist conditions for at least part of their lifecycle. They include areas that are inundated cyclically, intermittently or permanently with fresh, brackish or saline water, which is generally still or slow moving”* (NSW OEH 2010). In this definition there is an implicit relationship between the occurrence of wetlands and water-dependent plants, so it follows that the presence of water-dependent plants could be used to predict the occurrence of wetlands.

From the beginnings of ecology, the simplest classification system of water plants have been into ‘hydrophytes’ (plants with submerged organs, growing in water) and

‘helophytes’ (marsh plants with foliage growing above the water surface or in wet soil) (Warmer 1909). However, this dichotomy masks the range of habitats and habitat requirements where wetland plants occur, particularly where water-levels vary in space and time. Functional groupings of water plants based on the species responses to depth and water-level change rather than just the depth where the plant typically occurs have been developed (Brock and Casanova 1997, Casanova 2011) and adapted to incorporate life history (i.e. annual vs perennial) and life form (Capon and Reid 2016). These Water Plant Functional Groups (WPFGs) are based on information about each species’ germination, establishment and growth behaviour in seed bank studies, overall morphology and ecological information obtained from the literature. WPFGs have been used to compare water plant responses to different depths, durations and frequencies of flooding (Casanova and Brock 2000), overall water regimes (Leck and Brock 2000, Porter *et al.* 2007, John *et al.* 2015), to contrast wetlands (Liu *et al.* 2006; Porter *et al.*, 2007) and to assess environmental water requirements (*sensu* Arthington *et al.* 2006, Casanova 2011). Although this WPGF grouping is explicit about water requirements and the definition of each group of species, it is not comprehensive for all stressors. The allocation of water for environmental purposes, which is a major undertaking in the Murray-Darling Basin, means that research on the responses of wetland plants to different environmental stressors is becoming available (e.g., Wen *et al.* 2009, Thomas *et al.* 2010, Colloff *et al.* 2014). However, data about plant life history and water requirements are not currently available for all water plants in any one region or state, and a comprehensive listing of wetland dependent plant species does not currently exist for NSW.

In Europe, the study of plant biology has been extensive with the development of the Ellenberg indicator values (specific scores for individual species) to predict soil acidity, soil productivity or fertility, soil humidity, soil salinity, climatic continentality and light availability (Ellenberg 1974). The moisture index (F) is of particular interest with reference to species occurrence in wetlands. It ranges from 1-12, with 1 indicating extremely dry soil, 9 indicating wet soil, 10 indicating an aquatic habitat, and 12 indicating a completely submerged habitat. This ranking has been extensively applied and tested to assess relationships between vegetation and the environment (ter Braak *et al.* 1987, Ertsen *et al.* 1998, Krecek *et al.* 2010). In the United States, Adamus and

Gonyaw (2000) estimate that only 17% of all wetland plant species have been the subject of studies that detail their responses to specific stressors.

In Australia, however, a number of states have lists of wetland plant indicators which have been developed using expert opinion. Queensland have developed a Flora Wetland Indicator Species List (WISL) to assist in the delineation of wetlands (QEHP 2013). In Victoria (DELWP 2016), there is a list of indicator species associated with each Ecological Vegetation Class (EVC indicator species), rather than for wetlands (although there are wetland EVCs), and the list of indicator species can refer to different phases or water regimes. Although there is likely to be overlap with species that occur in New South Wales, the geographical and climatic differences of Queensland (tropical and subtropical, semi-arid) and Victoria (alpine to Mediterranean and semi-arid) reduces the potential for using lists from other states for wetland delineation in New South Wales. As such, one of the aims of this project was to better understand the use of expert elicitation for developing a wetland indicator list using plants, since plants are one of the most conspicuous features of a wetland, and often used as an indicator of the presence of a wetland, its boundaries, and as the basis for many wetland classification schemes.

As discussed by Keeney and von Winterfeldt (1989), expert judgments are not equivalent to technical calculations based on universally accepted scientific laws or the availability of extensive data on precisely the quantities of interest. They should be used for problems where neither of the above are available. Expert assessments express what the expert knows through their experiential knowledge which may include that gained through their research. The use of expert judgement has been extensively used on complex problems where the information has significant knowledge gaps or is difficult to analyse because the variables are so inherently complex. This is particularly true in environmental science where intrinsic knowledge is required. In Australia, much of environmental flow assessments methods rely on an expert-based approach to predict environmental effects (Stewardson and Webb 2010), and to prioritise monitoring and management actions including the allocation of environmental water (Fazey *et al.* 2006a, Nicol *et al.* 2018).

Categorising a plant as a wetland indicator or not, using expert judgement, is therefore appropriate as there is limited published literature on all plant species. Although species that require water in which they are “*adapted to, and depend on, moist conditions for at*

least part of their lifecycle” (DECC 2010) i.e. ‘aquatic obligates’ (capable of existing only in an aquatic environment) are well documented, there is also a suite of species where the association is not well documented, especially in Australia where floodplain wetlands are often more dry than wet.

Expert elicitation has been used in the USA to develop an extensive list of wetland plants (over 8,092 species) (Federal Register 2012). The National Wetland Plant List (NWPL) is the standard reference for wetland indicator status ratings of vascular plants in the United States and territories, and is used for wetland delineation, assessment, mitigation, and habitat restoration (Lichvar *et al.* 2014). It also plays a critical role in determination of wetland areas under the Clean Water Act and the Wetland Conservation Provisions of the Food Security Act (Lichvar *et al.* 2014). The status list was initially compiled (Reed 1988) using expert elicitation of 142 ecologists to define or determine individual species association with wetlands.

A common challenge for expert elicitation in any region is scoping the breadth of expertise to cover the diversity of wetland systems (from arid-zone wetlands to alpine systems), and recognition of different categories of wetland plants to those in other climatic regions (particularly for temporary wetlands). For example, although there is a suite of species that occur only when water is present (submerged species such as *Vallisneria australis* and emergent species such as *Schoenoplectus tabernaemontani*), there are also species that only occur in wetlands that are dry, and not elsewhere in the landscape. An example of this is the short herb *Centipeda cunninghamii* that completes its life cycle on damp and drying soils and dies before standing water is again present. There are also species that tolerate the presence of surface water, but thrive when wetlands are dry (*Eucalyptus* species), and species that require surface water in order to complete different stages of their life-history (e.g. *Duma florulenta* survives extreme drought, reproduces while or after being flooded, and germinates on damp mud). Another challenge of expert elicitation is the understanding of how much agreement there was among experts, and how many expert opinions are necessary to provide a robust listing of wetland plants.

The aims of this project were to have a better understanding of the use of expert elicitation to develop, by consensus, a list of wetland indicator plant species. To test the independence of this list, we also compare the results with the corresponding Water

Plant Functional Groupings (WPGF) rankings and the Queensland Flora Wetland Indicator Species List (WISL). This method can then be used to develop a list that could be applied consistently to all wetland plant species across NSW to assist mapping (Ling *et al.* 2017) and decision making.

Methods

Indicator codes

We provided five plant indicator codes or scores using a 5-point Likert-type scale (Likert 1931) (Table 1; after Reed 1988) to be used by experts to score a plants species' preference for or occurrence in a wetland: Obligate (*required to or restricted to*) wetland plants (1), Facultative (*capable of but not restricted to*) wetland plants (2), Discretionary (*ability to occur depending on other environmental factors*) wetland plants (3), Indiscriminate (*not discriminating in relation to wetlands*) plants (4), and Terrene (occurring on or inhabiting dry land, i.e., terrestrial) plants (5) . A sixth code was provided for species with which experts were not familiar. These codes represent the estimated likelihood of a species occurring in wetlands by the experts.

Table 1: Description of the characteristics in each wetland plant indicator codes (after Reed 1988E).

[*\[Insert Table 1\]*](#)

Indicator list trial area

The trial area was the Lachlan River catchment, western New South Wales (Fig. 1). The boundary of this region is aligned with the NSW Vegetation Mapping Program (NSW OEH 2017) and so provides appropriate data for wetland mapping and validation. This catchment area (approximately 86,000 km² and covering around 10% of NSW) has a diversity of landscapes and ecosystems, including nine nationally significant wetlands (listed on the Directory of Important Wetlands: DIWA) with particular value as waterbird and migratory bird habitat (Environment Australia 2001).

[*\[Insert Figure 1\]*](#)

Figure 1: Lachlan River catchment study area

Expert elicitation

In order to allocate a code to species a three-stage process was undertaken:

Stage 1: This stage required to collate a list of known plant species from the trial area. A list of species recorded from the Lachlan River catchment was extracted from the repository of biodiversity data in NSW (NSW Atlas / BioNet database, NSW OEH 2012, accessed 22/09/2016) by selecting Lachlan Catchment Management Authority. As a ‘first-cut’ of the list to eliminate definitive terrestrial species, species were investigated through NSW PlantNet (accessed 2016-17) to identify whether their distribution and occurrence included wetted areas (wetlands, rivers, floodplains etc.). This plant list consisted of 3138 taxa (some of which were actually genera, e.g. *Typha*). If a species also occurred on the Queensland Flora Wetland Indicator Species List (WISL) then it was assigned that indicator status – wetland or non-wetland (QEHP 2013) – for further analysis by experts in the next stage. By eliminating the taxa that were considered obligate terrestrial (always occur in dry habitats), this reduced the total number of taxa for analysis of water plants from 3138 taxa to 467. Those taxa identified only to genus and contained both wetland and non-wetland species were categorised as ‘Indiscriminate (*not discriminating in relation to wetlands*) plants’ (code 3, Table 1), and thus eliminating a further 46 taxa from the next stage.

Stage 2: This stage required a ‘second-cut’ of the list for wetland or non-wetland species. Three wetland vegetation experts were asked to score the remaining 421 species from 1 to 5 (Table 1), (mindful of the definition of ‘wetland’ in the NSW Wetland Policy), based on their experience. These three experts had cumulative field botanical experience of over 75 years. Species that were identified by all three botanists as either Code 1 (Obligate wetlands) or 5 (Terrene / terrestrial), were removed from the list to reduce the number of species for the next stage. These experts scored 106 species in common as Code 1, and 65 species as Code 5. This reduced the list for the next stage to 250 species.

Stage 3: This stage involved botanists from a range of expertise to score the remaining species. Experts were sourced from the author’s networks and from recommendations by

other botanists. Wetland and other vegetation experts that responded to the call came from within state (NSW and Queensland) government agencies, research institutions and consultants (a total of 15 experts). They were asked to score the remaining 250 species according to their experience, using the categories in Table 1, and with the NSW Wetland Policy definition in mind, with the understanding that the species list had been reduced through the processes described in Stage 1 and 2. Thus, only equivocal or ambiguous, facultative or discretionary wetland species were subject to expert scoring. The scores from all 15 experts were then analysed to obtain average indicator codes for each species.

Analysis of the expert opinion

The assigned codes (1, 2, 3, 4, 5) for each species by each expert was used to produce the fractional scores ($1.00 \leq \text{score} \leq 5.00$) for analysis. Variability of expert opinion and different levels of scientific knowledge, in regard to each species, meant that the following assumptions were made: not all experts will agree on the level of wetland association for each species; each expert's personal perceptions and professional differences will result in slightly higher or lower scores consistently across species when compared to other experts, and such differences are especially likely when a species is close to a boundary between the allowable scores (1, 2, 3, 4, 5); when scientific information about a species is limited or ambiguous experts may produce quite different scores.

The analysis to compute the scores for each species involved the following:

- i. The scores were initialised using the codes provided by the experts.
- ii. The scores were used to perform a binomial test for all combinations of pairs of experts. This produced a divergence matrix showing the pattern of expert differences.
- iii. An 'offset' was calculated for each expert relative to their peers in order to minimise the disagreement between experts. The offset was determined by adding small increments (positive and negative) to each expert in turn. This was continued until the divergence matrix showed no further reduction in disagreement (between the expert and their peers). In the determination of offsets, all the species rated by four or more experts were used.

- iv. After calculating offsets for all experts, each expert's score was adjusted by the corresponding offset. The process was iteratively repeated from step iii until a stable solution of no further change was reached (which occurred after 7 iterations).

The final offsets determined for each expert were between -1.33 to 0.73 (Appendix B-2) with a mean value across all 15 experts of -0.07. The offsets (positive and negative) were added to the corresponding experts scores (maintaining a minimum value of 1 and a maximum value of 5) to produce a rating in line with a total group consensus.

Interaction tables produced by the procedure (Appendices B-3 and B-4) indicate where one expert (in column) is judged to have a lower ranking than another (shown in column). The stable solution did not necessarily have all experts (after offset adjustment) aligned exactly.

The mean, median and precision (giving a measure of the agreement of the experts' adjusted ratings for the species) were determined. The precision value ranges from 0.0 (complete agreement of all experts) to 2.0 (complete disagreement of two experts, one assessing the species as 1 and the other expert assessing it as a 5), though it only exceeded 1.0 for 3.2% of the species. This technique allowed for personal rating differences between the experts, and for different numbers of experts giving valid ratings for each species.

How many experts are enough?

To determine the minimal number of experts for coding plants to a consistent level we investigated how species scores changed when the number of experts was sequentially reduced, and restricted this analysis to species with at least 5 scores between 1 and 5. For each count of experts from 15 to 9 we determined the scoring of an unbiased sub- group of the original 15. For 15 and 14, this was by direct enumeration of all possibilities and for values 13 to 9 by using a uniform random sample of size 200. Across each sub-group, the minimum, maximum, mean and median of the correlations (across all species) between each reduced set of experts and the given 15 was used as a measure of the loss of information due to using a reduced number of experts. When standardising scores, most combinations of two experts rated a majority of the same species. If both experts (here referred to as Expert A and Expert B) had a similar rating system, any cases where the ratings differed would just as likely have the lower value for Expert A as for Expert

B. The extent to which the number of species were rated lower by Expert A was greater than the number of species rated higher by Expert A was used to assess each pair of experts. The threshold for determining if Expert A rated lower than Expert B was the 95% binomial probability for equal probability trials.

This measure provided a 'best possible case' to be compared with other analyses below. This was then repeated for every possible combination of the whole analysis deleting one expert in turn to determine the species ranking scores from each of the modified sets and related those to the 'best possible case'. This analysis was then repeated deleting 2 experts, and then 3 experts and so on taking a uniform random sample of all possible combinations.

Comparison with WPGF and Queensland WISL

Along with the code described above, we (MC) provided water plant functional group (WPGF) categories for each species (Brock and Casanova 1997, Casanova and Brock 2000, Casanova 2011) on the basis of information about germination and establishment behaviour, growth form and reproductive requirements. This information was contributed by participants in an Australian Center for Ecological Analysis and Synthesis working group (16 wetland ecologists) with expertise in taxonomy, seedbank studies, and ecological information, and the data is being amalgamated into a national WPGF database. The WPGFs were then documented and compared with the codes derived from expert elicitation (Appendix A).

Using Queensland's Flora Wetland Indicator Species List (WISL) (QEHP 2013), we also compared the alignment of the species present in the trial area to their wetland / non-wetland status in the Queensland list, expecting that not all species will be listed in Queensland.

Results

Expert elicitation

Of the 3138 plant species downloaded from the Bionet/Atlas of NSW Wildlife database for the Lachlan River catchment, 15 experts scored 371 species as wetland indicator species (average codes 1-3.99). Each expert had a unique familiarity with the species in the list, and all but three experts confidently rated more than 300 species (Appendix B-1). The optimisation process to determine offsets for standardisation of codes required 7

iterations. The experts were not necessarily well ordered. The relation “lower expert value” was not always transitive in that it was possible for Expert A to score less than Expert B who scored less than Expert C who scored less than Expert A. This is due to different subgroups of plant species being rated by each pair of experts.

After adjusting with experts’ offsets, each species had a much-reduced range of fractional scores. Typically, the range was less than 2 units. The new scale with fractional units and a small within-species range takes on the characteristics of an interval scale in that differences between fractional scores are approximately equal across the narrow range. Hence, for calculating indicator scores for each plant species across experts, mean values are appropriate and better discriminate between plant species than median values. For the 371 wetland species (average codes between 1-3.99), the average number of experts who coded each species was 7, with an average precision of 0.31.

Precision refers to how close the expert scores differed from the average, after adjustment. Not unexpectedly, the species with lowest precisions (precision > 1.0) or highest discrepancies between experts, were mainly Discretional (average code 3-3.99) wetland indicator species. The main implication of the precision values is when a code changes the wetland status of the species from non-wetland to wetland or visa versa. For example, those species grouped as non-wetland indicators (Indiscriminate: average code between 4 - 4.99), that could be considered potential wetland indicators (Discretional: average code 3-3.99) due to consideration of their precision. These 9 species had average codes between 4.07 and 4.32, with precisions from 0.25-0.78 suggesting that their status could change from non-wetland to potential wetland indicator (Table 3). These species have not been included in the WPIL in Appendix A.

Table 2: Indiscriminate species (average codes 4-4.99) that could be considered as potential wetland species if precision scores are taken into account. They have not been included in Appendix A.

[\[Insert Table 2\]](#)

At the other end of the spectrum are those species that change groupings from Discretional (potential indicator) to Facultative (wetland species). Acknowledging these

27 species in Appendix A could potentially improve efficiencies in wetland determination, when a simple binary wetland vs non-wetland process is involved for large datasets.

Wetland indicator species

Through the process of iterative expert opinion, a Wetland Plant Indicator List (WPIL) for the Lachlan River catchment was developed (Table 3) with 292 species with average codes between 1 – 2.99, as scored by 15 experts. The 292 Obligate and Facultative species (average code between 1-2.99) comprised mainly grasses, sedges or herbs (89%) and 33 (11%) trees and shrubs (Appendix A).

Discretionary species are defined as potential wetland indicators and likely to have a broad ecological range, and this was reflected in the range of scores between 1 to 5 given by experts for 17% of the species. These species if present, are capable of occurring in wetlands but not restricted to them and further investigation may be required (e.g., occurrence with other plant species, inundation frequency etc) for their use as wetland delineators. They can also occur on the floodplain. Of the 79 Discretionary wetland species (average code between 3.0 – 3.9), only 13 were trees and shrubs, with the majority (84%) being grasses, sedges and herbs. These species have also been listed in Appendix A because of the discrepancies in the experts scores ranged from 1 to 5, and perhaps reflecting the complexity of their habitat requirements and occurrence.

Of the 72 families, the most species-rich wetland families were Cyperaceae (51 species) and Poaceae (47 species). As expected, over 325 species (80.3%) were categorised as non-woody vegetation (Grassland/Sedges/Herbs), with the remaining species as woody (7.4% 'Shrub', 5.4% 'Forests or Woodland'). Of the 371 species (including Discretionary species), 12 species are considered introduced in New South Wales (according to PlantNet): *Cyperus eragrostis*, *Myriophyllum aquaticum*, *Rorippa nasturtium-aquaticum*, *Juncus acutus subsp. acutus*, *Cotula coronopifolia*, *Rorippa palustris*, *Juncus articulatus*, *Ranunculus sceleratus*, *Salix babylonica*, *Salix x reichardtii*, *Arundo donax*, and *Juncus bufonius*.

Table 3: Obligate and Facultative wetland species (codes 1-2.99) in the Lachlan River catchment identified by the experts. Genera listed contain all or mostly wetland species. See Appendix A for full list and codes.

[\[Insert Table 3\]](#)

Comparison with Water Plant Functional Groups (WPFGs)

Of the 371 species coded for the Lachlan River catchment, 14 species (3.8%) were classed as Submerged (Sk, Se), 178 species (48%) were classed as Amphibious (ARp, ARf, ATl, ATe or ATw), and 179 species (48%) were classed as Terrestrial (Tda or Tdr) (Figure 2). When compared to the WPIL, the WPFG Submerged species ranged in average WPIL codes between 2.28 to 1.33 (mean 1.5, median 1.3), indicating they were all considered Obligate or Facultative wetland species. The WPFG Amphibious species had WPIL average codings ranging between 3.65 and 1.22 (mean 1.8, median 1.8), highlighting their range from Facultative to Discretionary wetland species. The WPFG Terrestrial species had a WPIL average codings between 3.98 and 1.57 (mean 2.9, median 2.87), indicating their range from wetland to non-wetland status.

Figure 2: Comparison of the Water Plant Functional Groups (WPFG) (Casanova 2011) and the codings from the Wetland Plant Indicator List (WPIL: see Table 1). Numbers indicate the number of species in each WPFG.

WPFG: Submerged - k-selected (Sk); Perennial - emergent (Se); Amphibious fluctuation-responders - floating (ARf); Amphibious fluctuation-responders - morphologically plastic (ARp); Amphibious fluctuation-tolerators - emergent (ATe); Amphibious fluctuation-tolerators - low growing (ATl); Amphibious fluctuation-tolerators - woody (ATw); Terrestrial: damp places (Tda); Terrestrial: dry places (Tdr).

[\[Insert Figure 2\]](#)

Comparison with Queensland's Flora Wetland Indicator Species List (WISL)

Of the 371 species coded for the Lachlan River catchment, 101 species (27%) were listed with a wetland status in the Queensland WISL (also noted in Appendix A). When compared with the WPIL, 98 species (listed in the Queensland list) had average WPIL

codes less than 2.99 (Obligate and Facultative wetland species), and 3 species had average codes between 3-3.99 (Discretionary wetland species). No species had WPIL average codes less than 3.99. Figure 3 is a plot of the WPIL codes for the species that occurred concurrently in NSW and Queensland.

Figure 3: Comparison of the Queensland's Flora Wetland Indicator Species List (WISL) (QEHP 2013) and the average codings from the Wetland Plant Indicator List (WPIL). Numbers above each box and whisker plot indicate the number of species from the Queensland WISL that also occur in the Lachlan River catchment.

[\[Insert Figure 3\]](#)

How many experts are enough?

Decreasing the expert group size for assessment of plant species in the Lachlan CMA showed a small decrease in accuracy and consensus (Figure 4). Given that 15 experts provided the 'best possible case' the comparison values (correlation coefficients) close to 1.0 signified that little information was lost by relying on fewer experts. There was a slow decline in consensus until the group size declined to 10, after which there was a marked decrease in consensus.

Figure 4: : Correlation coefficient of increasing the number of experts from 9 to 15 experts. (a) the arrow highlights the shift in the value of the correlation coefficient from 9 to 10 experts. (b) Noting the Y axis scale change from graph a, this graph clarifies the differences in the values of the correlation coefficient by omitting the 'lowest' category (in graph a). These graphs suggest the need for a minimum of 10 experts are required for scoring the plant species in the Lachlan River catchment.

[\[Insert Figure 4\]](#)

Removing one expert resulted in essentially the same result as using all experts, where the worst case or lowest value gave a value of 98%, but over all possible cases the average was better than 99% (Figure 4). In removing 2 experts the worst case was 95% and the average case was better than 98%. Removing 3 experts (or using 13 experts) the

worst case was 92% and the average case was 98%. Thus, conformation to the consensus decreased down to 9 experts (i.e. removing 6 experts) where the worst case was 32% and the average was 92%.

Extrapolating this data suggests that reaching a tighter consensus is unlikely with more than 15 experts. However, it must be noted that these results are appropriate for the Lachlan River catchment area of NSW, and were developed from this specific group of experts. Within the group there are likely to be similarities due to common education and field experiences, and differences linked to speciality areas of interest. The group is also not an unbiased sample of experts available although they might be a large proportion of all possible experts with appropriate knowledge.

Discussion

The subset of the NSW Wetland Plant Indicator List (WPIL) developed here, for the Lachlan River catchment wetlands, provides a first iteration of a list of plants that have a strong association with wet conditions that can be used diagnostically. This paper addressed the challenge of better understanding how many experts are necessary to provide a robust listing of wetland plants. The consensus expert knowledge method used provided a high degree of reliability in the allocation of wetland plants to codes, in the absence of comprehensive ecological data about each species. The use of indicator codes, determined through analysis of expert elicitation, provides a means to identify wetland species from a large pool of candidates. The results of our analysis in the Lachlan catchment suggests that using 10 of the 15 available experts would have had no significant detrimental effect on results. While fewer than 10 experts will usually be adequate, our results indicate that some combinations of experts would not have sufficient diversity to duplicate the scoring of the full cohort of experts. It is entirely plausible that 10 experts would be sufficient for other NSW, and indeed Australian, catchments having matching plant diversities with the experts drawn from similarly composed pools.

Indeed, one of the challenges of the diversity of species across different habitat scenarios is the use of a range of expertise (and perhaps ‘the-more-the-merrier’ for a wider geographical range such as a statewide or national database) and the need for regular revision. The NWPL addresses some of these challenges by recognising the need for regular revision. In 2012, the NWPL 2012 list was updated online, with over 130,000

comments received through a public website (Federal Register 2012). The list of over 8,092 species (in the 2016 revision) incorporated the process of changing species status through accredited botanists, with additional public comment, data and information to inform any changes. This online process could provide a template for updating the allocation of wetland plants in Australian systems once developed.

Another consideration to improve the information elicited from the experts is to enable them to score each species at a higher level of refinement. That is, instead of coding whole numbers from 1 – 5, but in decimal places from 0-5, including a level of confidence score would provide additional information in calculating the final indicator scores. The methods used to evaluate the expert scores use conventional statistical methods and can be replicated by others.

Comparing the WPIL codes with Water Plant Functional Groups (WPGFs) and the Queensland's Flora Wetland Indicator Species List (WISL), provided an independent assessment of the WPIL codings for NSW. Both were developed by combining scientific research (literature) and intrinsic knowledge of experts. The WPIL Obligate and Facultative wetland species were well aligned with the WPGF allocations and the Queensland WISL. All but three species that coincided with both the Queensland WISL and the Lachlan WPIL were considered either Obligate or Facultative wetland species. That is, nearly all of the species considered as wetland indicators in Queensland, that also occur in the Lachlan, were also coded in the WPIL as wetland indicators, thereby providing further consensus of their wetland status. The three species coded as Discretionary (WPIL average code between 3-3.99) from the Queensland WISL - *Crinum flaccidum* (Darling Lily), *Chenopodium auricomum* (Queensland Bluebush), and *Walwhalleya subxerophila* (Gilgai Grass) - were considered Terrestrial (Tda, Tdr) from the WPGF ratings, and usually found in drier habitats, which further confirmed alignment between the three lists.

Nearly all species allocated from the WPGF as Submerged or Amphibious were also coded in the WPIL as either Obligate or Facultative wetland indicators. Species that have been grouped as Terrestrial (Tda: damp or Tdr: dry) were more problematic. The existence of such species in wetland areas indicates that water levels fluctuate, and that these systems become too dry for submerged or amphibious species to exist. Tda and Tdr species produce ground-cover, nutrient retention and carbon fixation during those

dry times. These functional groupings are based, not only on occurrence in wetlands, but also on additional information related to establishment and reproductive requirements, whereas wetland indicator codes can provide an important line of evidence for spatial scientists to determine consistent wetland boundaries across large areas.

This is especially important because when detecting wetland boundaries in mapping on floodplains and additional wetland types, more and more diverse plant species are recorded in flora surveys than are usually recorded in the relevant literature on wetland plants, as these studies have focused on sampling individual wetlands or wetland types. A comprehensive list of wetland plants with their association to watering requirements therefore provides an important line of evidence for spatial scientists delineating consistent wetland boundaries across large areas. Indeed, polygons with any of the Obligate and Facultative wetland species will be within the wetland boundaries. The challenge will come with the Discretionary wetland species where further information will be required to determine wetland vs non-wetland status of the polygon. Other information that could support delineation could include amongst many others: inundation and water regime modelling, topographic and geomorphic data, soil data, vegetation data, and monitoring of water dependent fauna habitat use.

Another major challenge for using a binary system for wetland indicators in Australia are the nature of the plant species themselves. Australian wetlands, compared to those in the northern hemisphere, are subject to larger between year climatic variation and less distinct within year variation. More often than not they are temporary. That is, wetlands can be dry for many years, with plants appearing to be dead or disappearing from the landscape during extended drought periods. In comparing NSW temporary wetlands and North American wetlands, Leck and Brock (2000) suggested that Australian seeds germinate in response to wet-dry cycles rather than season, and that Submerged and Amphibious functional groups are more diverse in Australian wetlands where all the species might tolerate drying. Australian wetland species are resilient to dry times, and with the return of water can resume their life cycles (Brock *et al.* 2003) by relying on seed banks, germination strategies, life history patterns, groundwater access and desiccation tolerance (Casanova and Brock 1990, Brock and Casanova 1997, Leck and Brock 2000, Doody *et al.* 2009, Brock 2011).

A further challenge in using wetland indicators codes as a binary system for delineating temporary wetlands is that for some species their water requirements are complex. For example, Black box (*Eucalyptus largiflorens*) is coded here as a wetland indicator species (average code 1.67 ± 0.55). It can opportunistically access water from rainfall and groundwater, and may tolerate an absence of flooding for 10 years. However it cannot regenerate unless flooded (Rogers and Ralph 2010 and references within). Thus, the presence of Black box may indicate a wetland, but without additional evidence (such as regeneration or other wetland species in the community) the species presence may indicate an historical wetland.

Expert knowledge has an intrinsic role in environmental conservation that interplays with scientific research and experiential knowledge, as each component can be derived and extended towards learning of the other (Fazey *et al.* 2006b). Expert knowledge will always have a role in decision-making processes and influencing research and monitoring directions to effect conservation outcomes through each individual's networks, so the extraction and synthesis of intrinsic knowledge through scientific processes, such as trialled in this paper, can add further information to guide our scientific endeavours towards conservation actions. This paper supports the role of expert knowledge as complimentary to experiential and qualitative methods as part of the evidence-based approach to decision making in environmental science.

It is expected the resulting Wetland Plant Indicator List (WPIL), and the method developed here, will have a broader application to assist with environmental assessment and decision making. This information will support a more consistent and repeatable approach to on-ground identification of wetlands, the delineation of wetland boundaries and wetland assemblages required for mapping wetlands over large areas. This list will also support the inclusion of NSW vegetation datasets to refine a national wetland classification system, which is currently in its infancy (AETG 2012) and largely untested (Claus *et al.* 2011, Brooks *et al.* 2014).

As this tool is used, and a statewide database is developed, it is likely that the information will be iteratively tested against reality and improved. This makes the maintenance of such a list a high priority.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Figure 1: Lachlan River catchment study area.

Figure 2: Comparison of the Water Plant Functional Groups (WPFG) (Casanova 2011) and the codings from the Wetland Plant Indicator List (WPIL: see Table 1). Numbers indicate the number of species in each WPFG.

WPFG: Submerged - k-selected (Sk); Perennial - emergent (Se); Amphibious fluctuation-responders - floating (ARf); Amphibious fluctuation-responders - morphologically plastic (ARp); Amphibious fluctuation-tolerators - emergent (ATe); Amphibious fluctuation-tolerators - low growing (ATl); Amphibious fluctuation-tolerators - woody (ATw); Terrestrial: damp places (Tda); Terrestrial: dry places (Tdr).

Figure 3: Comparison of the Queensland’s Flora Wetland Indicator Species List (WISL) (QEHP 2013) and the average codings from the Wetland Plant Indicator List (WPIL). Numbers above each box and whisker plot indicate the number of species from the Queensland WISL that also occur in the Lachlan River catchment.

Figure 4: Correlation coefficient of increasing the number of experts from 9 to 15 experts. (a) the arrow highlights the shift in the value of the correlation coefficient from 9 to 10 experts. (b) Noting the Y axis scale change from graph a, this graph clarifies the differences in the values of the correlation coefficient by omitting the ‘lowest’ category (in graph a). These graphs suggest the need for a minimum of 10 experts are required for scoring the plant species in the Lachlan River catchment.

Table 1: Description of the characteristics in each wetland plant indicator code

Code	Indicator status	Designation	Comment
1	Obligate wetland	Wetland indicator species	If present, then certainly indicates a wetland ecosystem Always occur in wetlands
2	Facultative wetland	Wetland indicator species	If present, then likely indicates a wetland ecosystem Usually occur in wetlands, but may occur in non-wetlands
3	Discretionary wetland	Potential wetland indicator species	If present, further investigation required (e.g., other plant species, inundation frequency etc). Can occur on the floodplain. Capable of occurring but not restricted to wetlands
4	Indiscriminate	Non-wetland indicator species	Usually occur in areas other than wetlands, but may also occur in wetlands
5	Terrene	Non-wetland indicator species	Almost never occur in wetlands
6	Insufficient knowledge or information		

Table 2: Indiscriminate species (average codes 4-4.99) that could be considered as potential wetland species if precision scores are taken into account. They have not been included in Appendix A.

Scientific Name	Family	Common Name	WPFG	Wetland code (mean)	precision
<i>Myriocephalus rhizocephalus</i>	Asteraceae	Woolly-heads	Tda	4.22	0.781
<i>Phyllanthus gunnii</i>	Phyllanthaceae		Tdr	4.07	0.25
<i>Chloris divaricata</i> var. <i>divaricata</i>	Poaceae	Slender Chloris	Tdr	4.32	0.359
<i>Echinopogon cheelii</i>	Poaceae	Long-flowered Hedgehog Grass	Tdr	4.32	0.359
<i>Echinopogon intermedius</i>	Poaceae	Erect Hedgehog Grass	Tdr	4.32	0.359
<i>Grevillea arenaria</i>	Proteaceae		Tdr	4.32	0.359
<i>Grevillea arenaria</i> subsp. <i>canescens</i>	Proteaceae	Hoary Grevillea	Tdr	4.32	0.359
<i>Pultenaea polifolia</i>	Fabaceae (Faboideae)	Dusky Bush-pea	Tdr	4.32	0.359
<i>Thelymitra carnea</i>	Orchidaceae	Tiny Sun Orchid	Tdr	4.32	0.359

Table 3: Wetland Plant Indicator List (Obligate and Facultative: average codes 1-2.99) for the Lachlan River catchment.

Genera listed contain all or mostly wetland species.

* indicate introduced species (according to PlantNet). See Appendix A for full list and codes.

Note: Naming conventions from PlantNet (accessed 2018)

Scientific Name	Scientific Name	Scientific Name	Scientific Name
<i>Acacia stenophylla</i>	<i>Diplachne fusca</i>	<i>Juncus fockei</i>	<i>Persicaria attenuata</i>
<i>Alisma plantago-aquatica</i>	<i>Diplachne muelleri</i>	<i>Juncus gregiflorus</i>	<i>Persicaria decipiens</i>
<i>Ammannia multiflora</i>	<i>Diplachne parviflora</i>	<i>Juncus holoschoenus</i>	<i>Persicaria hydropiper</i>
<i>Amphibromus macrorrhinus</i>	<i>Drosera auriculata</i>	<i>Juncus ochrocoleus</i>	<i>Persicaria lapathifolia</i>
<i>Amphibromus neesii</i>	<i>Drosera glanduligera</i>	<i>Juncus planifolius</i>	<i>Persicaria orientalis</i>
<i>Amphibromus nervosus</i>	<i>Drosera peltata</i>	<i>Juncus procerus</i>	<i>Persicaria praetermissa</i>
<i>Amphibromus pithogastrus</i>	<i>Duma florulenta</i>	<i>Juncus psammophilus</i>	<i>Persicaria prostrata</i>
<i>Arundo donax*</i>	<i>Echinochloa colona</i>	<i>Juncus radula</i>	<i>Phragmites australis</i>
<i>Azolla filiculoides</i>	<i>Eclipta platyglossa</i>	<i>Juncus remotiflorus</i>	<i>Phyllanthus lacunarius</i>
<i>Azolla pinnata</i>	<i>Elatine gratioloides</i>	<i>Juncus sarophorus</i>	<i>Pilularia novae-hollandiae</i>
<i>Azolla spp.</i>	<i>Eleocharis acuta</i>	<i>Juncus subglaucus</i>	<i>Pimelea bracteata</i>
<i>Baloskion australe</i>	<i>Eleocharis atricha</i>	<i>Juncus usitatus</i>	<i>Plagiobothrys elachanthus</i>
<i>Baloskion longipes</i>	<i>Eleocharis obicis</i>	<i>Juncus vaginatus</i>	<i>Plantago drummondii</i>
<i>Baumea rubiginosa</i>	<i>Eleocharis pallens</i>	<i>Kippistia suaedifolia</i>	<i>Poa fordeana</i>
<i>Blechnum minus</i>	<i>Eleocharis plana</i>	<i>Lachnagrostis filiformis</i>	<i>Potamogeton crispus</i>
<i>Blechnum nudum</i>	<i>Eleocharis pusilla</i>	<i>Leiocarpa brevicompta</i>	<i>Potamogeton ochreateus</i>
<i>Blechnum patersonii</i> subsp. <i>patersonii</i>	<i>Eleocharis sphacelata</i>	<i>Lemna disperma</i>	<i>Potamogeton perfoliatus</i>
<i>Bolboschoenus caldwellii</i>	<i>Epacris breviflora</i>	<i>Lepidosperma gunnii</i>	<i>Potamogeton sulcatus</i>
<i>Bolboschoenus fluviatilis</i>	<i>Epacris gunnii</i>	<i>Lepidosperma urophorum</i>	<i>Potamogeton tricarlinatus</i>
<i>Bolboschoenus spp.</i>	<i>Epacris microphylla</i>	<i>Leptochloa digitata</i>	<i>Prasophyllum campestre</i>
<i>Burchardia umbellata</i>	<i>Epilobium billardierianum</i> subsp. <i>cinereum</i>	<i>Leptospermum continentale</i>	<i>Pratia concolor</i>
<i>Callistemon linearis</i>	<i>Epilobium billardierianum</i> subsp. <i>hydrophilum</i>	<i>Leptospermum grandifolium</i>	<i>Pratia pedunculata</i>
<i>Callistemon sieberi</i>	<i>Epilobium gunniamum</i>	<i>Leptospermum juniperinum</i>	<i>Pseudoraphis spinescens</i>
<i>Callitriche sonderi</i>	<i>Epilobium hirtigerum</i>	<i>Leptospermum lanigerum</i>	<i>Puccinellia stricta</i>
<i>Callitriche umbonata</i>	<i>Eragrostis australasica</i>	<i>Leptospermum myrtifolium</i>	<i>Pultenaea dentata</i>
<i>Calotis scapigera</i>	<i>Eragrostis falcata</i>	<i>Leptospermum polygalifolium</i> subsp. <i>polygalifolium</i>	<i>Pycnosorus chrysanthus</i>
<i>Carex appressa</i>	<i>Eremophila bignoniiflora</i>	<i>Leptospermum polygalifolium</i> subsp. <i>transmontanum</i>	<i>Pycnosorus globosus</i>
<i>Carex bichenoviana</i>	<i>Eryngium paludosum</i>	<i>Levenhookia dubia</i>	<i>Ranunculus inundatus</i>
<i>Carex fascicularis</i>	<i>Ethuliopsis cunninghamii</i>	<i>Lilaeopsis polyantha</i>	<i>Ranunculus papulentus</i>
<i>Carex gaudichaudiana</i>	<i>Eucalyptus aggregata</i>	<i>Limosella australis</i>	<i>Ranunculus pentandrus</i>
<i>Carex iynx</i>	<i>Eucalyptus camaldulensis</i>	<i>Limosella curdieana</i>	<i>Ranunculus pentandrus</i> var. <i>platycarpus</i>
<i>Carex klaphakei</i>	<i>Eucalyptus elata</i>	<i>Lindsaea linearis</i>	<i>Ranunculus pumilio</i>
<i>Carex lobolepis</i>	<i>Eucalyptus largiflorens</i>	<i>Lindsaea microphylla</i>	<i>Ranunculus pumilio</i> var. <i>pumilio</i>
<i>Carex tereticaulis</i>	<i>Euphrasia collina</i> subsp. <i>paludosa</i>	<i>Lipocarpha microcephala</i>	<i>Ranunculus sceleratus*</i>
<i>Casuarina cunninghamiana</i> subsp. <i>cunninghamiana</i>	<i>Gahnia sieberiana</i>	<i>Lobelia darlingensis</i>	<i>Ranunculus sessiliflorus</i>
<i>Cenchrus purpurascens</i>	<i>Gahnia subaequiglumis</i>	<i>Lomandra fluviatilis</i>	<i>Ranunculus undosus</i>
<i>Centella asiatica</i>	<i>Geranium neglectum</i>	<i>Lomandra montana</i>	<i>Rorippa nasturtium-aquaticum*</i>
<i>Centipeda crateriformis</i> subsp. <i>compacta</i>	<i>Glinus oppositifolius</i>	<i>Lomatia myricoides</i>	<i>Rorippa palustris*</i>
<i>Centipeda cunninghamii</i>	<i>Glossostigma diandrum</i>	<i>Ludwigia peploides</i> subsp. <i>montevidensis</i>	<i>Rumex bidens</i>
<i>Centipeda minima</i> subsp. <i>minima</i>	<i>Glossostigma elatinoides</i>	<i>Luzula densiflora</i>	<i>Rumex crystallinus</i>
<i>Centipeda spp.</i>	<i>Glyceria australis</i>	<i>Luzula modesta</i>	<i>Salix babylonica*</i>
<i>Centipeda thespidioides</i>	<i>Glycyrrhiza acanthocarpa</i>	<i>Luzula ovata</i>	<i>Salix x reichardtii*</i>
<i>Chenopodium nitrariaceum</i>	<i>Gonocarpus micranthus</i>	<i>Lycopus australis</i>	<i>Schoenoplectiella dissachantha</i>
<i>Comesperma defoliatum</i>	<i>Gonocarpus micranthus</i> subsp. <i>micranthus</i>	<i>Lythrum hyssopifolia</i>	<i>Schoenoplectus validus</i>
<i>Cotula alpina</i>	<i>Gonocarpus micranthus</i> subsp. <i>ramosissimus</i>	<i>Lythrum salicaria</i>	<i>Schoenus apogon</i>
<i>Cotula coronopifolia*</i>	<i>Goodenia paniculata</i>	<i>Marsilea costulifera</i>	<i>Schoenus latelaminatus</i>

Developing a Wetland Indicator Plant List

<i>Craspedia canens</i>	<i>Goodenia stelligera</i>	<i>Marsilea drummondii</i>	<i>Scirpus polystachyus</i>
<i>Craspedia paludicola</i>	<i>Gratiola pedunculata</i>	<i>Marsilea hirsuta</i>	<i>Selaginella uliginosa</i>
<i>Crassula decumbens</i> var. <i>decumbens</i>	<i>Gratiola peruviana</i>	<i>Marsilea</i> spp.	<i>Solanum karsense</i>
<i>Crassula helmsii</i>	<i>Gratiola pumilo</i>	<i>Melaleuca erubescens</i>	<i>Solanum lacunarium</i>
<i>Crassula peduncularis</i>	<i>Haloragis glauca</i> f. <i>glauca</i>	<i>Melaleuca hypericifolia</i>	<i>Spergularia diandroides</i>
<i>Cressa australis</i>	<i>Haloragis heterophylla</i>	<i>Melaleuca styphelioides</i>	<i>Sphaeromorphaea australis</i>
<i>Cycnogeton dubium</i>	<i>Hemarthria uncinata</i>	<i>Mentha australis</i>	<i>Spirodela polyrrhiza</i>
<i>Cycnogeton multifructum</i>	<i>Hemarthria uncinata</i> var. <i>uncinata</i>	<i>Microtis parviflora</i>	<i>Sporobolus mitchellii</i>
<i>Cycnogeton procerum</i>	<i>Hydrocotyle acutiloba</i>	<i>Mimulus gracilis</i>	<i>Sprengelia incarnata</i> f. 'incarnata'
<i>Cyperus alterniflorus</i>	<i>Hydrocotyle algida</i>	<i>Minuria integerrima</i>	<i>Stellaria angustifolia</i>
<i>Cyperus concinnus</i>	<i>Hypoxis vaginata</i> var. <i>brevistigmata</i>	<i>Montia fontana</i>	<i>Stemodia florulenta</i>
<i>Cyperus difformis</i>	<i>Isoetes drummondii</i> subsp. <i>anomala</i>	<i>Montia fontana</i> subsp. <i>chondrosperma</i>	<i>Stemodia glabella</i>
<i>Cyperus eragrostis</i> *	<i>Isoetes muelleri</i>	<i>Myosurus australis</i>	<i>Stylidium despectum</i>
<i>Cyperus exaltatus</i>	<i>Isolepis cernua</i>	<i>Myriophyllum aquaticum</i> *	<i>Symphionema paludosum</i>
<i>Cyperus flavidus</i>	<i>Isolepis congrua</i>	<i>Myriophyllum caput-medusae</i>	<i>Tecticornia pergranulata</i>
<i>Cyperus gunnii</i> subsp. <i>gunnii</i>	<i>Isolepis habra</i>	<i>Myriophyllum crispatum</i>	<i>Tecticornia pergranulata</i> subsp. <i>pergranulata</i>
<i>Cyperus gymnocaulis</i>	<i>Isolepis inundata</i>	<i>Myriophyllum papillosum</i>	<i>Thyridia repens</i>
<i>Cyperus iria</i>	<i>Isolepis victoriensis</i>	<i>Myriophyllum</i> spp.	<i>Tricostularia pauciflora</i>
<i>Cyperus lhotskyanus</i>	<i>Isotoma fluviatilis</i>	<i>Myriophyllum variifolium</i>	<i>Triglochin</i> sp. B
<i>Cyperus lucidus</i>	<i>Isotoma fluviatilis</i> subsp. <i>borealis</i>	<i>Myriophyllum verrucosum</i>	<i>Triglochin</i> spp.
<i>Cyperus pygmaeus</i>	<i>Isotoma fluviatilis</i> subsp. <i>fluviatilis</i>	<i>Neopaxia australasica</i>	<i>Trigonella suavissima</i>
<i>Cyperus rigidellus</i>	<i>Juncus acutus</i> subsp. <i>acutus</i> *	<i>Nymphoides crenata</i>	<i>Typha domingensis</i>
<i>Cyperus sanguinolentus</i>	<i>Juncus articulatus</i> *	<i>Ophioglossum lusitanicum</i>	<i>Typha orientalis</i>
<i>Cyperus squarrosus</i>	<i>Juncus australis</i>	<i>Ottelia ovalifolia</i> subsp. <i>ovalifolia</i>	<i>Utricularia dichotoma</i>
<i>Cyperus victoriensis</i>	<i>Juncus bufonius</i> *	<i>Panicum queenslandicum</i>	<i>Vallisneria australis</i>
<i>Damasonium minus</i>	<i>Juncus continuus</i>	<i>Paspalidium jubiflorum</i>	<i>Veronica gracilis</i>
<i>Deyeuxia quadriseta</i>	<i>Juncus flavidus</i>	<i>Paspalum distichum</i>	<i>Viola caleyana</i>