Spring wetlands in seasonally arid Queensland: floristics, environmental relations, classification and conservation values

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Abstract. The vegetation and environmental setting of permanent spring wetlands are described from a survey of 269 spring complexes throughout seasonally arid Queensland. Wetlands associated with springs in the western and southern discharge areas of the Great Artesian Basin are floristically distinct from other spring wetlands. Ordination analysis suggests that the biogeographic regions and the broad geological substrates that support spring wetlands provide a meaningful representation of floristic range. An existing classificatory system that defines 'regional ecosystems' on the basis of the biogeographic region and broad geological substrate is adopted to define 15 spring-wetland types in seasonally arid Queensland. The conservation value of the springs is assessed by a scheme that weights plant species' populations on the basis of their endemicity and isolation from other populations, demonstrating that both Great Artesian Basin and non-Great Artesian Basin springs have similar conservation values.

Introduction

Australian spring wetlands are identified as a distinct wetland type (Australian Nature Conservation Agency 1996). Recently there has been some interest in the hydrology and biological values of springs, particularly those emanating from the Great Artesian Basin. The water pressure in this aquifer has declined substantially because of the extraction of water from artificial bores and it is considered that the long-term sustainability of the resource is imperilled (Great Artesian Basin Consultative Council 2000). This has serious implications for both the agricultural and mining sectors that use the Great Artesian Basin. Large amounts of public monies are being spent on rehabilitating bores with the aim of restoring aquifer pressure. Spring flows have also declined, particularly in discharge areas, and preservation of their natural values is highlighted as an important justification for the rehabilitation program (Great Artesian Basin Consultative Council 2000).

Fensham and Fairfax (2003) described results from a comprehensive ground survey of the spring wetlands associated with the Great Artesian Basin in Queensland. That study confirmed and extended previous findings from South Australia (Ponder 1995) regarding the significance of the biological values of the springs emanating from the Great Artesian Basin. These spring wetlands provide habitat for a number of endemic plants, as well as fish, snails and other invertebrates (Ponder 2003).

The conservation values of Great Artesian Basin springs have been ranked on the basis of their endemic plant populations and the habitat they provide for isolated populations of plant species (Fensham and Price 2004). Although the high values of Great Artesian Basin spring wetlands have been confirmed, there has been almost no floristic data available to yield comparison with spring wetlands of other aquifers. One exception is the information on rainforests that occur on spring-fed landforms in the Northern Territory (Russell-Smith 1991; Liddle et al. 1994). These forest communities support a distinctive flora including endemic species; however, they are climatically, structurally and floristically almost totally unrelated to spring wetlands of the Great Artesian Basin for which survey information is available.

Some spring wetlands in seasonally arid Queensland, including those outside the Great Artesian Basin, were listed as distinct regional ecosystems by Sattler and Williams (1999) (see description in Methods). Regional ecosystems seek to provide a logical system of landscape classification that can be used in environmental planning and should provide an approximate surrogate for biodiversity. There have been few tests of that assumption in relation to floristic data. However, there are some studies that examine floristic variation in relation to underlying environmental features, such as climatic regions, geological substrate and dominant vegetation that can be equated to levels in the regional ecosystem hierarchy (e.g. Fensham 1995, 1998a, 1999). Some of these patterns have been interpreted by Fensham (2000) who, not surprisingly, concluded that in some cases the regional ecosystems...
provide excellent surrogates and in other cases they are not well related to segments of the floristic continua. For example, floristic variation in dry rainforests is not well related to geological substrate (land zones), but the strong pattern related to latitude is effectively segmented by the biogeographic regions of the Einasleigh Uplands and the Brigalow Belt (Fensham 1995).

The current study investigates the floristic variation within the spring wetlands of seasonally arid Queensland, using survey information from both Great Artesian Basin springs and permanent springs associated with other aquifers. It attempts to evaluate the effectiveness of regional ecosystems as a means of classifying spring wetlands by examining floristic relations to biogeographic regions, broad geomorphic units defined by land zones and other environmental variables. The study also seeks to investigate whether the flora of spring wetlands of the Great Artesian Basin aquifer are distinct from other spring wetlands in seasonally arid Queensland.

The conservation status of the regional ecosystems representing spring wetlands (as per Wilson et al. 2002) and the conservation rank of the individual spring-wetland complexes (as per Fensham and Price 2004) is applied to the available data from seasonally arid wetlands to present a ranking based on conservation values. A brief mention of the conservation issues is included for each of the defined regional ecosystems.

Methods

Locating springs and survey design

The total dataset includes the sites included in the survey of the Queensland portion of the Great Artesian Basin (excluding Cape York Peninsula) by Fensham and Fairfax (2003) and floristic data from other spring wetlands of the seasonally arid biogeographic regions: the North-west Highlands, Gulf Plains, Mitchell Grass Downs, Channel Country, Mulga Lands, Einasleigh Uplands, Desert Uplands and Brigalow Belt (Fig. 1). The data-collection procedure for the springs outside the Great Artesian Basin follows that of Fensham and Fairfax (2003). For the purposes of the current paper the relevant data include a precise locality, an assessment of the wetland area, a complete vascular-plant species list for each spring wetland (species nomenclature follows: Henderson 2002), the identification of the geological setting, the soil texture of the substrate surrounding the wetland (according to the 16-point scale from 1 = sand to 16 = heavy clay in McDonald et al. 1996), the pH of the substrate surrounding the wetland, the pH of the water, a measure of total dissolved solids within spring water sampled near the discharge vent and an excavation-damage score (0 = none, 1 = adjacent to wetland, 2 = sand to 16 = heavy clay in McDonald et al. 1996). The soil texture of the substrate surrounding the wetland (as per Fensham and Price 2004) and the pH of the water, a measure of total dissolved solids within spring water sampled near the discharge vent and an excavation-damage score (0 = none, 1 = adjacent to wetland, 2 = sand to 16 = heavy clay in McDonald et al. 1996).

The intent of the survey was not to locate and survey every spring throughout seasonally arid Queensland but rather to sample the range of representative situations, including all geological substrates and a selection of springs from throughout the region. In some cases our survey was limited by access considerations and time constraints, but in general we were able to survey a representative range of situations where springs have permanent flows, and particularly those springs discharging major water flows. Of all known spring types the limestone springs in the North-west Highlands were the most poorly sampled.

The survey work for the spring wetlands within the Great Artesian Basin was conducted between 1995 and 2002 and for the springs outside the Great Artesian Basin between 1998 and 2002.

Floristic analysis

Data from 569 individual spring wetlands were amalgamated to 269 spring complexes (defined by Fensham and Fairfax (2003) as springs or spring groups within 6 km and in the same geographic setting). One hundred and forty-seven of the spring complexes are within the Great Artesian Basin and formed the basis of the analysis and description in Fensham and Fairfax (2003) and Fensham and Price (2004). Incidental species, defined as those that occur in spring wetlands but have their primary habitat in the terrestrial habitats adjoining the springs (see Fensham and Price 2004), were not included.

To examine floristic gradients, ordination was performed by non-metric multi-dimensional scaling using the default values in DECODA (Minchin 1991), using native taxa only. Complexes that had a mean excavation score greater or equal to 3.5 and/or with less than four native taxa were excluded. Exploratory analysis indicated that the dataset would be most parsimoniously explained within a two-dimensional ordination environment (minimum stress value = 0.200). We could find no environmental meaning to the subsequent dimensions. The relationship between the spectrum of floristic variation and the variable soil pH, soil texture, water pH and total dissolved solids was investigated by vector analysis (Kangur and Minchin 1999). The statistical significance of the correlation is determined by using random permutations of the values of the variable among sites (Faith and Norris 1989).

Classificatory frameworks for spring wetlands

Regional Ecosystems were developed to summarise the natural environments of Queensland and to provide a framework for conservation strategy and are more fully described in Sattler and Williams (1999). They comprise a three-tiered hierarchy: biogeographic region—broad regions reflecting climate, geomorphology and vegetation; land zone—broad geomorphic categories describing major geological units and associated landforms of Queensland; and the individual ecosystem usually identified by the dominant vegetation. By way of example, for regional ecosystem 1.10.6 (Appendix 1) the first tier of the hierarchy (1) identifies that it is in the North-west Highlands biogeographic region; the second tier (10) identifies that it occurs on coarse-grained quartzose sandstone; and the third tier (6) identifies the individual ecosystem as distinguished by its dominant vegetation, or unique environment. The numbering of the third tier is not comparable among biogeographic regions or land zones. The existing regional ecosystems that represent or include spring wetlands in seasonally arid Queensland are 1.10.6, 2.10.8, 4.3.22, 5.3.23, 6.3.23, 9.3.10, 10.3.16, 10.10.6 and 11.3.21 (Sattler and Williams 1999).

A system of generating the conservation status of regional ecosystems is outlined in Wilson et al. (2002), based on estimated extent.
Fig. 1. Location of the spring complexes and the biogeographic regions in seasonally arid Queensland.

I, Great Artesian Basin discharge; R, Great Artesian Basin recharge; N, non-Great Artesian Basin.

Of concern: 10–30% of the pre-clearing distribution remaining or >30% of the pre-clearing distribution if its remnant extent is less than 10,000 ha;

Not of concern: >30% of the pre-clearing distribution remaining and remnant extent is greater than 10,000 ha.

Fensham and Fairfax (2003) distinguished between ‘recharge springs’ and ‘discharge springs’ in the Great Artesian Basin where the former are associated with the eastern areas of the basin where the sandstones forming the main water-bearing aquifer have surface expression. The recharge springs are not necessarily situated directly in the sandstone but are in the general vicinity and therefore the water has relatively short residence times. The discharge springs are remote from the recharge areas on the western and southern margins of the basin (see Fig. 1 in Fensham and Fairfax 2003). The recharge and discharge Great Artesian Basin and non-Great Artesian Basin spring complexes were identified within the ordination space, as were the biogeographic regions. Land zones (determined from field notes, after Sattler and Williams 1999, see Fig. 5) were also identified within separate ordinations for each biogeographic region.

A regional ecosystem classification was developed to capture the biogeographic region × land zone combinations where they were floristically distinct. Estimates were made regarding the original and current area of spring wetlands. For the Great Artesian Basin springs, these estimates are based on historical assessments (see Fensham and Fairfax 2003), but are less reliable for other springs because they were incompletely sampled and historical assessments are only cursory. For non-Great Artesian Basin springs, estimates are based on the survey of the sampled springs, the authors’ understanding of springs that were not sampled and limited historical information. Destruction of wetlands (i.e. the difference between current and original area) in the context of springs is taken to only include mechanical clearing by excavation, the cessation of spring discharges as a result of pressure draw-down and sealing of springs because of stock trampling or explosives. Most draw-down has resulted from the artificial extraction of ground water (Fensham and Fairfax 2003). Notes are made regarding other threatening processes (e.g. severe animal trampling, ponded pastures), and where their consideration may result in a change in conservation status according to the conservation status described in Wilson et al. (2002) (see above).
The conservation ranking system of Fensham and Price (2004) prioritises spring complexes such that for each spring, spring-wetland plant endemics are given a score proportional to their number of known populations, and scores are also given to taxa, depending on their isolation from other known populations. The taxa records generated by this survey were compared with 65 131 records of the taxa from the Queensland Herbarium specimen and survey databases. In some cases, the scores for taxa from the north-western spring wetlands were downgraded on the basis of the supplementary data from the Northern Territory (Northern Territory Herbarium specimen database).

**Results**

**Wetland classification**

The dataset included 384 native taxa from 269 seasonally and spring complexes in Queensland [Appendix 2](#) available as an accessory publication on the web). Another 36 exotic species were recorded and are listed in Appendix 2 but they were not included in the analysis. The ordination of native species included 194 spring complexes and indicates that the discharge springs of the Great Artesian Basin are floristically distinct from Great Artesian Basin recharge springs and non-Great Artesian Basin springs, but that there is no clear floristic distinction between the latter two groups (Fig. 2). The discharge springs of the Great Artesian Basin are generally alkaline, with high levels of dissolved solids, reflecting the long residence time of the ground water within the aquifer (Fensham and Fairfax 2003). Other springs are in close proximity to recharge areas and are fed by water of relatively short residence times. These patterns are borne out by the general direction of the significant vectors soil pH and texture and water pH through the ordination space roughly perpendicular to the plane that separates the recharge and discharge spring wetlands (Fig. 3).

Thirty combinations of biogeographic region and land zone contain spring wetlands (Table 1). The Brigalow Belt has the highest number with six land-zone settings. The ordination shows some separation in relation to biogeographic region, with the Mulga Lands, North-west Highlands, Einasleigh Uplands and Desert Uplands occupying relatively discrete ordination space (Fig. 4).

A broad pattern that distinguishes spring wetlands on relatively fertile alluvial or igneous substrates from those emanating from relatively acid substrates such as quartzose sandstone or lateritised sandstone is repeated in most of the individual ordinations for individual biogeographic regions (Fig. 5). This is especially clear in relation to the springs of the Gulf Plains, Mulga Lands and Desert Uplands biogeographic regions. For the North-west Highlands, the two spring wetlands emanating from metamorphic rocks are distinct from the springs in sandstone. The single spring complex in fine-grained sediments (limestone in this case) may represent a distinct type of spring wetland; however, the limestone springs were poorly sampled in this study. For the Einasleigh Uplands, the springs emanating from basalt and sandstone occupy discrete sections of the ordination space. The springs on the assorted other land zones are less distinct. The alluvial springs perhaps show greatest affinity to the springs on basalt and fine-grained sediments (limestones in the region), whereas springs from metamorphic rocks and granites show affinities with those in quartzose sandstone. In the Brigalow Belt, the springs on quartzose sandstones are generally distinct from springs on recent alluvia. The springs on fine-grained sediments (mostly shales) have the greatest affinity with springs on recent alluvia. The spring wetlands on basalts occupy an intermediate position in the ordination space (Fig. 5).
Table 1. Number of surveyed spring wetland complexes according to biogeographic region and land zone

<table>
<thead>
<tr>
<th>Biogeographic region</th>
<th>Recent alluvium (3)</th>
<th>Ancient clay sheets (4)</th>
<th>Lateritised sandstone (7)</th>
<th>Alkaline igneous (8)</th>
<th>Fine-grained sediments (9)</th>
<th>Coarse-grained sediments (10)</th>
<th>Metamorphics (11)</th>
<th>Acid igneous (12)</th>
<th>Grand total</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-west Highlands (1)</td>
<td>1</td>
<td>9</td>
<td>2</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gulf Plains (2)</td>
<td>10</td>
<td>2</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitchell Grass Downs (4)</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel Country (5)</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mulga Lands (6)</td>
<td>25</td>
<td>1</td>
<td>12</td>
<td>2</td>
<td></td>
<td></td>
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<td>9</td>
<td>12</td>
<td>13</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
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<td>5</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Brigalow Belt (11)</td>
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<td>1</td>
<td>5</td>
<td>13</td>
<td>28</td>
<td>1</td>
<td>57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
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<td>2</td>
<td>21</td>
<td>38</td>
<td>30</td>
<td>86</td>
<td>9</td>
<td>13</td>
<td>269</td>
</tr>
</tbody>
</table>

Of the 30 biogeographic region × land zone combinations supporting spring wetlands in seasonally arid Queensland (Table 1), many represent only rare occurrences and are not floristically distinct. Here we provide a revised regional ecosystem classification of spring wetlands, using the guiding principle that floristic distinctions should reflect the distinct environments of separate regional ecosystems within biogeographic regions. In general, our scheme reflects the fundamental division between spring wetlands emanating from relatively acid and relatively alkaline substrates (Fig. 5). For the Great Artesian Basin this also reflects the fundamental division between recharge springs and discharge springs (Fensham and Fairfax 2003).

For the North-west Highlands, we define three distinct regional ecosystems: one on sandstone, one on limestone and the one on metamorphics. Although data for limestone springs are insufficient, Fig. 5 suggests that the limestone springs may be distinct. Certainly, there are large unsurveyed limestone springs (Drysdale et al. 1998) that feed major perennial streams (Gregory River and tributaries). Here we separate the limestone springs, pending further survey. For each of the Gulf Plains, Mulga Lands and Desert Uplands there are two distinct regional ecosystems: one that includes spring wetlands on lateritised sandstone and coarse-grained sandstone, and the other on recent alluvia or fine-grained sediments. For the Mitchell Grass Downs and Channel Country, the spring wetlands are few in number, floristically related and generally restricted to positions in the landscape covered by recent alluvia. In the Channel Country there is at least one spring emanating from lateritised sandstone, although its wetland has been destroyed by excavation and was not included in the ordination analysis.

For the Einasleigh Uplands, two regional ecosystems are defined: one to encompass springs emanating from sandstone, fine-grained sediments (limestone), metamorphics and granites, and another to encompass basalt and recent alluvia. This dichotomy is justified by the ordination (Fig 5). The simple segregation of the
springs into land-zone categories is most difficult in the Brigalow Belt. In this biogeographic region we have opted for a simple dichotomy between a regional ecosystem for the sandstone springs and another encompassing remaining land zones: recent alluvia, ancient alluvia, basalt, fine-grained sediments (shales) and metamorphics. This is at least partially supported by the ordination (Fig. 5).

Fifteen regional ecosystems are defined to encompass the range of spring wetland types in seasonally arid Queensland (Appendix 1). They are represented within the complete ordination space on Fig. 6. The separate regional ecosystems defined on the basis of land-zone groups within individual biogeographic regions are generally well distinguished within the ordination space (Fig. 5), as are the separate biogeographic regions (Fig. 4).
Spring wetlands of Queensland

The method of ranking spring complexes on the basis of their endemic and isolated plant populations identifies a number of endemic and isolated plant species that occur in discharge spring complexes in western Queensland. The species that are endemic to the spring wetlands include

- Eryngium fontanum
- Fimbristylis ferruginea
- Sporobolus pamelae
- Hydrocotyle subterranea
- Distichlis spicata
- Sparganium subglobosum
- Myriophyllum alterniflorum
- Utricularia caerulea
- Isotoma fluviatilis
- Schoenus falcatus
- Mytilis aquaticus
- Potamogeton polygonus
- Eleocharis tetraquetra
- Eriocaulon carsonii
- Mimulus aquatilis
- Plectranthus subulatus
- Pouzolzia sp.
- Sparganium subglobosum
- Eriocaulon athertonense
- Wahlenbergia stricta subsp. alterna
- Rhynchospora gracilis
- Microcarpa minima

Discussion

This study suggests that the regional ecosystem scheme (Sattler and Williams 1999) serves as a useful framework for classifying spring wetlands. There are independent floristic associations with both biogeographic region and land zone. However, the pre-existing regional ecosystems that encompass spring wetlands do not adequately describe the range of environmental settings occupied by spring wetlands or their floristic variants. The 15 regional ecosystems defined here encompass the floristic range of spring wetlands in seasonally arid Queensland, and hence, should represent adequate surrogates of the environmental range of spring wetlands.

Although the regional ecosystem framework provides an adequate representation of floristic patterning in spring wetlands, several other factors probably affect floristic composition. The strength of the vector for water pH through
Table 2. Spring complexes scoring five or more according to the Fensham and Price (2004) selection algorithm employed here
The regional ecosystem (see Appendix 1 for key to first two numbers of the regional ecosystem hierarchy) of the high-scoring springs and their occurrence as either Great Artesian Basin (GAB) recharge or discharge springs (according to the definition in Fensham and Fairfax 2003) or in other aquifers is indicated. The total number of spring complexes included in the analysis per regional ecosystem is: 1, 1, 10, 9, 1, 11, 2, 2, 3, 10, 2, 10, 18, 4, 6, 5, 13, 6, 3, 28, 6, 7, 12, 9, 46; 9, 10, 34, 10, 3, 9, 10, 10, 29, 11, 3, 28, 11, 10, 29. One hundred and forty-seven GAB spring complexes are included in the total of 269 spring complexes. PA identifies spring complexes within areas managed for conservation

<table>
<thead>
<tr>
<th>Spring complex</th>
<th>Region</th>
<th>Regional ecosystem</th>
<th>Aquifer</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moses</td>
<td>Desert Uplands</td>
<td>10.5</td>
<td>GAB (recharge)</td>
<td>61.4</td>
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<td>Desert Uplands</td>
<td>10.5</td>
<td>GAB (recharge)</td>
<td>18.4</td>
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<td>Mayor Mitchell (PA)</td>
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<td>GAB (recharge)</td>
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<td>Younghoon Creek</td>
<td>Malga Lands</td>
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<td>GAB (discharge)</td>
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<td>GW</td>
<td>Einasleigh Uplands</td>
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<td>Other</td>
<td>24.0</td>
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<td>Conners</td>
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<td>Other</td>
<td>9.0</td>
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<td>Whitewater/Rocky</td>
<td>Einasleigh Uplands</td>
<td>9.8</td>
<td>Other</td>
<td>9.0</td>
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<td>Bowraville</td>
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the ordination space suggests that water chemistry may be an important influence on floristic composition. Water chemistry is a product of aquifer hydrology and the nature of subsurface geology and may be little influenced by surface geology. Spring wetlands with obvious signs of major excavation were excluded but it is probable that some wetlands that have undergone major excavation in the past have been recolonised by weedy wetland plants, with profound implications for current species composition.

The only springs in our survey that have any floristic resemblance to the spring wetlands dominated by rainforest species described for the Northern Territory (Russell-Smith 1991; Liddle et al. 1994) are in the North-west Highlands biogeographic region (1.10.6, Appendix 1). These simple closed-canopy forests are dominated by the single rainforest species Syzygium angophoroides. Rainforest and non-rainforest wetland communities on springs are known to occur in the Cape York Peninsula biogeographic region where rainfall is seasonally high and groundwater discharge abundant in places (Great Artesian Basin Consultative Council 1998); however, this bioregion awaits systematic survey.

The spring wetlands in the discharge areas of the Great Artesian Basin (i.e. 4.3.22, 5.3.23, 6.3.23, 10.3.31, Appendix 1) occur in relatively arid areas and generally seem to be distinct from other spring wetlands. These spring wetlands include sites with populations of endemics, but also isolated populations of plant species that would not otherwise occur in these arid environments. Some of these sites also represent habitats for extremely rare and endemic fauna (Ponder 2003). The spring wetlands in the discharge areas of the arid zone of South Australia (Symon 2000) appear to be floristically related, but distinct from other spring wetlands. These spring wetlands include sites with populations of endemics, but also isolated populations of plant species that would not otherwise occur in these arid environments. Some of these sites also represent habitats for extremely rare and endemic fauna (Ponder 2003). The spring wetlands in the discharge areas of the arid zone of South Australia (Symon 2000) appear to be floristically related, but distinct from other spring wetlands. These spring wetlands include sites with populations of endemics, but also isolated populations of plant species that would not otherwise occur in these arid environments. Some of these sites also represent habitats for extremely rare and endemic fauna (Ponder 2003).


Acknowledgments

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References


## Appendix 1. Proposed regional ecosystem descriptions for spring wetlands in seasonally arid Queensland

It is proposed that the springs components in the existing descriptions for the broader regional ecosystems 9.3.10, and 10.3.16 (Sattler and Williams 1999) be removed from those descriptions, as they are now represented by regional ecosystems 9.8.8 and 10.3.31, respectively.

### Regional ecosystem 1.9.8

**Supplementary description:** Drysdale et al. (1998).

**Description:** Spring wetlands on undeformed fine-grained sedimentary rock (limestone).

**Protected areas:** Lawn Hill NP.

**Extent reserved:** Moderate.

**Special ecological values:** Potentially significant refugia for remote plant populations and rare flora.

**Comments:** Some springs affected by stock disturbance. The biological values are poorly known.

**Estimated extent:** >30% remains of a naturally restricted type.

**Conservation status:** of concern.

### Regional ecosystem 1.10.6

**Description:** Spring wetlands on quartzose sandstone.

**Protected areas:** Lawn Hill NP.

**Extent reserved:** Moderate.

**Special ecological values:** Regionally significant refugia for remote plant populations and rare flora, including *Fimbristylis blakei* and *Plectranthus* sp. RJ Fensham 4616. Closed canopy forest dominated by *Scygmus angophoroides* can develop.

**Comments:** Affected by stock disturbance.

**Estimated extent:** >30% remains of a naturally restricted type.

**Conservation status:** of concern.

### Regional ecosystem 1.11.5

**Description:** Spring wetlands on metamorphic rock. *Cyperus vaginatus* appears to be a characteristic species.

**Protected areas:** None.

**Extent reserved:** None.

**Comments:** Affected by excavation and stock disturbance. Poorly surveyed, but probably few permanent springs.

**Estimated extent:** >30% remains of a naturally restricted type.

**Conservation status:** of concern.

### Regional ecosystem 2.3.39

**Supplementary description:** Habermehl (1982); Fairfax and Fensham (2002); Fensham and Fairfax (2003).

**Description:** Spring wetlands on recent alluvium.

**Protected areas:** None.

**Extent reserved:** None.

**Comments:** All the springs are within Great Artesian Basin discharge areas. Peat mounds have developed in some instances, but no specialised organisms identified. The springs have been dramatically affected by artificial water extraction. Affected by excavation and degraded by stock disturbance and pig rooting.

**Estimated extent:** 10–30% remains of a naturally restricted type.

**Conservation status:** endangered.

### Regional ecosystem 2.10.8

**Supplementary description:** Fensham and Fairfax (2003).

**Description:** Spring wetlands on either quartzose sandstone or lateritised sandstone in gullies and gorges.

**Protected areas:** Bulleeniya NP.

**Special ecological values:** Regionally significant refugia for remote plant populations and rare flora, including *Eriocaulon carsonii* and *Fimbristylis blakei*.

**Extent reserved:** Low.

**Comments:** The springs on quartzose sandstone are within Great Artesian Basin recharge areas. The spring wetlands in some instances have been degraded by stock disturbance and pig rooting.

**Estimated extent:** >30% remains of a naturally restricted type.

**Conservation status:** of concern.

### Regional ecosystem 4.3.22

**Supplementary description:** Habermehl (1982); Ponder and Clark (1990); Fairfax and Fensham (2002); Fensham and Fairfax (2003); Fensham and Price (2004).

**Description:** Spring wetlands on either recent alluvia or fine-grained sedimentary rock (shales).

**Protected areas:** Elizabeth Springs CP.

**Special ecological values:** Habitat for endemic species including fish (Elizabeth Springs goby *Chlamydogobius micropterus*), the snail *Jardinella isolata*, and flora species including *Eriocaulon carsonii*, *Eragrostis* sp. (RJ Fensham 3705), *Fimbristylis* sp. (RJ Fensham 3743) and *Myriophyllum artesium*.

**Extent reserved:** Moderate.
Appendix 1. (continued)

Comments: all the springs are within Great Artesian Basin discharge areas. Affected by artificial extraction, excavation, pig rooting and stock disturbance. Springs in Tertiary aquifers may exist, but are poorly known.
Estimated extent: 10–30% remains of a naturally restricted type.
Conservation status: endangered.

Regional ecosystem 5.3.23
Supplementary description: Habermehl (1982); Ponder (2003); Fensham and Fairfax (2003); Fensham and Price (2004).
Description: spring wetlands on either recent alluvia or fine-grained sedimentary rock.
Protected areas: none.
Extent reserved: none.
Comments: all the springs are within Great Artesian Basin discharge areas. Affected by artificial extraction, excavation, pig rooting and stock disturbance. There may also be rare examples of springs in Tertiary aquifers, although no intact examples have been surveyed.
Estimated extent: >30% still active of a naturally restricted type.
Conservation status: of concern.

Regional ecosystem 6.3.23
Description: spring wetlands on recent alluvia, ancient alluvia or fine-grained sedimentary rock (shales).
Protected areas: Culgoa Floodplain NP and Carawoinya NP (poor examples of type).
Extent reserved: low.
Special ecological values: habitat for rare flora including Eriocaulon carsonii, Eragrostis sp. (R.J. Fensham 3705), Hydrocotyle sp. (R.J. Fensham 3338), Myriophyllum artesium and Sporobolus pamelae, endemic snails and other endemic invertebrates (Ponder 2003).
Comments: All the springs are within Great Artesian Basin discharge areas. Affected by artificial extraction, excavation, pig rooting and stock disturbance.
Estimated extent: 10–30% remains of a naturally restricted type.
Conservation status: endangered.

Regional ecosystem 6.7.18
Supplementary description: Habermehl (1982).
Description: spring wetlands on lateritised sandstone.
Protected areas: Idalia NP.
Extent reserved: low.
Special ecological values: habitat for isolated populations of the fern Lindsaea ensifolia and fish (e.g. Mogurnda sp.)
Comments: affected by excavation, pig rooting and stock and feral goat disturbance. More survey is required.
Estimated extent: >30% remains of a naturally restricted type.
Conservation status: of concern.

Regional ecosystem 9.8.8
Description: spring wetlands on either basalt or alluvium.
Protected areas: Undara Volcanic NP, Blackbraes NP, Porcupine Gorge NP.
Extent reserved: moderate.
Special ecological values: springs associated with this ecosystem are significant for local fauna and rare flora species; Fimbristylis blakei, Mimulus aquatilis and Pouzolzia hirta.
Comments: affected by the introduction of ponded pastures, excavation, pig rooting and stock disturbance. There are records to suggest that many of these springs became extinct in the early pastoral period (White undated). Some of these springs within basalt aquifers flow large volumes (e.g. >5 ML day$^{-1}$). Many have moderately geothermally heated water.
Estimated extent: >30% remains of naturally restricted type.
Conservation status: of concern.

Regional ecosystem 9.10.2
Description: springs on either quartzose sandstone, fine-grained sedimentary rock (limestone), metamorphic rock or granite.
Protected areas: Blackbraes NP.
Extent reserved: low.
Special ecological values: springs associated with this ecosystem are significant for local fauna and rare flora species, Eriocaulon carsonii, Fimbristylis blakei. Specialised organisms may be associated with hot springs.
Comments: affected by the introduction of ponded pastures, excavation, pig rooting and stock disturbance. Includes springs that are geothermally heated including the hottest spring in Queensland (~65°C).
Estimated extent: >30% remains of naturally restricted type.
Conservation status: of concern.
Appendix 1. (continued)

Regional Ecosystem 10.3.31
Supplementary descriptions: Habermehl (1982); Fairfax and Fensham (2002); Fensham and Fairfax (2003); Fensham and Price (2004).
Description: spring wetlands on recent alluvia.
Protected area: Doongmabulla Mound Springs Nature Refuge.
Extent reserved: low.
Special ecological values: rare and threatened species including the plants Eriocaulon carsonii, Eryngium fontanum, Hydrocotyle sp. (R J Fensham 3338), Sporoibis pamelae, Piptuldum sp. (RJ Fensham 3341), Piptuldum sp. (R J Fensham 3380), Myriophyllum artesium; the fishes red-finned blu-eye (Scaturiginichthys vermeilipinnis) and a goby (Chlamydogobius squamigenus); and numerous endemic invertebrates (Ponder 2003).
Comments: most springs in this regional ecosystem are within Great Artesian Basin discharge areas. Affected by artificial extraction, excavation, pig rooting, stock disturbance and the introduction of ponded pastures.
Estimated extent: >30% remains of a naturally restricted type.
Conservation status: of concern.

Regional ecosystem 10.10.6
Supplementary descriptions: Habermehl (1982); Fairfax and Fensham (2002); Fensham and Fairfax (2003); Fensham and Price (2004).
Description: spring wetlands on quartzose sandstone and lateritised sandstone.
protected area: no representation.
Extent reserved: none.
Special ecological values: springs associated with this ecosystem are significant for local fauna and rare flora species, Fimbriostylis blakei, Microcarpaea sp. (RJ Fensham 4176).
Comments: most of the springs are within the Great Artesian Basin recharge areas. Affected by excavation, pig rooting, disturbance by domestic stock and the introduction of ponded pastures.
Estimated extent: >30% remains of a naturally restricted type.
Conservation status: of concern.

Regional ecosystem 11.3.22
Description: spring wetlands on recent alluvia, fine-grained sedimentary rocks (shale), basalt, ancient alluvia or metamorphic rocks.
Protected area: Boggomoss and Mt Rose Nature Refuges, Carnarvon NP.
Extent reserved: low.
Special ecological values: rare and threatened species associated with mound springs including the plants Arthraxon hispidus, Eriocaulon carsonii and Myriophyllum artesium.
Comments: some of the springs are within the Great Artesian Basin recharge areas. Includes springs in the Dawson River Valley described as ‘boggomosses’. Affected by excavation, pig rooting, stock and feral horse disturbance, artificial extraction, inundation by impoundments and the introduction of ponded pastures.
Estimated extent: >30% remains of a naturally restricted type.
Conservation status: of concern.

Regional ecosystem 11.10.14
Description: spring wetlands on quartzose sandstone.
Protected area: Blackdown Tableland NP, Carnarvon NP, Palm Grove NP, Expedition NP and Precipice NP.
Extent reserved: high.
Special ecological values: rare and threatened species associated with mound springs including the plants Arthraxon hispidus, Dimeria sp. (RJ Fensham 3643), and endemic snails (Ponder and Clark 1990). Disjunct populations of coastal plant species.
Comments: all springs are within Great Artesian Basin recharge areas. Affected by excavation, pig rooting, stock and feral horse disturbance, artificial extraction from the aquifer, inundation by impoundments and the introduction of ponded pastures.
Estimated extent: >30% remains of a naturally restricted type.
Conservation status: of concern.