Biodiversity and Conservation Science

Biodiversity Survey, Mapping, Delineation and Assessment of Selected Organic Mound Springs of the Kimberley Region

Ecosystem Science Program

Species and Communities Branch

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Contents

1 Acknowledgments

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The Bunda Bunda organic mound springs are on Bindunbur country, and survey work was carried out with the cooperation and assistance of Traditional Owners and Nyul Nyul Rangers. The Carlton Hill springs are located on Miriuwung Gajerrong (MG) land and MG rangers working for DBCA were involved in this survey work. This report reports on the flora component of a survey of Nimalarragan wetland on Yawuru lands.

Invertebrate survey. Some copepods from the 1999 collections were identified by Maria Holynska (Museum and Institute of Zoology, Polish Academy of Sciences). Some of the earlier collected odonates and molluscs were identified by Gunther Theischinger (Office of Environment and Heritage, NSW) and Shirley Slack-Smith (Western Australian Museum) respectively. Most other pre-2016 identifications would have been made by Stuart Halse, Jane McRae, Michael Scanlon and Jim Cocking (all ex DBCA, now Bennelongia Pty Ltd). Jane McRae identified the 2017 harpacticoids and Stuart Halse identified the ostracods. Taxonomic assistance for the 2017 sampling was provided by Lars Hendrich (Zoologische Staatssammlung München, Germany) for dytiscid beetles, Chris Watts (South Australian Museum) for other beetles, Alice Wells (Department of Sustainability, Environment, Water, Population and Communities, Canberra) for hydroptilid caddisflies, Ros St Clair for leptocerid trichopteran) and Tom Weir (Australian Museum) for Hemiptera. Harry Smit provided some advice on *Mamersella* mites. For assistance with testate rhizopods, and provision of taxonomic literature, thanks to Yuri Mazei (Penza State University, Penza, Russia). Confirmation of rotifer identifications was provided by Hendrik Segers (Royal Belgian Institute of Natural Sciences, Brussels, Belgium). For diagnostic help with some species of Cladocera, thanks to Alexey Kotov (Macrotrichidae), Artem Sinev (Chydoridae) and Anna Neretina (Moinidae) (A. N. Severtsov Institute of Ecology and Evolution, Moscow, Russia).

Flora Survey. Thanks to Dr. Kelly Shepherd (Western Australian Herbarium) for providing determinations for *Tecticornia* collections.

2 Introduction

This report documents the results of a project designed to map and describe selected organic mound springs of the Kimberley region of Western Australia. These springs are a distinctive wetland type in the Kimberley and are listed as threatened or priority ecological communities, but most have been poorly described and their biodiversity values not well understood. In an effort to provide additional information on these springs, funds were made available through the Kimberley Science and Conservation Strategy to undertake survey work on a number of these mound springs, with a focus on those located on Carlton Hill Station north of Kununurra and two spring complexes in the West Kimberley. Proposed agricultural developments in the region are likely to have impacts on a number of these springs so this was also seen as an opportunity to collect some baseline data on their current extent and condition.

The report has four components:

Chapter 2: Flora (Michael Lyons, Margaret Collins, Jill Pryde and Val English)

Chapter 3: Invertebrate diversity (Adrian Pinder, Kirsty Quinlan, Russell Shiel and Loretta Lewis),

Chapters 4 to 6: Threatened ecological community assessments (Jill Pryde and Val English)

Chapter 7: Mapping and delineation (Adam Turnball and Michael Coote),

2.1 Organic mound springs in the Kimberley region

Organic mound springs in Western Australia are primarily found in the Kimberley Region, other than the Walyarta (Quinlan, Pinder & Lewis, 2016) and Dragon Tree Soak springs in the Great Sandy Desert, plus some near Three Springs in the Wheatbelt (Pinder & Leung, 2010) and near Perth on the Swan Coastal Plain (Jasinska & Knott, 1994). Their occurrence in Western Australia was reviewed by Shanahan and Coote (2008). They are sites of discrete permanent groundwater discharge supporting mesic vegetation complexes that are highly productive (compared to the surrounding landscape) and form peat deposits that accumulate to form low mounds. The vegetation communities on the springs are distinct from those in the surrounding landscape and the aquatic habitats that are usually present (pools and seepages, plus the saturated peat itself) support distinct assemblages of aquatic invertebrates, often with stygal and restricted elements. The mesic environments in these springs probably also support distinct terrestrial fauna communities, but these have not been surveyed. There are a range of other types of springs scattered across Western Australia and these can share some of the same biotic elements but not the same ecological communities. Many such springs are listed as Priority or Threatened Ecological Communities, with the primary threat usually being reduced groundwater discharge, but damage by stock and weed infestation are also significant issues.

Currently documented mound springs occur in five areas of the Kimberley Region (Figure 1). These are:

Dampier Peninsula	Bunda Bunda Springs and Lollywell Spring.
Eastern King Sound Coast	Big Springs.
Central Springs	Springs located on the upper Drysdale River and northern edge of the adjacent Fitzroy River catchment in the central Kimberley.
Kachana spring	On Kachana Station in the Pentecost catchment, south-west of Lake Argyle.
Victoria Bonaparte Coast	Numerous springs on the northern edge of Carlton Hill Station.

Those springs with a history of biological survey, at least for aquatic invertebrates and flora, are listed in Table 1. A few springs appear to have been sampled under different names or the same name applied to different springs. The table includes some alternative names used for the same springs for DBCA studies. Each spring has also been given a six-character code (KMS …) to be consistent with other wetland projects in DBCA.

In the following list springs are listed by their names on the TEC database with alternatives names.

Black01a (Black Spring). The site sampled by Bennelongia (2017) is about 0.5 km north-west of the site with the same name sampled by Sally Black, and these appear to be separate springs on aerial imagery.

MtElizabeth3a. This site on the TEC database has the same coordinates as the site called Kangaroo Spring by Bennelongia (2017). However, these coordinates are 2 km west of a site marked as Kangaroo Spring on the 1:250000 map. This site had not been sampled previously.

MtElizabeth4. This site on the TEC database has the same coordinates as Waterfall Yard Spring sampled by Bennelongia (2017). This site had not been sampled previously.

Drsydale 1a. This TEC has the same coordinates as Fern Spring sampled by Bennelongia (2017) and was referred to as Native Wells Drysdale by Sally Black who sampled it in 1999.

GibbR1. This is the Gibb River Spring sampled by Bennelongia (2017). This site had not been sampled previously.

VBMoundspring06. This has also been called Enigma Spring and was sampled by Sally Black in 2000 and by us in 2017. It was given the code KMS012 by us in the field

Moon Spring. Sally Black sampled a spring she called Moon Spring in 1999. Appendix 1 suggests this is in the Central Kimberley (Elizabeth Station), but the coordinates in Appendix 1 place the site off the coast of the Yampi Peninsula. There is no Moon Spring listed on the Australian Gazetteer of Place names and it is not mentioned in Shanahan and Coote (2008).

Attack Spring. A site sampled in 2017 was given the name Attack Spring but this is 1.5 km west of the spring of the same name shown on topographic maps and the coordinates for

Attack Spring on http://www.ga.gov.au/placename. The spring we sampled is much closer to the location of 'Hayleys Spring' on the topographic maps but this is not listed on http://www.ga.gov.au/placename. See also Potential spring 9 below.

Potential Spring 9. This site is 500m ESE of the location for Attack Spring provided on http://www.ga.gov.au/placename.

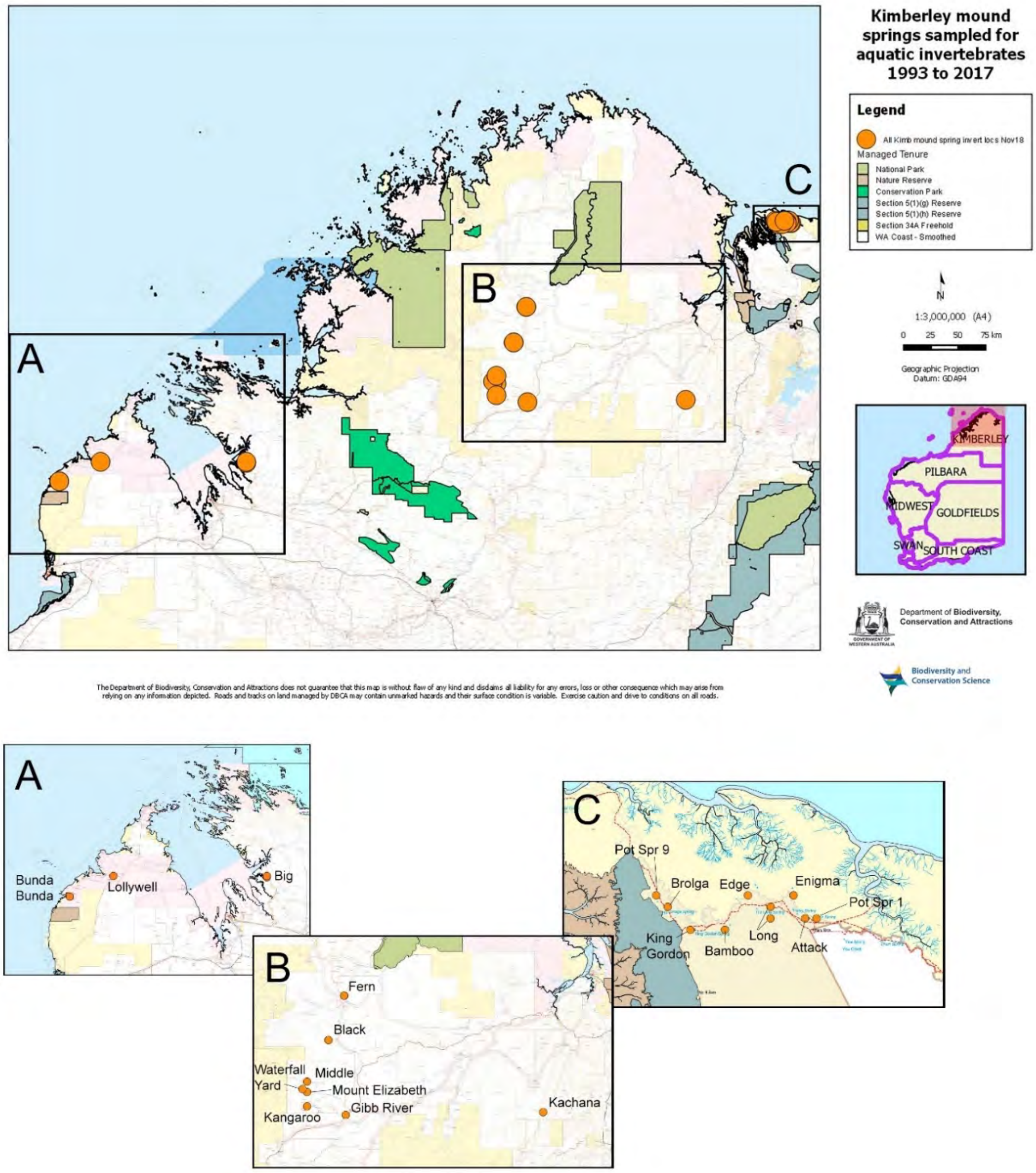

Figure 1. Map showing locations of the Kimberley mound springs included in Table 1.

Table 1. Listing of all sites and dates for Kimberley mound springs surveyed since 1987. Coordinates represent general locations of the springs rather than sampling points.

Spring area	TEC ocurrence	Site code	Name used in relevant project	Project	TEC or PEC	Date visited	Lat deg	Lat min	Lat sec	Long deg	Long min	Long sec
Central	-	KMS002?	Middle Spring	Bennelongia 2016	TEC	29 May 2016	16	17	57.84	126	8	3.48
Central	Black01a	KMS004	Black Spring	Sally Black/WATSCU 1999-2003	TEC	18 Sep 1999	15	38	2.40	126	23	16.80
Central	Black01a	KMS004	Black Spring	Bennelongia 2016	TEC	26 May 2016	15	38	1.32	126	23	23.28
Central	Drysdale1a	KMS005	Native Wells/Drsydale	Sally Black/WATSCU 1999-2003	TEC	19 Sep 1999	15	56	20.40	126	16	55.20
Central	Drysdale1a	KMS005	Fern Spring	Bennelongia 2016	TEC	27 May 2016	15	56	14.28	126	16	59.88
Central	GibbR1	KMS020	Gibb River Spring	Bennelongia 2016	TEC	28 May 2016	16	27	34.56	126	24	6.12
Central	MtElizabeth 3a	KMS023	Kangaroo Spring	Bennelongia 2016	TEC	30 May 2016	16	24	14.40	126	8	1.32
Central	MtElizabeth1a	KMS002	Mount Elizabeth	Sally Black/WATSCU 1999-2003	TEC	14 Sep 1999	16	18	4.00	126	7	59.00
Central	MtElizabeth4	KMS021	Waterfall Yard	Bennelongia 2016	TEC	29 May 2016	16	16	49.08	126	6	14.40
Dampier	Bunda01	KMS017	Bunda Bunda Spring	Sally Black/WATSCU 1999-2003	TEC	27 Jul 2001	17	9	8.00	122	19	22.90
Dampier	Bunda01	KMS017	Bunda Bunda Spring	DBCA 2017 sampling - this report	TEC	07 Aug 2017	17	9	8.00	122	19	22.90
Dampier	Lollywell01?	KMS006	Lollywell Spring	Sally Black/WATSCU 1999-2003	PEC	18 Jul 1999	16	58	33.00	122	40	37.20
Kachana	Kachana01	KMS009	Kachana Spring	Sally Black/WATSCU 1999-2003	PEC	06 Sep 2003	16	26	24.94	127	47	5.35
King Sound	-	KMS003	Moon Spring 4	Sally Black/WATSCU 1999-2003		14 Sep 1999						
King Sound	Big01	KMS018	Big Spring	Sally Black/WATSCU 1999-2003	TEC	07 Sep 1999	16	59	18.00	123	57	9.00
King Sound	Big01	KMS018	Big Spring	DBCA 2017 sampling - this report	TEC	09 Aug 2017	16	58	53.00	123	56	52.00
Victoria Bonaparte	-	KMS014	Potential spring 1	DBCA 2017 sampling - this report	PEC	04 Aug 2017	14	52	54.50	128	33	36.50
Victoria Bonaparte	-	KMS025	Edge Swamp (site VBMES)	Halse (1996)	-	18 Feb 1993	14	52	44.40	128	38	32.70
Victoria Bonaparte	Attack Spring	KMS011	Attack Spring (should be Hayley Spring?)	DBCA 2017 sampling - this report	PEC	01-02 Aug 2017	14	53	45.70	128	41	7.90
Victoria Bonaparte	Brolga Spring	KMS024	Brolga Springs (site VBMBS)	Halse 1996	PEC	17 Feb 1993	14	53	41.60	128	34	8.10
Victoria Bonaparte	King Gordon Spring	KMS015	King Gordon Spring	DBCA 2017 sampling - this report	PEC	04 Aug 2017	14	54	43.60	128	35	37.70
Victoria Bonaparte	KMS13a	KMS013	Long Spring/Rainforest Spring (site VBMRS)	Halse 1996	PEC	18 Feb 1993	14	53	28.60	128	39	33.30
Victoria Bonaparte	KMS13a	KMS013	Long Spring/Rainforest Spring	DBCA 2017 sampling - this report	PEC	03 Aug 2017	14	53	43.50	128	39	40.20
Victoria Bonaparte	KMS13a	KMS013	EK06	McKenzie et al. 1991	PEC	Jun 1987, March 1989	14	53	50.00	128	39	40.00
Victoria Bonaparte	VBMoundspring02	KMS016	Bamboo Spring	DBCA 2017 sampling - this report	PEC	04 Aug 2017	14	54	26.60	128	37	18.20
Victoria Bonaparte	VBMoundspring06	KMS012	Potential spring 6 = Enigma Spring	DBCA 2017 sampling - this report	PEC	02 Aug 2017	14	52	48.30	128	40	38.40
Victoria Bonaparte	VBMoundspring06	KMS012	Enigma Spring = Potential Spring 6	Sally Black/WATSCU 1999-2003	PEC	01 Oct 2000	14	52	48.00	128	40	33.60
Victoria Bonaparte	VBMoundspring09	KMS010	Potential spring 9 (?Attack Spring on 1:250000 topo)	DBCA 2017 sampling - this report	PEC	01 Aug 2017	14	54	10.10	128	42	14.00

2.2 Survey history of Kimberley mound springs

Several field campaigns conducted between 1987 and 2018 have contributed to documenting the biodiversity values of these springs.

1. Long Spring ("site "EK06") on Carlton Hill Station was included in a survey of rainforest patches of the Kimberley (McKenzie et al. 1991). Biological components surveyed included vegetation, earthworms, snails, and birds.
2. Halse et al. (1996) sampled three spring sites during a survey of invertebrates and waterbirds of Victoria-Bonaparte wetlands in 1993. These were Brolga Spring, a site on the northern side of Long Spring ("Rainforest Swamp") and a small isolated spring ('Edge Swamp") on the edge of the mudflats 1 km north of Long Spring.
3. Between 1999 and 2003 staff of Species and Communities Branch, led by Sally Black, sampled invertebrates at several sites across all five of the areas listed above. Invertebrate samples were processed by Stuart Halse and his team at DBCA (then CALM). Unfortunately, there are very few documents surviving from those 1999-2003 surveys (see Appendix 1) and we lack precise coordinates for some of the sampling sites. As part of this program Andrew Storey (then at UWA, now managing Wetland Research and management) sampled Kachina Spring.
4. In May 2016 DBCA staff were unavailable to undertake field work so Bennelongia Environmental Consultants were contracted to survey invertebrates, flora and birds from six springs in the central Kimberley (Bennelongia Environmental Consultants, 2017). Five of these appear to be the same as springs sampled by Sally Black for DBCA (then CALM).
5. In June 2016 DBCA (then DPAW) staff member Val English and consultant botanist Matt Barrett collected plot based floristic data at three springs (Waterfall Yard, Gap Spring, and Mud / Kangaroo Spring) on Mt. Elizabeth Station in the central Kimberley (see Barrett & English, 2017).
6. In 2017 DBCA staff (Ecosystem Science Program, Wetlands Section of Environmental Management Branch and Species and Communities Branch) visited seven springs on Carlton Hill Station, plus Bunda Bunda Spring and Big Spring in the West Kimberley. Biological components surveyed were aquatic invertebrates and flora and the springs had their boundaries mapped and vegetation described.
7. In May 2018 Nimalarragun Wetland north of Broome was sampled for aquatic invertebrates (see Pinder *et.al.* 2018) terrestrial fauna and flora. The wetland complex includes a central area containing mound spring vegetation. The flora component is reported here.

2.3 References

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Pinder A.M., Quinlan K., Shiel R. & Lewis L. (2018). *A survey of aquatic invertebrates of Nimalarragan wetland north of Broome.* Department of Biodiversity Conservation and Attractions, Western Australia.

3 Flora

Michael Lyons, Margaret Collins, Jill Pryde and Val English

3.1 Summary

Selected mound springs in the NE Kimberley (Carlton Hill station) north of Kununurra and in the SW Kimberley were sampled for flora during August 2017, with an additional spring north of Broome (Nimalarragan) sampled during March 2018. Quadrat based floristic data was collected at a total of nine mound springs with twelve 50 x 50 quadrats established. The limited sampling attempted to document the core mound spring habitat but did not capture the full array of plant communities associated with each spring. Some additional quadrat sampling was undertaken of the plant communities adjoining springs but was not comprehensive except at Nimalarragan wetland in 2018. Here the inner mound spring habitat and an array of *Melaleuca* dominated vegetation, and coastal flats were sampled. Within mound springs, a total of 79 taxa (species, subspecies and varieties) were recorded including six species listed as of conservation significance. Alien taxa were uncommon with only 3 species (*Phoenix dactylifera*, *Musa acuminata* and *Passiflora foetida*) recorded within core discharge areas at few springs.

The springs sampled during the current survey occurred in similar geomorphologic settings where hinterland groundwater discharges at the landward interface with coastal flats. The floristic composition of spring vegetation differed between the NE Kimberley and SW Kimberley with the Carlton Hill springs including richer assemblages of aquatic species, rainforest elements and a group of tropical taxa at their western distributional limit. Collectively these NE and SW Kimberley coastal springs are distinct from the mound springs of the central Kimberley documented in previous studies. The Walyarta springs are also a distinct, but relatively depauperate group, compositionally related to the coastal springs of the SW Kimberley with some floristic elements more typical of the Pilbara.

3.2 Methods

3.2.1 Field sampling

The current study sampled springs in the NE Kimberley on the northern edge of Carlton Hill Station (seven springs, nine quadrats), and in the SW Kimberley on the western side of Dampier Peninsular (two springs) and the eastern side of King Sound (one spring) (Appendix 2, Figure 2).

At springs surveyed during August 2017, the full vegetation zonation of each spring was not sampled. Vegetation and floristics were sampled with a single 50 x 50 m quadrat placed to sample the vegetation representative of areas of major groundwater discharge and organic soils. For springs with surface water expression (i.e. pools), quadrats captured the mosaic of small surface pools and vegetation on elevated organic mounds and flats. Areas of high groundwater discharge also featured floating root mats peripheral to pools. Several springs particularly in the Carlton Hill study area showed significant zonation, including peripheral moats with deeper water and open canopies relative to the often-closed *Melaleuca* canopies of the central area of the spring. These fringing moats were not sampled systematically during the current survey and were often dominated by *Typha domingensis* and *Phragmites karka*. Two examples of common fringing communities were sampled at Attack Spring (quadrat KMS 11B – fringing supra-tidal *Melaleuca alsophila* flat), and Long Spring (quadrat KMS13B – fringing Melaleuca woodland with *Typha domingensis*).

Sampling at Nimalarragun Wetland in March 2018 (quadrats NCP 1-8) was more comprehensive, including both mound spring vegetation (quadrats NCP 3 & 7) and the plant communities of the adjoining wetland and nearby supratidal coastal flats (quadrats NCP 1,2,4-6,8) (Appendix 2, Figure 2).

The locations of quadrats within mound springs broadly corresponded to the habitats sampled for aquatic invertebrates (when undertaken) by Pinder *et al* (chapter 3 of this report).

Quadrats were marked with steel pegs and labelled with a triangular aluminium tag stamped with quadrat code at the primary corner. Locations of the labelled corner were recorded using handheld GPS (Table 2, Appendix 2). Within each quadrat comprehensive plant collections including aquatics were made to generate quadrat species lists that were complete as possible. Charophytes were also collected although determinations were not completed prior to the preparation of this report.

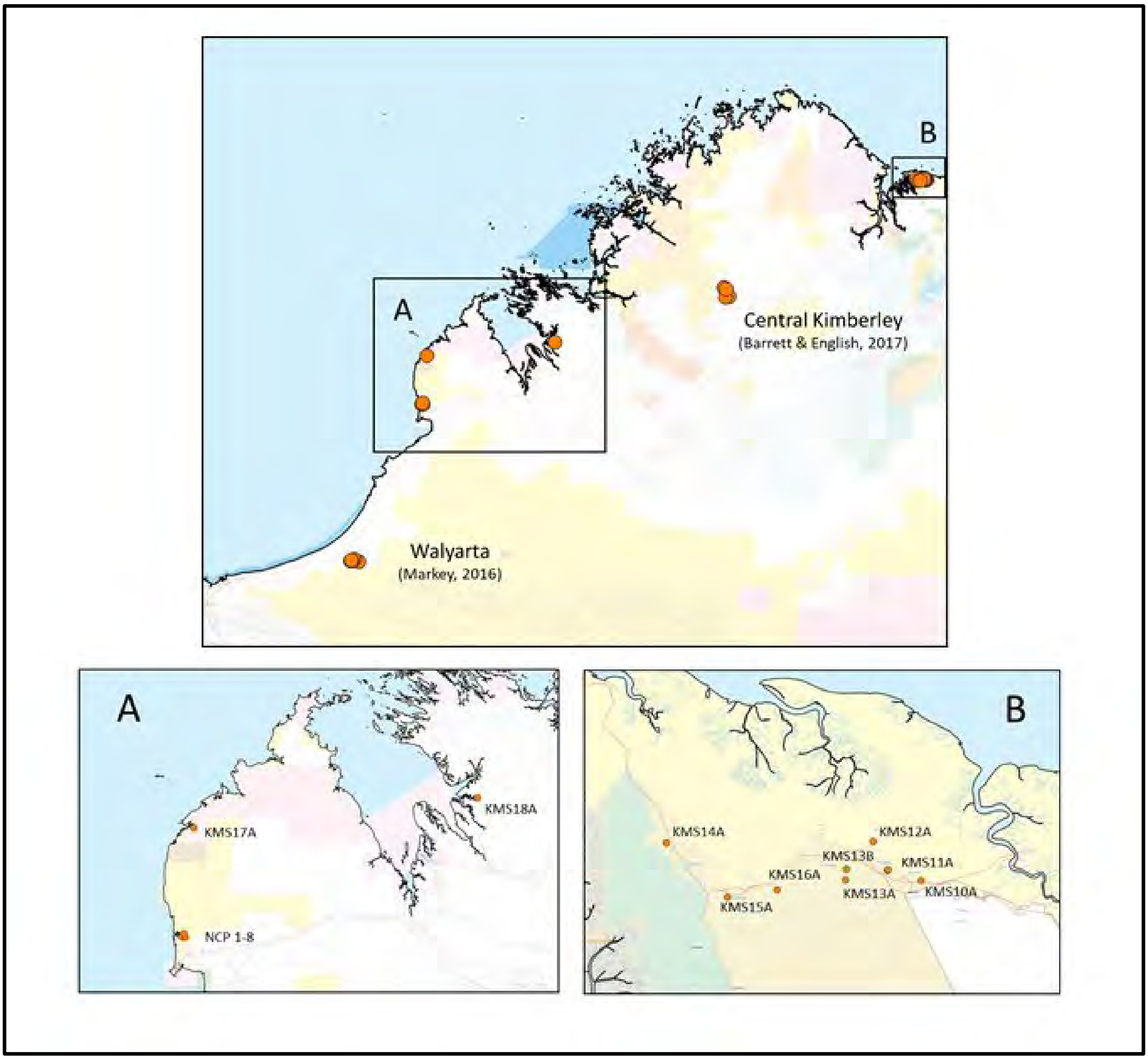

Figure 2. Map showing locations of Kimberley mound spring sampled for flora in 2017 & 2018 (see Table 2). Inset A, SW Kimberley and B; Carlton Hill NE Kimberley. Springs sampled in the central Kimberley (Barrett & English, 2017) and Walyarta (Markey, 2016) were used in the biogeographic analysis.

3.2.2 Specimen identification

Plant material was determined to the lowest possible taxonomic rank. Nomenclature, alien/native status and conservation codes follow the Western Australian Herbarium (2019) and Jones (2018) respectively. The broader distributional patterns of taxa were examined using the specimen data from *Florabase* (Western Australian Herbarium, 2019) the Atlas of Living Australia (2019) and GBIF.org (2019). Representative voucher collections have been lodged with the Western Australia Herbarium (PERTH) with collection labels annotated with *voucher for* ‘Kimberley Mound Springs Survey’ and ‘Nimalarragun Survey’ respectively.

Table 2. Flora quadrats sampled 2017-18.

Flora Quadrat Code	Quadrat Latitude (WGS 84)	Quadrat Longitude (WGS 84)	Survey region	Wetland name	Habitat	Vegetation description	sample date
NCP01	-17.773439	122.256313	Dampier Peninsular	Nimalarragun claypan	Supra-tidal Samphire	Low chenopod shrubland of *Tecticornia indica* subsp. *julacea* and *Tecticornia halocnemoides* subsp. *tenuis* over very open low grassland of *Eragrostis falcata*.	08-Mar-18
NCP02	-17.773916	122.253968	Dampier Peninsular	Nimalarragun claypan	Supra tidal flat	Sparse tussock grassland of *Panicum decompositum* over low closed heathland/low closed shrubland of *Tecticornia indica* subsp. *julacea, Vincetoxicum carnosum* and *Hibiscus panduriformis*, over low sparse sedgeland of *Fimbristylis cymosa* and *Fimbristylis rara*.	08-Mar-18
NCP03	-17.781576	122.263149	Dampier Peninsular	Nimalarragun claypan	Spring riparian margin	Open forest of *Melaleuca cajuputi* over sparse forbland of *Acrostichum speciosum*, over low sparse sedgeland of *Fimbristylis cymosa*, *Fimbristylis polytrichoides* and *Sporobolus mitchellii*.	08-Mar-18
NCP04	-17.768746	122.256750	Dampier Peninsular	Nimalarragun claypan	Upland spring margin	Low woodland of *Melaleuca alsophila* over low isolated trees of *Timonius timon* over low sedgeland of *Fimbristylis cymosa* and low grassland of *Sporobolus mitchellii*.	09-Mar-18
NCP05	-17.781169	122.259328	Dampier Peninsular	Nimalarragun claypan	Spring upper margin	Low woodland of *Melaleuca alsophila* over tall sparse shrubland of *Acacia colei* var. *colei* over low isolated shrubs of *Hibiscus panduriformis*, *Vincetoxicum carnosum* and *Gymnanthera oblonga* over isolated grasses and sedges of *Panicum mindanaense* and *Fimbristylis* sp.	09-Mar-18
NCP06	-17.780197	122.249588	Dampier Peninsular	Nimalarragun claypan	Supra-tidal flat	Isolated clumps of grasses of *Panicum decompositum* with emergent *Melaleuca alsophila* over low sparse chenopod shrubland of *Tecticornia indica* subsp. *julacea.*	10-Mar-18
NCP07	-17.781518	122.268472	Dampier Peninsular	Nimalarragun claypan	Mound spring	Open forest of *Melaleuca cajuputi* over woodland of *Timonius timon*, over fenland of *Acrostichum speciosum*	10-Mar-18
NCP08	-17.760147	122.262702	Dampier Peninsular	Nimalarragun claypan	Seasonally wet Pindan flat	Low open woodland of *Corymbia opaca*, *Melaleuca alsophila* and *Corymbia paractia* over low isolated clumps of *Bauhinia cunninghamii* and *Acacia colei* over closed grassland of *Chrysopogon pallidus* and *Sorghum sp*., over sparse forbland of *Buchnera* spp., *Calandrinia tepperiana* and mixed herbaceous Fabaceae.	11-Mar-18
KMS10A	-14.902755	128.704084	Carlton Hill North Kimberley	Unnamed spring	Mound spring	Tall open forest of *Melaleuca leucadendra* over vineland of Apocynaceae spp. and *Flagellaria indica*, over low open vines of *Flagellaria indica* over low open fernland of *Cyclosorus interruptus*.	01-Aug-17
KMS11A	-14.896823	128.684779	Carlton Hill North Kimberley	Attack Spring	Mound spring	Tall open forest of *Melaleuca leucadendra* over low isolated vines of *Flagellaria indica* over tall isolated rushes of *Typha domingensis* over isolated clumps of sedges and ferns of *Cyclosorus interruptus* and *Cyperus platystylis.*	01-Aug-17

Flora Quadrat Code	Quadrat Latitude (WGS 84)	Quadrat Longitude (WGS 84)	Survey region	Wetland name	Habitat	Vegetation description	sample date
KMS11B	-14.896382	128.685083	Carlton Hill North Kimberley	Attack Spring	Supra-tidal margin of mound spring	Low isolated trees of *Melaleuca alsophila* over tall shrubland of *Melaleuca alsophila* over low open sedgeland of Cyperaceae sp.	02-Aug-17
KMS12A	-14.880484	128.676647	Carlton Hill North Kimberley	Unnamed spring	Mound spring	Open forest of *Melaleuca leucadendra* over low woodland of *Timonius timon* and *Melochia* sp. over low sparse vineland of *Flagellaria indica* and sparse sedgeland of *Cyperus haspan* and *Cyperus javanicus* over low isolated clumps of ferns of *Cyclosorus interruptus*.	02-Aug-17
KMS13A	-14.902392	128.660870	Carlton Hill North Kimberley	Long Spring	Mound spring	Tall open forest of *Melaleuca leucadendra* over low open woodland of *Sterculia holtzei* and *Nauclea orientalis* over low isolated palms of *Pandanus spiralis* over tall isolated sedges of *Typha domingensis* over emergent ferns and isolated aquatics of *Cyclosorus interruptus* and *Nymphaea violacea.*	03-Aug-17
KMS13B	-14.896122	128.661569	Carlton Hill North Kimberley	Long Spring	Mound spring	Woodland of *Melaleuca leucadendra* over tall rushland of *Typha domingensis*.	03-Aug-17
KMS14A	-14.881075	128.559330	Carlton Hill North Kimberley	Unnamed spring	Mound spring	Low open forest of *Melaleuca alsophila*, *Lumnitzera racemosa* and *Thespesia populneoides* over low isolated clumps of sedges of *Fimbristylis* sp. and *Malvaceae* sp. indet., over low isolated tussock grassland of *Panicum seminudum* var. *seminudum.*	04-Aug-17
KMS15A	-14.912050	128.593906	Carlton Hill North Kimberley	King Gordon Spring	Mound spring	Tall woodland of *Melaleuca leucadendra* over low woodland of *Nauclea orientalis* and *Pandanus spiralis* over low isolated vines of *Flagellaria indica* over isolated clumps of forbs of *Adenostemma lavenia* var. *lanceolatum* over low sparse sedgeland of *Fimbristylis* sp. (cf. AA Mitchell 7822).	04-Aug-17
KMS16B	-14.907897	128.622158	Carlton Hill North Kimberley	Bamboo Spring	Brackish wetland on Supra-tidal flat	Tall open forest of *Melaleuca leucadendra* over low isolated vine clumps of *Flagellaria indica* over low isolated clumps of ferns of *Acrostichum aureum* and rushes *Typha domingensis* over isolated aquatics *Nymphaea violacea* and *Ceratophyllum demersum*.	04-Aug-17
KMS17A	-17.151627	122.318308	Dampier peninsular	Bunda Bunda Spring	Mound spring	Closed forest of *Carallia brachiata* and *Sesbania formosa* over isolated trees of *Sesbania formosa* over low isolated trees of *Timonius timon* and *Gymnanthera oblonga* over low fernland of *Cyclosorus interruptus*, *Acrostichum speciosum* and *Lygodium microphyllum*.	07-Aug-17
KMS18A	-16.978531	123.952859	Eastern King Sound	Big Spring	Mound spring	Tall woodland of *Melaleuca leucadendra* over woodland of *Terminalia microcarpa*, *Sesbania formosa* and *Nauclea orientalis* over tall sparse fernland of *Lygodium microphyllum* over *Pandanus spiralis* over tall sparse fernland of *Acrostichum speciosum*.	08-Aug-17

3.2.3 Data analysis –regional compositional patterns

To provide some perspective on the compositional patterns of the springs sampled during the current survey, floristic data sampling core mound spring vegetation from previous surveys was combined with the current survey data to generate a presence absence matrix for multivariate analysis. Additional data included six quadrats from the Walyarta/Mandora Marsh (Markey, 2016) and six quadrats from central Kimberley springs (Barrett & English, 2017). The combined data yielded a 22 quadrat x 167 species matrix. A quadrat association matrix was generated using the Bray -Curtis measure of dissimilarity and ordinated using the non-metric multidimensional scaling (nMDS) routines in PRIMER 7 (Clarke & Gorley, 2015).

3.3 Results

3.3.1 Flora diversity

Within the 12 quadrats sampling well developed mound spring vegetation a total of 79 taxa (species, subspecies and varieties) was recorded. An additional 130 taxa were recorded from the periphery of mound springs and in adjoining plant communities, with these records dominated by records from Nimalarragan wetland where sampling was more comprehensive (Appendices 2 and 3).

Mound spring species richness ranged from 5 to 26 taxa per 50x50 m quadrat (2500m^2). Average species richness was 14 taxa per quadrat. Species richness was related in part to habitat heterogeneity. At Big Spring (KMS18A – 26 taxa) the site included a mosaic of habitats, with pools, adjacent areas with a dense of canopy of *Melaleuca cajuputi* interspersed with small areas of sandy substrate that were not subject to inundation. Other species rich sites with limited areas of surface water and relatively open canopies were similarly relatively species rich (e.g. KMS12A – 22 taxa). Species poor sites were characterised by closed canopies of *Melaleuca* spp., and extensive areas of surface water (e g. Bamboo Spring, KMS16A).

3.3.2 Conservation significant taxa.

Despite having extensive distributions outside Western Australia, typically extending across tropical Northern Australia, five taxa recorded during the current surveys are deemed of conservation significance due to the limited number of records within Western Australia. Two additional taxa have limited distributions within the SW Kimberley. Priority flora categories follow Jones (2018).

- ***Acrostichum aureum* (Priority 1).** The Golden Mangrove fern has a pantropical distribution but with few known records in WA. Previously recorded from Big Spring in the SW Kimberley and the Charnley River area, *A. aureum* was recorded during the current survey at Bamboo Spring (KMS 16B). At Big Spring, *Acrostichum speciosum* occurred in the quadrat (KMS18A).

- ***Adenostemma lavenia var. lanceolatum* (Priority 3).** Scattered occurrences across northern Australia to southern Queensland. Also limited records from New Guinea and Borneo.

- ***Colocasia esculenta* var. *aquatilis* (Priority 3).** Taro (*Colocasia esculenta*) has a pan-tropical distribution facilitated by human introductions, with uncertainty as to the original natural range. Debate also exists regarding the recognition of varieties within *C. esculenta* (see Orchard, 2006). The putative wild type Taro recorded in Western Australia and the northern Australia is recognized as *C. esculenta* var. *aquatilis*. Current survey material conformed to *Colocasia esculenta var. aquatilis,* possessing stolons and a single diminutive (3-4 cm) tuber. The single occurrence was recorded from the margin of an unnamed spring at Carlton Hill (KMS10A) (Figure 3C)**.** In the Kimberley caution is required in determining the status of Taro collections in the vicinity of current and abandoned settlements where cultivated varieties can be encountered.

- ***Corymbia paractia* (Priority 1).** Recorded from Nimalarragun wetland at the upslope margin of the mound spring (adjacent to quadrat NCP 07). This taxon (Cable Beach Ghost Gum) is narrowly restricted to the Broome area, and occurs at the interface between Pindan and coastal sands.

- ***Utricularia aurea* (Priority 2).** Distributed from the Kimberley across tropical northern Australia, extending down the east coast to NSW with scattered inland occurrences. Widely distributed in Asia to India. Recorded at numerous quadrats in small pools within mound springs (Figure 4B). Often recorded growing with *Ceratophyllum demersum.*

- ***Sterculia holtzei* (Priority 1).** The only known WA occurrence was confirmed during the current survey at Long Spring (KMS 13) Carlton Hill Station. S. holtzei is widespread in the Northern Territory associated with permanently wet substrates including springs and rainforest patches (Figure 3A).

- ***Stylidium pindanicum* (Priority 3).** With a discrete distribution in the west Kimberley centred on Dampier Peninsular with an outlier near Fitzroy Crossing, *S. pindanicum* was recorded during the current survey in seasonally wet pindan flats on the northern periphery of Nimalarragun wetland within its current range.

3.3.3 Notable taxa.

Cyperus platystylis: Only known from two previous collections from WA (in the vicinity of Kununurra), *C. platystylis* was recorded during the current survey at two springs in the Carlton Hill area (KMS11A, KMS13A). It is at its western distributional limit near Kununurra and Carlton Hill but widespread in floodplains in the NT extending down the east coast to northern NSW, with scattered occurrences in New Guinea and SE Asia. The seed of this species is distinctive, being covered in pale spongy tissue which provides flotation, aiding dispersal in wetland habitats.

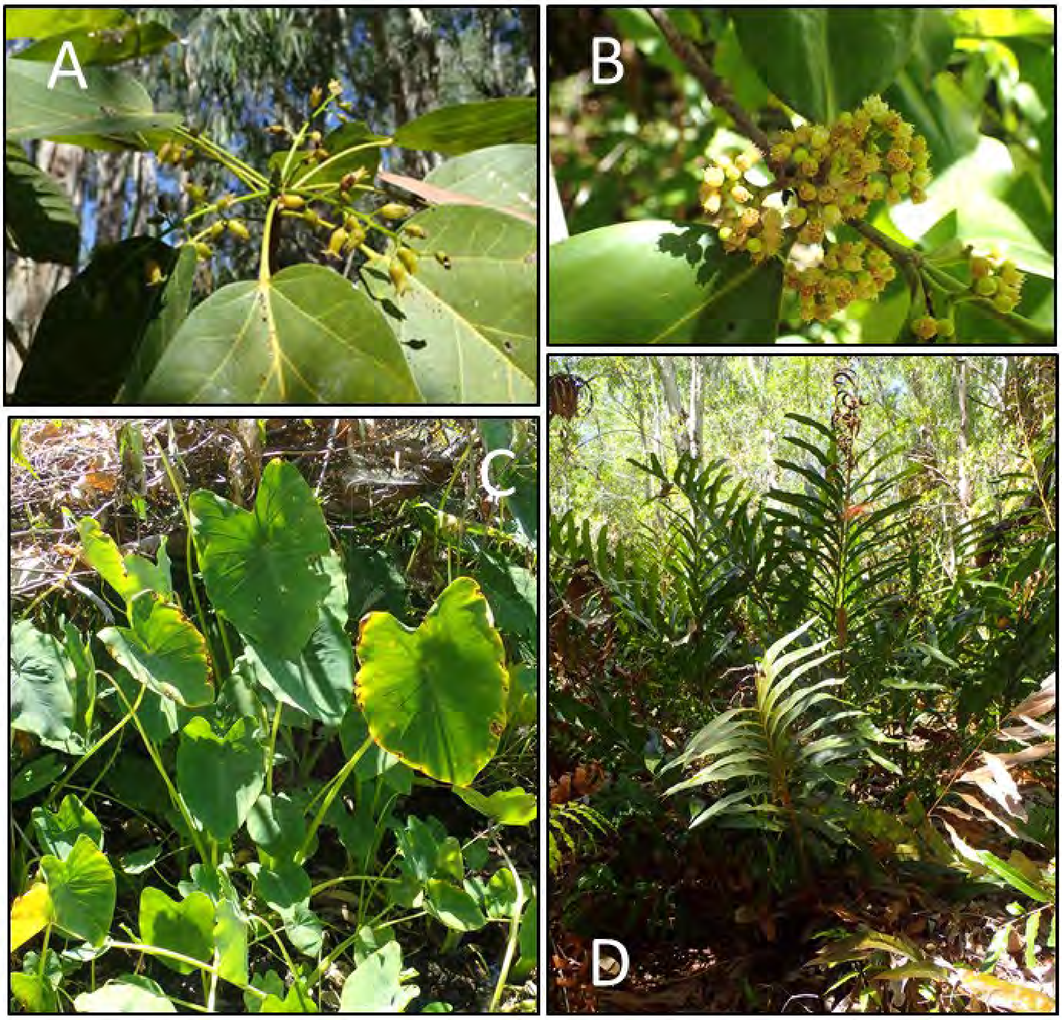

Figure 3. Taxa recorded from Kimberley mound springs. A, Sterculia holtzei (P3); B, Carallia bracteata; C, Colocasia esculenta var. aquatilis; D, Acrostichum speciosum.

- ***Fimbristylis sp*.:** (M.N. Lyons & J. Pryde KMS 039 –PERTH sheet 09163018): *Fimbristylis* material collected from King Gordon Spring (KMS 15A) and the vicinity of Haley's Spring (KMS 12A) could not be placed in current formal and phrase name taxa based on material in PERTH. The material matches earlier collections by A.A. Mitchell from King Gordon Swamp in August 2004 (A.A. Mitchell 7822, PERTH sheet 07833660). Further taxonomic work is required to determine if the collections justify the application of an informal (phrase) name. Additional collections include PERTH - M.N. Lyons & J. Pryde KMS 040 - KMS 042.

- ***Mucuna gigantea* subsp*. gigantea:*** This taxon is at its western distributional limit in the NE Kimberley with 3 previous records including the Berkeley River area (NW of Wyndham) and the Carlton Hill springs (Brolga Spring). Recorded during the current survey at KMS 10A and KMS 12 A. The distribution of *M. gigantea* subsp*. gigantea* extends across northern Australia down the east coast to northern NSW, with scattered occurrence in SE Asia and the SW pacific islands. Occurrences are mostly near coastal.

- ***Nauclea orientalis***: The western most Kimberley population was recorded at Big Spring (KMS 18A) in the West Kimberley (a record from Broome townsite is likely a planting), with additional survey records from Long Spring north Kimberley (Carlton Hill). *Nauclea orientalis* occurs across northern Australia, New Guinea and SE Asia, preferring alluvial soils often associated with rivers across most of its range. Suitable habitat in the Kimberley is tightly restricted to springs, creek lines and rivers, where dry season drought is ameliorated.

- ***Phyla nodiflora***: A cosmopolitan species with a core native distribution in Central America and southern North America, with a broader pan-tropical distribution regarded as variously comprising naturalised and native occurrences. In Western Australia, *P. nodiflora* is regarded as naturalised. Recent phylogenetic studies and the existence of collections pre-dating European settlement confirm that *P. nodiflora* is represented in Australia by both native lineages and post-European introductions (Gross *et al*., 2017). Populations in northern Australia, including those recorded in the current survey, occurring distant from human settlement /disturbance should be regarded as native. *P. nodiflora* was recorded during the current survey on the margin of Nimalarragan and the damp periphery of several springs in the Carlton Hill study area.

3.3.4 Alien taxa

Ten species of non-native weeds were recorded from the survey (see comments above regarding *Phyla nodiflora*) (Appendix 2). Most alien taxa (8 taxa) were recorded from the margins of Nimalarragan wetland noting that sampling intensity was greater for this area than elsewhere. Alien taxa were essentially absent from all the core mound spring vegetation sampled during the survey will the exception of *Phoenix dactylifera* at Big Spring (King Sound) and the widespread *Passiflora foetida* var*. hispida.* Weed records of note are detailed below.

- ***Azadirachta indica* (Neem).** Scattered individuals were recorded on the southern margins of both the mound spring and broader wetland area of Nimalarragun wetland. All individuals observed were juvenile and not reproductive in 2018. Neem has escaped from cultivation and is a Declared Pest Plant in Western Australia. It is highly invasive and competitive particularly in riparian habitats. Without ongoing control measures, it represents a major threat to the values of Nimalarragun.

- ***Musa acuminata* (Banana).** A single population of banana was recorded on the eastern side of Bunda Bunda spring on the Dampier Peninsular. The population was well known to the traditional owners suggesting it was not of recent origin. It is likely to persist but is limited to a discrete patch of not more than 25m^2 without apparent spread.

- ***Parkinsonia aculeata* (Parkinsonia).** *Parkinsonia* is a Declared Pest Plant in Western Australia. Populations were recorded at scattered localities in terrestrial habitats at Carlton Hill and a subsidiary wetland in the vicinity of Nimalarragun wetland, Dampier Peninsula.

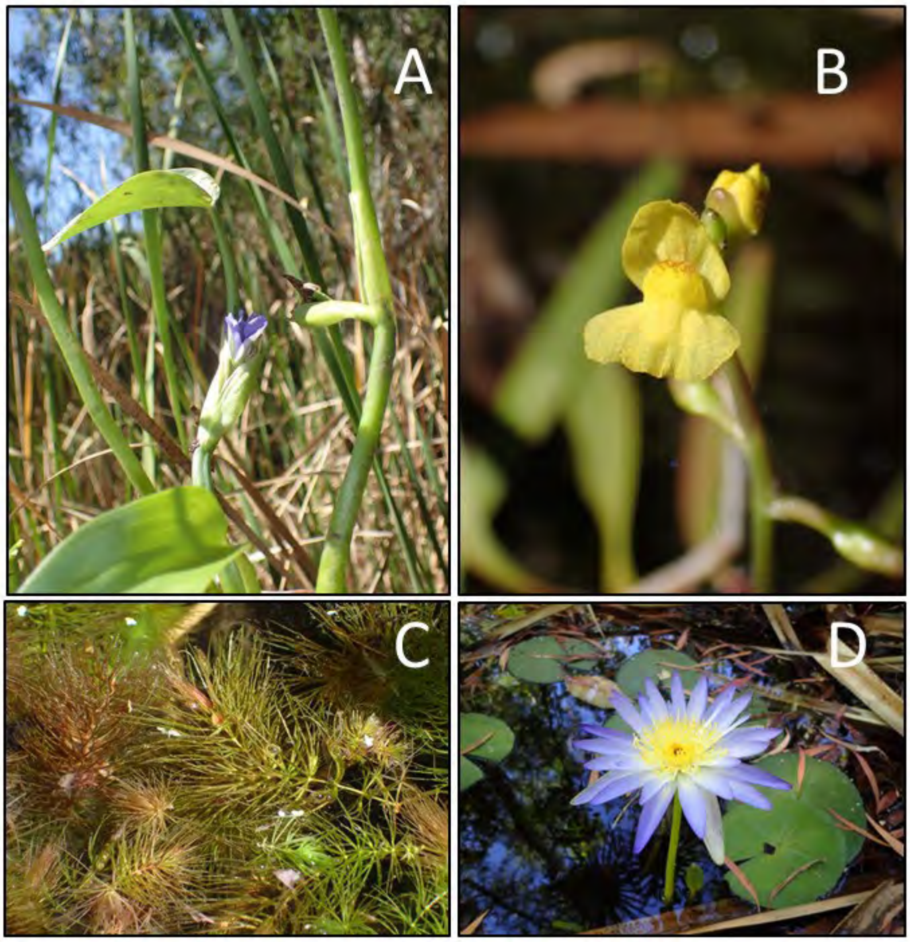

Figure 4. Selected aquatic taxa from mound springs. The springs in the Carlton Hill area showed a diverse array of aquatics habitats. A, Hygrophila angustifolia; B, Utricularia aurea; C, Ceratophyllum demersum; D, Nymphaea violacea.

- ***Phoenix dactylifera* (Date Palm).** A population of approximately 10 plants was recorded at Big Spring adjacent to the floristic sampling quadrat (KMS18A). Individuals appeared to be suckers, and tall fertile plants were not observed. The entire spring area has not been comprehensively searched for additional infestations.

- ***Tamarindus indica* (Tamarind).** A single juvenile plant was recorded from the periphery of Nimalarragan wetland having likely spread from nearby mature plants at Waterbank Station. Tamarind is naturalised around Broome and numerous locations across the Kimberley (and northern Australia).

3.3.5 Composition and regional patterning.

Figure 5 shows a two-dimensional ordination of mound spring floristic data (quadrat) from the current survey combined with data from the central Kimberley (Barrett & English, 2016) and from Walyarta (Markey, 2016). The clustering by region and separation in ordination space reflects differences in mound spring floristic composition between the four areas (see Figure 2).

Examination of a sorted two-way table (derived from clustering of species and quadrats) revealed central Kimberley springs were characterised by a large group of herbaceous taxa including *Eriocaulon inapertum, Fimbristylis tetragona, F. cephalophora, Germainia truncatiglume, Stylidium dunlopianum* and *Xyris complanata.* These springs support sedgeland and grasslands on organic soils distinct from the typically closed canopy Melaleuca dominated springs in the coastal Kimberley. Overstorey elements in the central Kimberley included *Banksia dentata*.

Springs in the north Kimberley (Carlton Hill) included a greater number of taxa typical of the high rainfall Kimberley including both wetland and rainforest elements of the flora (e.g. *Flagellaria indica, Carallia bracteata, Nauclea orientalis*) and occurrences of taxa that reach their distributional limit in the NE Kimberley (e.g. *Sterculia holtzei, Glochidion sumatranum, Mucuna gigantea*). Many of the springs in this region featured high groundwater discharge rates and included extensive aquatic habitats both within the central mound spring and periphery, as moats and outflow channels. These pools supported several aquatic taxa not recorded from springs elsewhere in the survey including *Ceratophyllum demersum, Hygrophila angustifolia, Nymphaea violacea* and *Utricularia aurea* (Figure 4).

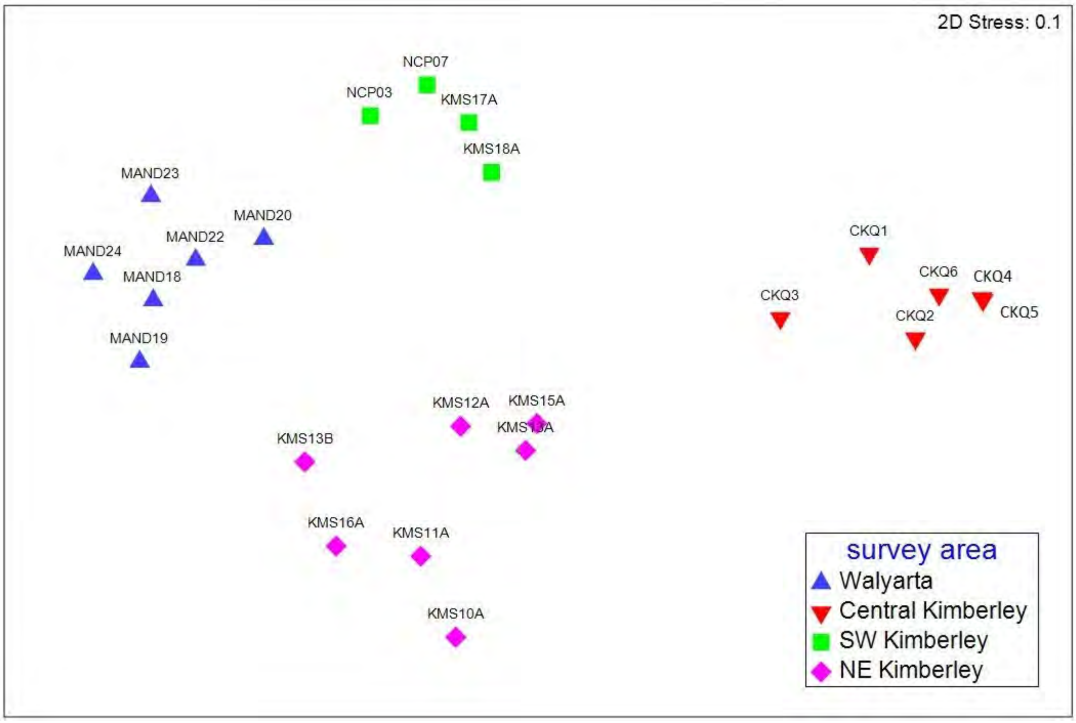

Figure 5. Two-dimensional nMDS ordination of organic mound spring floristic quadrats

Springs in the SW Kimberley on Dampier Peninsula and the eastern side of King Sound lacked the richness in aquatic species and many of the high rainfall rainforest elements recorded in the North Kimberley, although they do include SW outliers of some rainforest taxa including *Carallia brachiata, Nauclea orientalis,* and *Timonius timon.*

The high rainfall floristic elements of the Kimberley were absent from the mound springs at Walyarta (Mandora Marsh) (Markey, 2016). These springs included several riparian taxa more typical of the adjacent Pilbara IBRA region including *Acacia ampliceps*. Many springs were dominated by *Melaleuca alsophila Sesbania formosa,* and *Acrostichum speciosum.* Taxa recorded in the understorey and spring fringes e.g. *Eragrostis falcata,* and *Schoenoplectus subulatus* were not recorded at the sampled Kimberley Springs.

The flora of Kimberley organic mound springs is assembled from a pool of tropical taxa that occupy a range of mesic habitats across northern Australia. These elements include both wetland taxa, including aquatics, and components of the rainforest and vine-thicket flora. The proportion of these different floristic components at an individual spring is related to the hydrological and edaphic conditions at a given spring. Within the Kimberley further sampling and analysis is required to refine the very broad patterns revealed in the current study. Sampling of a broader array of springs types would enable the mound springs to be placed in context with other spring types within the Kimberley.

Damage by stock seeking shelter and water is a significant issue for Kimberley mound springs. In the current survey this was most evident at Carlton Hill sites in the north Kimberley (Figure 6).

Figure 6. Disturbance of springs by cattle at Carlton Hill. A, cattle entering core spring area seeking water cause compaction along trails; B, extensive pugging in areas that would be shallow pools.

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4 Aquatic Invertebrates

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4.1 Summary

In August 2017, 26 samples of aquatic invertebrates were collected from nine springs, doubling previous sampling effort and increasing the number of sampled springs from 15 to 21. At least 496 aquatic invertebrate taxa have now been collected, nearly half of which were first collected in 2017. The species pool at individual springs and across the springs would further increase with additional sampling. The springs were large compared to the sampling effort and sampling effort has been uneven across the range of springs, so it is difficult to compare invertebrate communities of the springs, but at present there is little evidence of subgroups of springs based on their aquatic invertebrate faunas, excepting that springs in the central Kimberley remain relatively poorly sampled. An analysis of the distribution and habitat associations of the invertebrates is hampered by low survey effort at other types of wetlands in the Kimberley and the paucity of readily accessible aquatic invertebrate data for northern Australia. Most individual species are likely to be widely distributed in the region, but a small suite of species is likely to be rare and possibly restricted to these springs or other groundwater discharge areas in the Kimberley. There was some overlap with composition of similar organic mound springs at Walyarta, but with many species known only from the Kimberley or Walyarta springs. The composition of the aquatic invertebrate fauna of the Kimberley Mound Springs is unlikely to be replicated in other wetlands within the region or elsewhere in Western Australia.

4.2 Background

4.2.1 Aquatic invertebrate survey in the Kimberley Region

There are very few published studies of aquatic invertebrates of the Kimberley Region. Williams (1979) undertook some early survey work and summarised the little that was known from the Kimberley region at that time, listing only 70 species from across the Kimberley and north-eastern Northern Territory. There has been some taxonomic work undertaken which has added to knowledge of particular groups (e.g. Watts, 1987; Andersen & Weir, 1998; Dean, 2001) and some taxonomically targeted surveys (Merrifield, Slack-Smith & Wilson).

The lower Ord River has been extensively surveyed as part of water resource allocation planning for the Ord Irrigation Area (Storey, 2002; Storey & Lynas, 2007; Buckle *et al.*, 2010). The Buckle et al. (2010) study only considered macroinvertebrates at family level but Storey (2002) listed 171 species of macroinvertebrate (microinvertebrates were not considered). Five Kimberley wetlands were included in baseline surveys (including of aquatic invertebrates) as part of a federally funded “Inland Aquatic Integrity Resource Condition Monitoring (IAI RCM) project”: These being Lake Eda (Department of Environment and Conservation, 2009e), Airfield Swamp (Department of Environment and Conservation, 2009a), Parrys Lagoon (Department of Environment and Conservation, 2009c), a swamp at the Ngallagunda Community (Department of Environment and Conservation, 2009d) and Le Lievre Swamp (Department of Environment and Conservation, 2009b). The Ngallagunda wetland is close to Gibb River Spring sampled by Bennelongia (2017). That project only processed the benthic samples (so excluded microinvertebrate groups) but plankton samples were collected and could be processed to improve knowledge of those wetlands. A total of 168 macroinvertebrate species were collected from these wetlands.

A substantial program of river condition assessment using aquatic invertebrates was undertaken across Australia, including 65 sites in the Kimberley, but this involved only family level identifications (Kay *et al.*, 1999; Smith *et al.*, 1999), except for a few insects (especially caddisflies and mayflies) used for taxonomic research.

The Kimberley region is the western extent of the wet/dry tropics so studies of aquatic invertebrates of the Northern Territory and northern Queensland are likely to be useful when assessing distribution and conservation status of species found in the Kimberley, although few studies have published species lists from these areas either. Humphrey et al. (2008) list 581 species for the whole 'northern tropical rivers' (Kimberley to north Queensland), of which they found 292 records from tropical Western Australia. However, the authors also encountered the issue of inaccessible aquatic invertebrate data and the list excludes microinvertebrates (ostracods, copepods, cladocerans, rotifers and protists), mites, and most hemiptera and diptera, which together comprise a large proportion of wetland aquatic invertebrate communities. It also focussed on rivers rather than lentic wetlands. Finlayson et al. (2006), collating information from Humphreys and Dostine (1994), Corbett (1996) and unpublished data, noted the presence of 600 species of macroinvertebrate and 300 species of rotifers, copepods and cladocera in the Kakadu region, but did not provide a species list. I It is likely that several thousand aquatic invertebrates inhabit northern Australian wetlands.

4.2.2 Invertebrate sampling history of Kimberley mound springs

There have been 44 aquatic invertebrate samples collected across four 'projects' between 1993 and 2018. These are listed in Table 1 and described below:

1. Halse et al. (1996) sampled three spring sites during a survey of invertebrates and waterbirds of Victoria-Bonaparte wetlands in 1993. These were a site on the northern side of Long Spring ("Rainforest Swamp"), a small isolated spring ('Edge Swamp") on the edge of the mudflats 1 km north of Long Spring and Brolga Spring. Invertebrates were sampled by taking two 50 metre long sweep net samples; using 53 µm and 110 µm mesh nets.

2. Between 1999 and 2003 staff of Species and Communities Branch, led by Sally Black, sampled invertebrates at several sites across all five of the areas listed above. Unfortunately, there are very few documents surviving from those 1999-2003 surveys (see Appendix 1) and we lack precise coordinates for some of the sampling sites. Most of these collections involved use of a 250 µm mesh net so was biased towards macroinvertebrates. The 2003 collection from Kachana Spring was collected by Andrew

Storey and included a coarse net sample and a fine net plankton sample (A. Storey per. comm.) so more planktonic microinvertebrates were collected.

3. In May 2016 DBCA staff were unavailable to undertake field work so Bennelongia Environmental Consultants were contracted to sample invertebrates from six springs in the central Kimberley (Bennelongia Environmental Consultants, 2017). Five of these appear to be the same as springs sampled by Sally Black for DBCA (then CALM). One core sample was collected from each spring, with 10 buckets of pumped interstitial water put through a 53µm mesh net. If collected, protozoans and rotifers were not identified from these samples and cladocerans were only partially identified.

4. In 2017 DBCA staff (Ecosystem Science Program, Wetlands Section of Environmental Management Branch and Species and Communities Branch) sampled seven springs on Carlton Hill Station, plus Bunda Bunda Spring and Big Spring in the West Kimberley. Twenty six samples were collected (methods below).

Springs sampled for invertebrates between 1993 and 2017 (and flora in 2017) have been given six character codes with the prefix KMS in Table 1, for consistency with other DBCA wetland projects, but in this chapter springs are mostly referred to by the names used in the original projects. It appears that 17 individual springs have been sampled.

4.3 2017 Methods

Seven springs along the Victoria-Bonaparte coast were sampled between 1st and 4th of August 2017, with Bunda Bunda Spring on the Dampier Peninsula sampled on 7th August and Big Spring on the 9th August (Table 3). Figure 7 has a selection of photos illustrating the field work.

4.3.1 Physico-chemical sampling

At each spring pH, temperature and conductivity were measured where surface water was most substantial – generally where the benthic and plankton samples were collected. From the same location three water samples were collected. An unfiltered 150 ml sample was collected for analysis of total nitrogen and phosphorus. Another water sample (mostly 400-500 ml) was filtered through a glass fibre filter paper for chlorophyll (with the filter paper frozen for later analysis of chlorophyll) and the filtrate further filtered (through a 0.45 um filter paper) and the filtrate then also frozen for analysis of total filterable phosphorus and nitrogen. Ideally the nutrient and chlorophyll samples would have been frozen but we had difficulty keeping these frozen for the first few days after collection. A third unfiltered water sample was used for analysis of nephelometric turbidity.

The depth at which the benthic invertebrate sample was collected was recorded and this usually equated to the maximum depth of the water body, which were mostly small ponds or inundated herb/sedge/grasslands under a tree canopy.

Table 3. Locations and details of sampling sites and invertebrate samples taken in 2017.

Site code	Site name	Sampling location	Latitude	Longitude	Benthic sample	Plankton sample	Interstitial sample
KMS0018	Big Spring	Saturated fine organic substrate on eastern side of main spring body	16˚58'45"S	123˚57'12"E			pumped 80L of interstitial water from a core sample
		Mangrove swamp on western side of main spring body with patchy but dense beds of Characeae and submerged vascular plants	16˚58'53"S	123˚56'52"E	10 m sweep	10 litres of scooped water	
KMS017	Bunda Bunda Spring	Shallow inundated area with sparse patchy mangrove fern beneath canopy of xxxxxxx providing dappled shade	17˚09'08.0"S	122˚19'22.9"E	10 m sweep	10 litres of scooped water	pumped 80L of interstitial water from a core sample
KMS010	Potential spring 9	A densely vegetated spring with little surface water. Sampled in a shallow area of dense sedges and *Typha* under canopy of xxxxxx.	14˚54'09.5"S	128˚42'15.0"E		10 lites of scooped water	pumped 80L of interstitial water from a core sample
KMS011	Attack Spring	through 40 metres of *Phragmites* - in clearing of dead *Typha* under *Melaleuca* and ground consisting of thick floating root mat. Corer penetrated through root mat, releasing water	14˚53'48.60"S	128˚41'4.80"E			pumped 80L of interstitial water (core 1)
		As above but about 20 metres to the west, still under *Melaleuca* canopy. Core taken in area of soft peaty material and plankton sample from a small boggy area with dense Characeae.	14˚53'48.2"S	128˚41'04.1"E		Plankton #2: 10 lites of scooped water from a small pond	pumped 80L of interstitial water (core 2)
		Within dense stand of *Phragmites* along the eastern edge of the spring	14˚53'47.6"S	128˚41'06.9"E	10 m sweep	Plankton #1: 10 lites of scooped water	
KMS012	Potential spring 6 = Enigma Spring	Core sample taken from saturated peat in relatively open area with dense mangrove fern.	14˚52'51.3"S	128˚40'36.5"E			pumped 64L of interstitial water from a core sample
		Plankton sample taken from small muddy puddles in clayey substrate	14˚52'48.3"S	128˚40'38.4"E		4 metres of sweeping while trying to catch fish	
KMS013	Long Spring/Rainforest Spring	Dense stand of *Typha* in north-eastern part of the spring near site EK06 in McKenzie (1991)	14˚53'43.5"S	128˚39'40.2"E		10 lites of scooped water	
		A site in from the mid-eastern edge of Long Spring, consisting of a substantial pool with sparse Typha and pond lilly leaves and very dense leaf litter under canopy of Melaleuca and with palms on the fringes.	14˚54'07.6"S	128˚39'39.7"E	10 m sweep	10 lites of scooped water	pumped 80L of interstitial water
KMS014	Potential spring 1	Large body of open water with no vegetated cover other than a patch of Typha, fringed by xxxxxxxx.	14˚52'54.5"S	128˚33'36.5"E	10 m sweep	10 m sweep	
KMS015	King Gordon Spring	A relatively deep pool under *Melaleuca* and palms with dense covering of leaf litter and some pond lilly leaves.	14˚54'43.6"S	128˚35'37.7"E	10 m sweep	10 lites of scooped water	pumped 80L of interstitial water
KMS016	Bamboo Spring	An extensive area of open water with very little canopy cover on the western side of the spring, with very dense submerged macrophytes.	14˚54'26.6"S	128˚37'18.2"E	10 m sweep	10 lites of scooped water	

Figure 7. Field photos. A, Adam Turnbull at Brolga Spring; B, Long Spring (southern site); C, King Gordon Spring; D, Big Spring (western side); E, sampling interstitial fauna at Enigma Spring , showing bund created around top of bore hole to minimize surface water inflows; F, pond at Bamboo Spring; G, corer in sediment before being withdrawn; H, Collecting a benthic sample at Attack Spring.

4.3.2 Invertebrate sampling

Three types of invertebrate sample were collected, depending on the amount of water present, with the aim of collecting at least one of each sample type at each spring.

Where possible, two samples of surface water aquatic invertebrates (a benthic and a plankton sample) were taken at each of the nine spring sites (both samples covering the same area of the wetland). Most previous DBCA wetland biodiversity survey work has involved sweeping both nets through the water for a total of 50 metres. However, that volume of muddy material would have been too much to sort through in the lab and would have caused excessive disturbance in the small pool areas present in the springs. Instead we have tried to use a reduced but standard method on these springs. Most plankton (water column) samples were collected by scooping up water in 900ml jugs and passing this through a 50 um mesh net, to give a total of 10 litres of collected water. The exception was 4 metres worth of sweep netting using the same mesh size net at Potential Spring 6 and 10 m sweeping at Potential spring 1. All benthic samples were collected by sweeping a 250 um mesh net through the water column and stirring up the substrate and benthic debris for a distance of 10 metres. Coarse inorganic sediment and coarse organic matter were removed from the benthic sample prior to sample preservation by washing debris and elutriating in buckets before passing the water back through the net. Samples were then preserved in 100% ethanol in the field and returned to the laboratory for processing.

Interstitial fauna was sampled at seven of the springs (Table 3), using methods similar to those employed by Bennelongia Environmental Consultants (2017). At each of these sites, an auger was used to extract an approximately 0.5 metre deep core of 8 cm diameter and the resultant hole was allowed to fill with water (which normally happened quickly). Using a manual bilge pump, eighty litres of water (8 x 10L buckets) was pumped out through a 110 µm mesh net and the contents of the net placed into 2 litre pots and preserved with 100% ethanol. The exception was Potential Spring 6 where only 64 litres were collected due to the volume of material remaining in the net. Interstitial samples were normally taken in areas of saturated peat without significant surface water. Where ingress of surface water was a problem it was impeded by creating a bund around the top of the hole. There was no need to excavate an area around the top of the holes in order to ensure the hole filled, as was undertaken by Bennelongia (2017). These samples were taken back to the laboratory for processing and identification of microfauna.

4.3.3 Processing and identification of invertebrate samples

Samples were washed with tap water and sieved through either 250 µm, 90 µm and 50 µm sieve sizes (for the core and plankton samples) or 2 mm, 500 µm and 250 µm sieve sizes (benthic samples). Each sieve fraction was examined separately (except for the 50 µm fractions from plankton and core samples), and representatives of each discernible species removed and preserved in 100% ethanol.

All protozoans, cladocerans and rotifers were identified by Russell Shiel, from specimens picked from samples in Perth and from residues of the plankton samples sent to him in Adelaide (including the 50 µm fractions not sifted in the DBCA lab). For residues, the first 200 animals encountered were identified and then the rest of the residue was scanned for additional species.

All taxa were identified to the lowest taxonomic level possible using keys and voucher specimens and undescribed taxa were assigned morphospecies names based on previous survey work by DBCA. All harpacticoids and some ostracod genera and selected specimens from the orders Hemiptera, Coleoptera and Trichoptera were also sent to relevant experts (see acknowledgements).

4.3.4 Specimen curation

All specimens removed from the samples (other than rotifers and cladocerans) have been retained and are stored in ethanol in glass vials with Western Australian Museum standard labels within larger ethanol filled jars. A subset of specimens representing most species was set aside for deposition in the Western Australian Museum. Rotifers and cladocerans have been retained by R. Shiel for the time being. A few other specimens have been retained by taxonomists.

4.3.5 Data management and analysis

All data analysis was performed using R (R Development Core Team, 2018), with code and input csv data files available at https://github.com/AdrianMP62/KMS7analyses. R packages used were vegan 2.5-2 (Oksanen *et al.*, 2018), Ternary 1.0.2 (Smith, 2018), iNEXT (Hsieh, Ma & Chao, 2018) and eulerr (Larsson *et al.*, 2018). Raw invertebrate data is provided below as Appendix 4.

4.4 Results

4.4.1 Water chemistry

Environmental data is provided in Table 4. Ionic composition data (and derivatives such as sum of major ions) and lab measured conductivity were analysed but are not presented as the ionic composition was significantly unbalanced and therefore results unreliable. This is likely to due to precipitation of ions prior to analysis.

Irrespective of measurement problems all springs were fresh, with field measured conductivity mostly ranging from 116.4 to 1071 µS/cm, except for Potential Spring 1 which was saline at 30000 µS/cm.

Nutrient concentrations were not excessive. Total nitrogen concentrations varied from 0.15 to 2.8 mg/L. When analysed this included very little nitrate, nitrite and ammonia but this could have been caused by difficulties keeping these samples frozen, so these forms of nitrogen could have been assimilated by microbial growth. Total phosphorus concentrations ranged from 0.026 to 0.3 mg/L, with soluble reactive phosphorus being below detectable limits in most samples, although the same caveat re difficulties of freezing of water applies. Chlorophyll concentrations were also low (chlorophyll plus phaeophytin mostly <0.02 mg/L).

The two exceptions were samples taken in areas with less canopy cover where greater photosynthesis was possible (Potential Spring 1 and the west side of Bunda Bunda Spring).

Five of the eight sites had slightly acidic water (pH 5.73 to 6.75). Other sites were about neutral to slightly alkaline (up to 8.34).

A fuller assessment of water chemistry at these springs to determine if they differ in character would involve replicate samples taken at various points at each spring, particularly at points representing different hydrological situations (isolated ponds, flowing vents, moats etc).

Table 4. Environmental data for springs sampled in 2017.

	Chemistry Centre analysis code	Detectable limit	Unit	KMS008 Big Springs 09 Aug 2017 collected at plankton/benthic sample site	KMS017 Bunda Bunda Spring 07 Aug 2017 collected at plankton/benthic sample site	KMS10 Potential Spring 9 01 Aug 2017 collected at plankton sample site	KMS11 Attack Spring 01 Aug 2017 collected at plankton #1 sample site	KMS11 Attack Spring 02 Aug 2017 collected at plankton #2 sample site	KMS12 Potential Spring 6 02 Aug 2017 collected at plankton sample site	KMS13 Long Spring 03 Aug 2017 collected at plankton #1 sample site	KMS13 Long Spring 03 Aug 2017 plankton #2/benthic sample site	KMS14 Potential Spring 1 04 Aug 2017 collected at plankton/benthic sample site	KMS15 King George Spring 04 Aug 2017 collected at plankton/benthic sample site	KMS16 Bamboo Spring 04 Aug 2017 collected at plankton/benthic sample site
LABORATORY MEASUREMENTS														
Cholorophyll	WL177	0.001	mg/L	0.001	0.035	0.004	0.005		0.008	0.002		0.043	0.008	0.011
Phaeophytin	WL177	0.001	mg/L	0.001	0.011	<0.001	0.006		0.006	0.002		0.009	<0.001	0.003
Nitrogen - ammonia	iAMMN1WFIA	0.01	mg/L	<0.01	0.01	0.06	0.02		<0.01	<0.01		<0.01	<0.01	0.01
Nitrogen - nitrite	iNTRN1WFIA	0.01	mg/L	<0.01	<0.01	<0.01	0.01		<0.01	<0.01		<0.01	<0.01	0.01
Nitrogen - nitrate	iNTAN1WCALC	0.01	mg/L	0.01	0.01	0.06	0.02		<0.01	<0.01		<0.01	0.01	<0.01
Nitrogen total	iNP1WTFIA	0.01	mg/L	0.31	0.71	1.8	1.9		1	1.6		2.8	0.15	2
Phosphorus soluble reactive	iP1WTFIA	0.01	mg/L	0.01	0.02	0.08	<0.01		<0.01	<0.01		<0.01	<0.01	<0.01
Phosphorus total	iPP1WTFIA	0.005	mg/L	0.042	0.057	0.15	0.18		0.19	0.094		0.3	0.026	0.16
Turbidity	iTURB1WCZZ	0.5	NTU	24	26	21	8.7		11	6.2		31	12	8.9
FIELD MEASUREMENTS														
Depth			cm	20	5	10		10	10	10	40	10	70	40
Salinity			mg/L	354	97.9	148	215	235	51.9	583	497	19300	466	334
Conductivity			µS/cm	354	191.7	286	407	444	116.4	1071	909	30000	855	629
pH (field)				8.18	6.3	5.8	6.2	5.73	7.01	6.4	6.59	7.89	6.75	8.34
Temperature			°C	24	25	22	26.7	23.7	27.7	25	22.9	19		21.3
Emergent macrophyte cover			%	5	20	90	0	50	20	100	5	1	2	5
Submerged macrophyte cover			%	40	0	0	0	50	0	0	0	0	2	90
benthic cover of coarse organic matter (leaves and sticks)			%	25	15	80	-	-	0	0	100	0	100	20
Other habitat						few logs				dense typha roots	dense roots and a few logs		few logs	few logs

4.4.2 Aquatic habitats

Most of the surface water expressions sampled for invertebrates were shallow (≤ 10 cm). The southern-most sampling location at Long Spring was 40 cm deep, as was the area on the edge of Bamboo Spring. The deepest site was the area sampled at King Gordon Spring (70 cm).

Most of the areas of open water large enough to sample had some emergent macrophytes (generally sedges), ranging from very sparse (estimated ≤ 5% of the areas sampled for invertebrates) to very dense (≥ 90%, e.g. at Potential Spring 9 and at one of the Long Spring sites – a dense area of *Typha*). Most sampling locations were under moderately dense canopies of trees, but the pools had dappled light. Few sites had substantial growth of submerged macrophytes, exceptions being the more open sites on the western sides of Big Spring and Bamboo Spring, plus the area on the northern edge of Attack Spring where the benthic sample was collected. Potential Spring 1 and the site on the edge of Bamboo Spring lacked significant canopy cover.

Sediment samples were not taken for quantitative analysis, but most substrates appeared to be fine-grained and dense clay-like organic matter under coarse organic litter covering 15-100% of the surface. At Attack spring the plankton sample was collected from a muddy area near the edge of the spring and potential Spring 1 also had inorganic fine muddy sediments. At Long Spring we noted the composition of the depth profile, with coarser organic sediments (recognisable plant debris) in the first 10 cm, then more consolidated fine-grained organic sediments for 50 cm, then a layer of sand at 60 cm.

4.4.3 Aquatic invertebrates

4.4.3.1 Regional mound spring aquatic invertebrate diversity

Appendix 4 contains the raw invertebrate identification data from all samples collected from 1993 to 2017. A total of 355 aquatic invertebrate taxa were collected in 2017, including 217 that had not previously been collected from Kimberley mound springs.

Up to 2003, 232 species had been collected from the springs. The six interstitial samples collected in 2016 by Bennelongia (2017) increased the total to 279 and the 2017 sampling (26 samples) increased the total to 496 (Figure 8). This an approximately linear trend of increasing total richness with increasing number of samples. These figures are derived after taxonomic alignment between the various datasets, including lumping to genus or tribe where inconsistent morphospecies names were used across the various projects (e.g. some pentaneurine and *Tanytarsus* chironomids, *Cypretta* and *Ilyodromus* ostracods and *Hydraena* beetles). The actual number of species collected by these samples, if these inconsistencies were resolved, would almost certainly be over 530. This is quite high diversity when it is considered that 200 samples from 100 sites collected only just over 1000 species during the Pilbara Biological Survey (Pinder *et al.*, 2010) and Pinder et al. (2004) collected about the same from 200 Wheatbelt wetlands.

Statistical estimators of species pool size were applied to this data, but without rotifers and protozoans since these were not collected for the 1999-2001 samples. This reduced dataset contained 412 species and the iNEXT routine of Hsieh et al. (2016) estimated that the total species pool (excluding rotifers and protozoans) would be around 580 species and that collection of the additional species would require an additional 100 or so samples. With the current rotifer and protozoan count of 84 species it is clear the total species pool utilising these springs could be well over 700. This estimate should be used with caution as the method assumes equal sampling types and effort, and this was certainly not the case, but further sampling would definitely increase the diversity of aquatic invertebrates known from these wetlands.

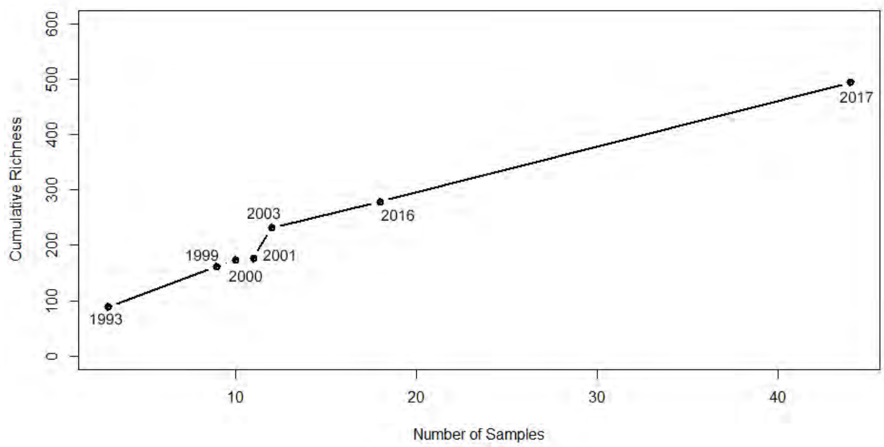

Figure 8. Cumulative number of species collected from Kimberley mound springs between 1999 and 2017, by year. Points are cumulative richness values in 1993, 1999, 2000, 2001, 2003, 2016 and 2017.

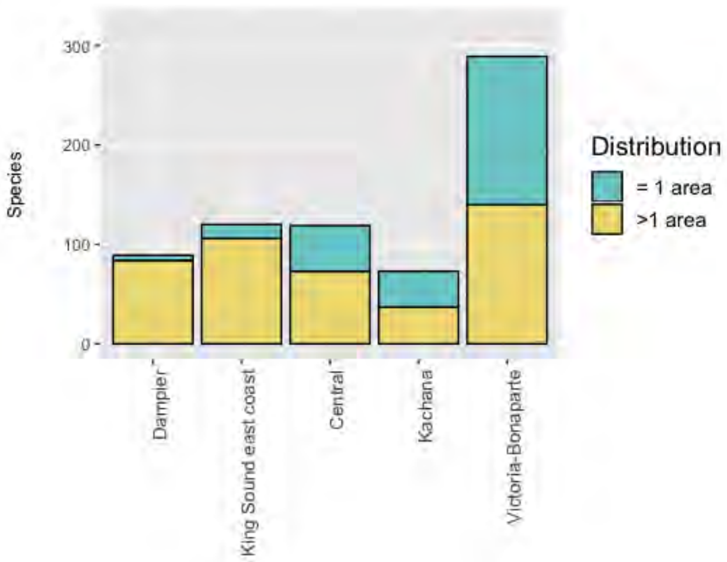

Figure 9. Number of species (other than rotifers and protozoans) recorded from springs in each of the five areas mentioned above showing the proportion (top segments) of those currently known only from that area. Numbers above the columns are the number of springs/number of samples.

Figure 9 shows the total number of species now known from mound springs in each of the five areas listed above (excluding rotifers and protozoans because they were not collected in most samples collected in 1999-2001). The number of species known from each area will reflect sampling effort and is not the focus of the graph. More important is the proportion of an area's species richness currently known only from that area (within the Kimberley Mound Spring dataset). This suggests that the central springs, Kachana Spring and the Victoria-Bonaparte springs have a greater proportion of their aquatic invertebrate fauna not present in other spring areas. By contrast, springs on the Dampier Peninsula (Bunda Bunda Spring and Lollywell Spring) and the east coast of King Sound (Big Spring and Lollywell Spring) have very few species not represented in springs from one or more of the other areas. Unlike richness, the proportion of species known only from one spring is not closely related to sampling effort, with the single sample from Kachana Spring having the same proportion of 'restricted' species (55%) as the 24 samples from the Victoria-Bonaparte coast (54%) and much higher than the 5 samples from each of the Dampier Peninsula and King Sound coast springs. In total 63% of species have been collected from just one of the five areas, but two-thirds of those were only collected in one sample, so the apparently higher 'uniqueness' of the invertebrate faunas of some spring complexes should be viewed as indicative at this stage. Many of the species known only from one area of springs do have broad distributions and occur in other wetland habitats.

4.4.3.2 Sample richness and composition

Richness of aquatic invertebrates within each of the 43 samples from Kimberley mound springs collected since 1993 is shown in Figure 10. In these plots, samples are grouped according to sample type across the different projects: benthic samples only (1999-2001), plankton and benthic samples combined (1993, 2003 and 2017), core samples only (2016 and 2017) and plankton or benthic samples separately (2017 only).

Sampling between 1999 and 2001. The lack of rotifers and protozoans and the relatively low diversity of microcrustacea (Figure 10A) reflects that fact that only a coarse mesh net (250 μm mesh) was used. Composition was therefore strongly insect dominated. Richness per sample varied between 12 and 43 which is low in comparison with later samples.

Samples with plankton and benthic samples combined (1993, 2003 and 2017*).* Figure 10B shows richness of invertebrate where both a plankton and a benthic sample has been collected at each spring, with data from the two samples combined. This was the case for three Victoria-Bonaparte springs sampled in 1993 by Halse et al (1996), Kachana Spring sampled by Andrew Storey[1] in 2003 and 7 springs sampled by us in 2017 (Big and Bunda Bunda Springs in the West Kimberley and five on the Victoria-Bonaparte coast), with Long Spring sampled in both 1993 and 2017. In 1993 and 2003 specimens from the benthic and plankton samples were combined before identification so there is no possibility of using the two samples separately. There are differences in sampling effort between 1993 (50 metre sweep net samples for plankton and benthic), 2003 (unknown sampling effort) and 2017 (10 metre benthic sweep and 10 litre plankton sample). The 1993 samples from Brolga Spring, Edge Swamp and Long Spring had lower richness (41 to 60 species) than most other samples in Figure 10B, despite the greater sampling effort, and few invertebrates other than insects,

[1] Andrew Storey, Wetland Research and Management

microcrustacea and rotifers. The 2003 sample from Kachana Spring was much richer and more diverse, with more water mites than other samples included on this graph but relatively few microcrustacea. Of the sites sampled in 2017 Potential Spring 1 had lowest richness (41 species) and was more insect and microcrustacean dominated, reflecting its higher salinity (30 mS/cm, 19.8 ppt). However, its fauna is almost entirely a subset of the freshwater fauna found in the other springs, with the exception of four rotifers, *Hexarthra brandorfi*, *Brachionus plicatilis* s.l., *Brachionus angularis* and *Cephalodella forficula* and an unidentified hemipteran '*Micronecta* KMS1'. *Brachionus plicatilis* s.l. is a complex of mostly saline water taxa. Presence of these rotifers probably reflects the more open water habitat as much as the higher salinity of this site. The other six springs sampled in 2017 were freshwater springs and had richness varying from 77 to 131 species. For these combined samples the richest springs were Attack Spring and Long Spring.

Figure 11 provides richness of combined benthic+plankton samples from the Walyarta springs (Quinlan *et al.*, 2016) and from the Kimberley region, with the additional species collected where an interstitial sample was also taken. This figure excludes Potential Spring 1 as it has a very different character. The Kimberley samples all had higher richness than the richest of the Walyarta samples, despite the latter involving significantly more sampling effort. This figure also shows the relatively small proportion of the fauna collected only in interstitial samples, although there may be a unique element to the interstitial fauna.

2017 plankton and benthic samples. Figure 10C shows richness by taxonomic group of invertebrates from benthic samples and plankton samples separately, for springs sampled in 2017. Benthic samples were richer which is not surprising considering the greater sample size (10 metres of sweep netting) compared to the plankton samples (10 litres of scooped water). Benthic samples were dominated by insects, mites and microcrustacea (especially ostracods). Plankton samples had relatively fewer insects, a similar number of microcrustacea (but more cladocerans) and had more rotifers and protozoans. The saline Potential Spring 1 had lowest richness in both sample types. Excluding this site, benthic and plankton samples had an average richness of 79 and 62 species respectively. Two plankton samples were taken at two of the springs. At Attack Spring a plankton sample was taken from a pool on the mound (P2) and another was taken from the *Phragmites* filled moat on the north-east side of the spring (P1). These two samples were the highest richness plankton samples with 81 and 89 species and included more microcrustacea than any other samples collected from Kimberley mound springs (23 and 26 species). Two plankton samples were also collected from Long Spring; one from the dense stand of inundated *Typha* on its north-eastern extent (P1) and another from a pool on the drier mound to the south (P2). These had similar total richness (71 and 65 species respectively) but the sample from the mound had fewer microcrustacea and more rotifers.

Interstitial samples collected in 2016 and 2017. Figure 10D shows invertebrate richness within samples of interstitial water pumped from holes in the peat (see Methods) in 2016 (central Kimberley) and 2017 (Victoria-Bonaparte coast). These samples contained relatively few species compared to surface water samples and were much more dominated by insects and microcrustacea. Interstitial samples collected in the central Kimberley in 2016 (Bennelongia Environmental Consultants, 2017) had higher total richness, mainly due to the higher number of insects. Bennelongia (2017) noted that they sometimes had to excavate an area around the ~50 cm deep core hole[2] to allow faster seepage of interstitial water and noted that this may have resulted in surface water species being collected. In 2017 there rarely a problem with the cored holes not filling fast enough and tops of the holes were not expanded. We also tried to take these interstitial samples in areas away from surface water but still in areas of saturated peat to minimise collection of invertebrates from surface water. This may explain the smaller number of insects collected in 2017, even though some taxa collected in 2017 interstitial samples were clearly surface water species (e.g. the damselfly *Ceriagrion aeruginsum* and *Glyptophysa* snails). The Victoria-Bonaparte interstitial samples had numerous species of annelids whereas none were present in the Bennelongia 2016 samples. In 2017, the richest interstitial samples were from Potential Spring 9 (48 species) and from Long Spring (41 species).

Together, the eight interstitial samples collected in 2017, contained 103 species, somewhat less than the 124 species from the six samples collected in 2016 in central Kimberley springs. Of the species collected in 2017, almost a third (31 species) were collected much more frequently (≥3x) in interstitial samples than in plankton or benthic samples and most of those (26) were collected only from interstitial samples. Most of those 31 species are sediment dwellers such as fly larvae, harpacticoid copepods and aquatic earthworms (oligochaetes) which would be expected to occur within the peat substrate. Others were mostly unidentified mites (which may have been living within the peat substrate matrix) plus five species of adult insects (beetles and hemipterans) which were likely to have been washed in from surface water.

In Figure 11 it can be seen that the interstitial samples did not significantly increase richness already revealed by collection of plankton and benthic samples.

Figure 12 shows occurrence of species across the three sampling methods (benthic, plankton and core samples) employed in 2017, using a reduced dataset so that there are five samples of each type collected from the same five springs (289 species). Only 13% of species were collected by all three sample types, showing the value of using multiple methods. Some caution is required here, however, since 71% of the 174 species that were collected only in one sample type were collected only once within this restricted dataset, so logically could not have occurred in more than one sample type.

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[2] M. Curran, Benelongia Pty Ltd

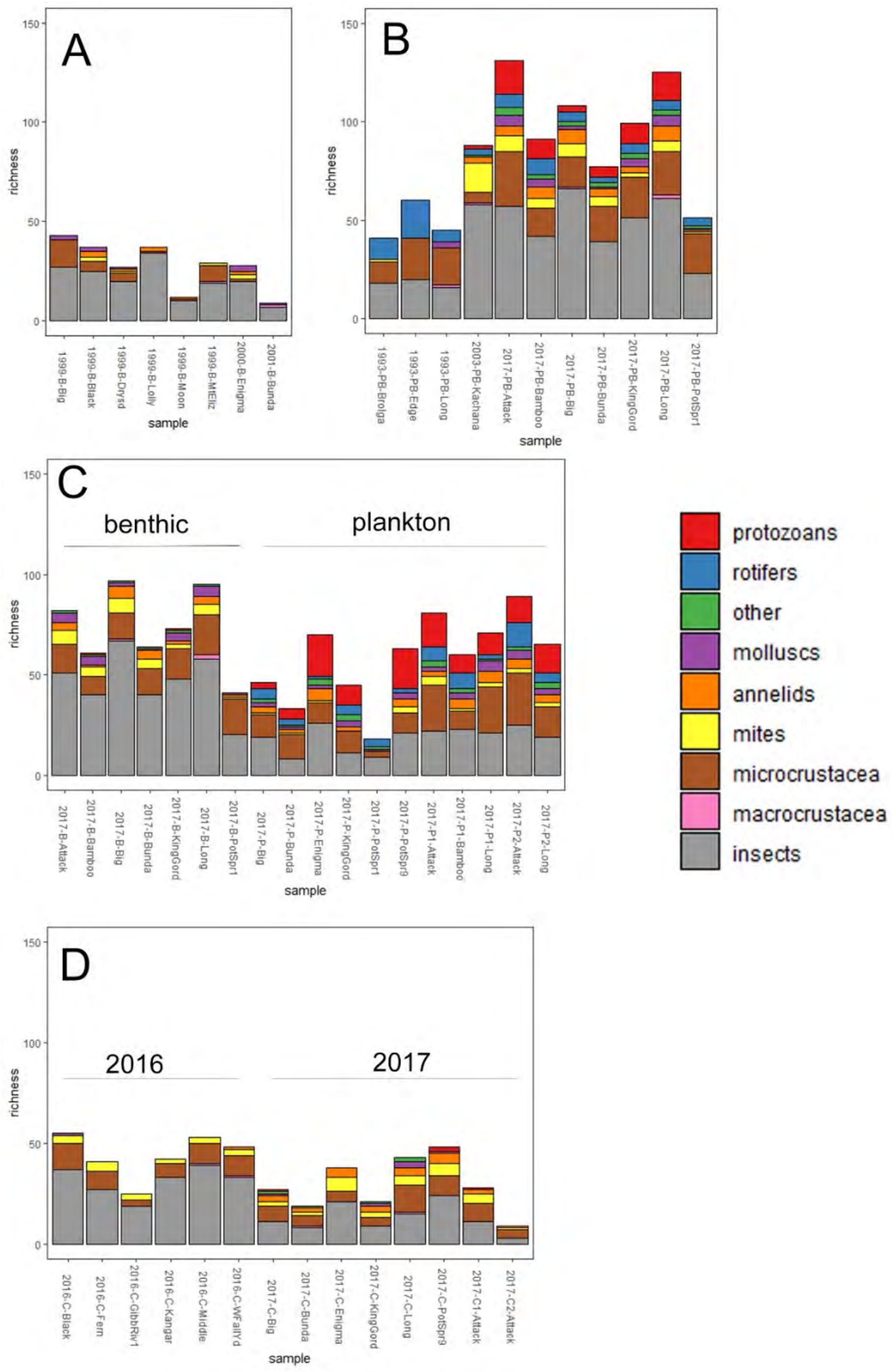

Figure 10. Richness of major taxonomic groups in subsets of similar sample type. A, Samples collected between 1993 and 2001; B, Combined plankton+benthic samples collected in 1993, 2003 and 2017; C, Individual plankton or benthic samples collected in 2017; D, Interstitial samples collected in 2016 (central Kimberley) and 2017 (Victoria-Bonaparte coast).

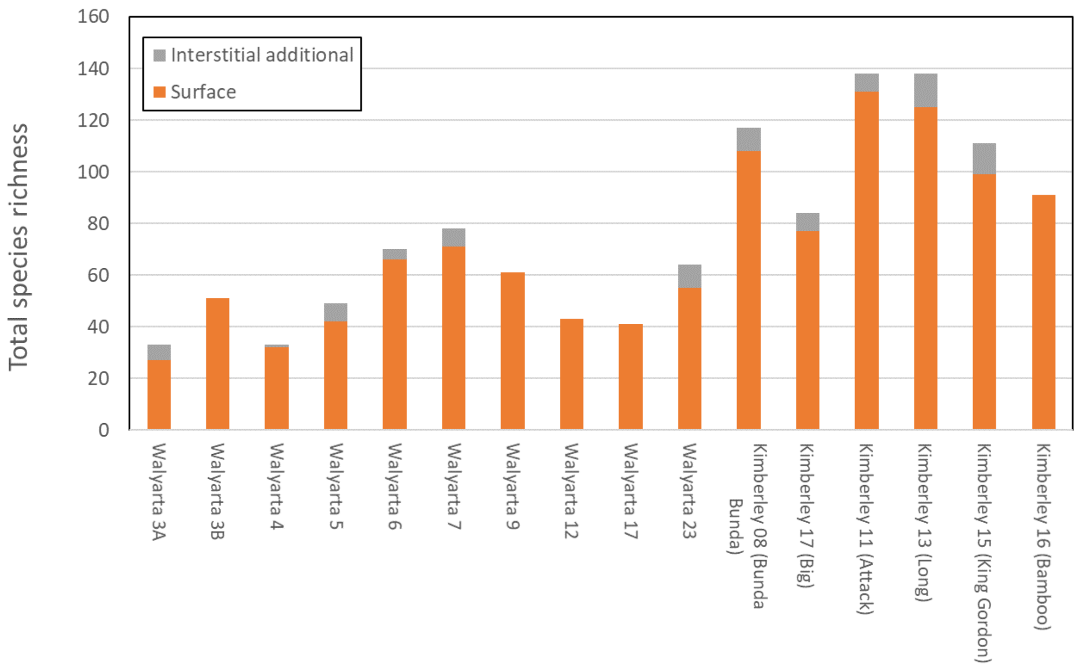

Figure 11. Richness of invertebrate samples collected from Walyarta springs in 2015 (10 left columns) and Kimberley springs sampled in 2017 (six right columns). Orange segments are richness of a combined plankton and benthic sample and grey segments are the additional species collected from an interstitial sample. Absence of grey segments means no interstitial sample was collected for that site.

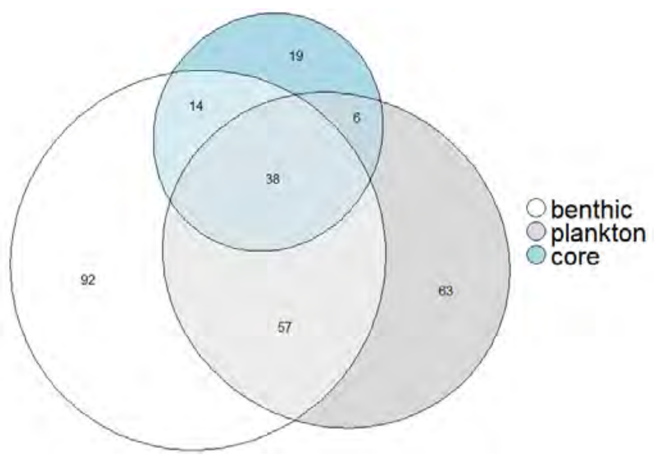

Figure 12. Relative proportions of the total species pool collected by the three sample types, each type represented by one sample collected at each of the same five springs. Ellipses are proportional to the total number of species collected by the five samples of each type. Drawn using the eulerr 5.0.0 R package by Larsson et al. (2018), with a test to confirm that the size of each segment is exactly proportional to the number of species it represents.

The differences between sample types are reflected in an ordination of the individual 2017 samples (Figure 13) produced using the vegan package for R (Oksanen *et al.*, 2018) with Bray-Curtis dissimilarity. In this plot, the plankton and benthic samples from the saline site 14 (Potential Spring 1) are placed well to the left of the remaining freshwater sites. This reflects the presence in this site of some halophilic species such as the rotifers *Brachionus plicatilis* and salt tolerant species such as the beetle *Berosus australiae*. Otherwise the spread of samples is different within each sample type, so the different sample types are not surrogates of one another. There is no indication from this analysis that the two western springs (Big Spring and Bunda Bunda Spring – sites 1 and 8) have different invertebrate communities to those of the Victoria-Bonaparte springs. Removing species with only one occurrence in the dataset produced an almost identical ordination plot. In both cases the ordination plot had a stress of 0.17 indicating that the analysis could not produce a plot that well represented differences in community composition between all samples. However, a 3D ordination (Figure 14) produced very similar separation of sample types with acceptable stress (0.12).

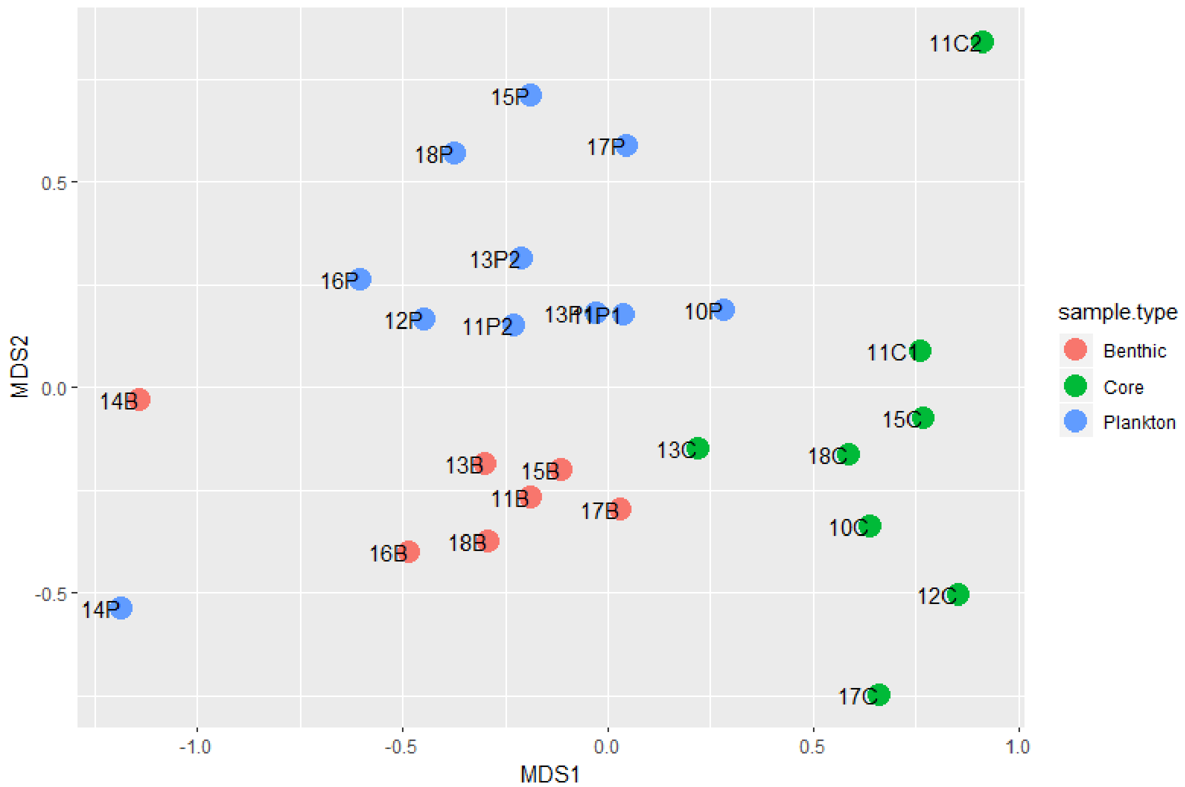

Figure 13. A two-dimensional ordination of invertebrates in all 2017 samples. Site numbers refer to the 'KMS' site codes in Tables 1 and 2. Stress = 0.17.

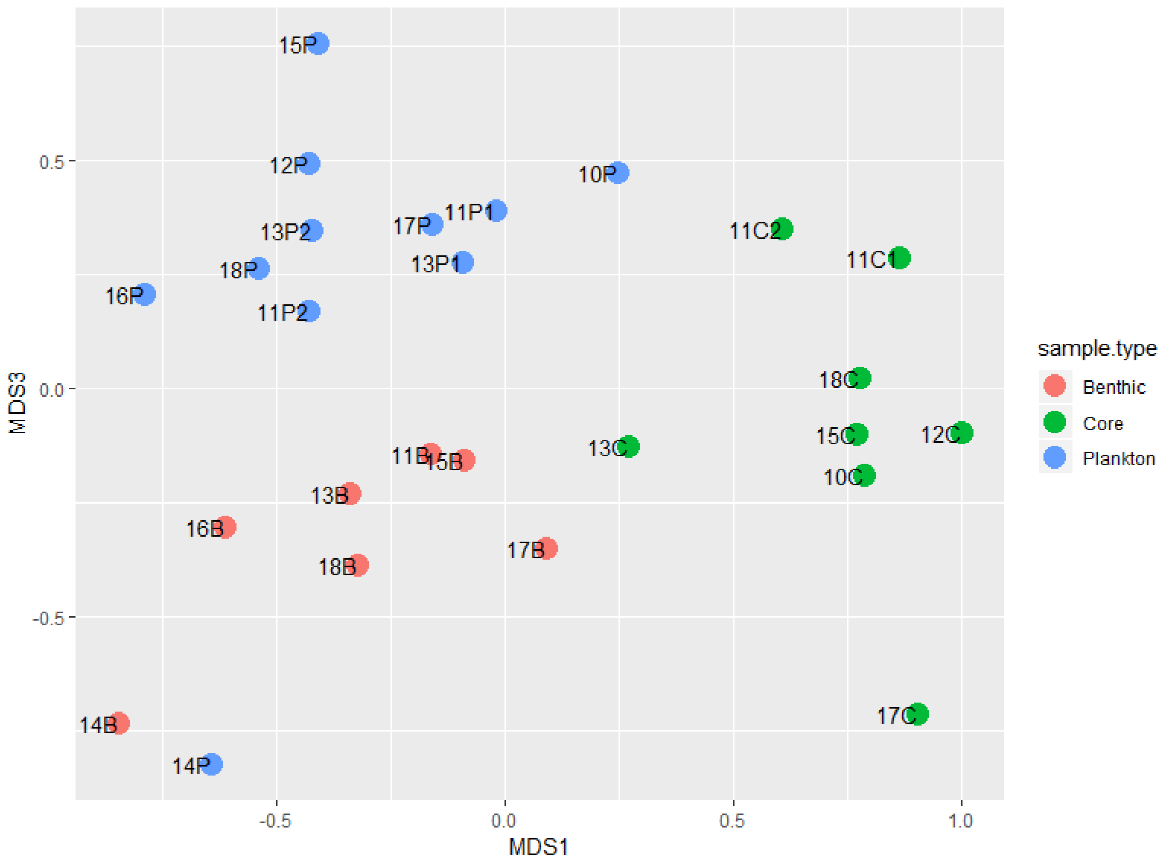

Figure 14. Axis 1 versus axis 3 of a three-dimensional ordination of invertebrates in all 2017 samples. Site numbers refer to the 'KMS' site codes in Tables 1 and 2. Stress = 0.12.

4.4.4 Significant species

None of the species collected are listed as threatened or priority species. However, there has been very little survey of aquatic invertebrates across the Kimberley region and relatively few published studies (with species lists) across northern Australia, making assessments of the distribution and conservation status of Kimberley aquatic invertebrates difficult at present. Nonetheless, some species in these samples have rarely or never been collected in Western Australia (at least in publicly available literature and datasets on Atlas of Living Australia) and some have been rarely collected at all(Table 5).

One of the testate protozoans from Attack Spring, Bamboo Spring and King Gordon Spring is *Difflugia gigantea* Chardez, 1967 and is the first record of this species from Australia (otherwise known from Europe and North America).

Halse et al. (1996) recorded an undescribed species of *Lecane* rotifer from Long Spring (=Rainforest Spring). Whether this is the same species as *Lecane* sp. A or *Lecane* sp. B collected in 2017 is yet to be determined. However, rotifers tend to be widely distributed and so, either way, the 1993 species is not likely to be restricted to these springs.

One of the aquatic earthworm species resembles *Allonais lairdi*, otherwise known from India, South-east Asia and South America, i.e. it is pan-tropical, but the record from Attack Spring is the first for Australia. Worms from Bamboo Spring are only the second Western Australian record of the similarly widespread *Haemonais waldvogeli*, with the only other records from

Australia being Marlgu Billabong (lower Ord River floodplain) and numerous sites in the Murray Darling Basin (Pinder, 2003). Some recent work is demonstrating significant cryptic diversity in supposedly widespread species of aquatic oligochaete, so these specimens may turn out to be distinct Australian lineages. Another oligochaete, from Attack Spring and Long Spring, *Dero* sp. WA5 is similar to *Dero graveli* but may be undescribed.

The anisitsiellid water mite tentatively identified as *Mamersella* sp. is the first record of this genus in DBCA studies and there are no Western Australian records on Atlas of Living Australia. It was recorded only at Attack Spring. The few *Mamersella* records on ALA are also from springs, primarily in the Great Artesian Basin. All previous DBCA records of this family are *Rutacarus* from springs (Pilbara and northern Wheatbelt) and a record of *Sigthoria nilotica* from Kachana Mound Spring in the Kimberley, plus there is an ALA record of *Anisitsiellides* from a spring near Chittering near Perth.

Another water mite, *Arrenurus* sp. WA29 is known only from north-western Australian groundwater fed wetlands: at Walyarta (Quinlan *et al.*, 2016), Nimalarragun wetland near Broome (DBCA report in prep.) plus Big Spring (west Kimberley) and Bamboo Spring (Victoria-Bonaparte) from the present survey. Three other *Arrenurus* have not been previously recorded in DBCA projects and are not described species known from Australia. These are *Arrenurus* sp. WA28 from Long Spring and *Arrenurus* sp. 30 from Big Spring. Bennelongia (2017) recorded an *Arrenurus* from Fern Spring in the central Kimberley and this is here given the code *Arrenurus* sp. WA27 and is also undescribed and not the same as any of the above species. Some of the other water mites may also be new, for example the *Australotiphys* and *Austraturus* from Kachana Spring and the *Axonopsella* from Bunda Bunda Spring.

The ostracod *Strandesia* sp. 653 was recorded from Big Spring in 1999 and again from there and from King Gordon Spring in 2017 but is not known from elsewhere. Other *Strandesia* have also been collected only from Kimberley springs. These are *Strandesia* sp. 360 from Long Spring and a species of uncertain generic identity (*Strandesia*/*Chlamydotheca* sp. 357) collected from Long Spring by Halse et al. (1996), the groundwater fed Nimalarragun wetland north of Broome and other groundwater fed wetlands in the Little Sandy Desert (Pinder & Quinlan, 2013). Other *Strandesia* are found in Pilbara groundwater (Halse *et al.*, 2014) and surface water wetlands in the Pilbara and Carnarvon Basin, especially in temporary waters (Halse *et al.*, 2000, 2014).

An ostracod collected from most of the Victoria-Bonaparte springs sampled in 2017 (but not other springs) belong to the tribe Nealecypridinae. Table 2 in Nagler et al. (2014) suggests these are *Tanycypris*. These are the same as specimens from Long Spring and Edge Spring collected in 1993 that Halse et al. (1996) named *Strandesia ?camaguinensis* Tessler. *Strandesia camaguinensis* has since been designated a junior synonym of the widespread *Tanycypris pellucida* (Nagler *et al.*, 2014) but neither the 1993 specimens nor the 2017 specimens match any of the five described *Tanycypris* in Nagler et al. (2014). *Tanycypris* is an otherwise Eurasian genus other than a species from Madagascar.

Another species of ostracod from several of the Victoria-Bonaparte springs sampled in 2017 appear to be conspecific with '*Herpetocypris* sp. 652' from Big Spring and Black Spring collected in 1999 and specimens collected from the groundwater fed Nimalarragun wetland near Broome in 2018. These appear to belong to the genus *Chrissia* which has not been recorded in Australia but is widespread in Asia and Africa and includes 34 species. In Karanovic

(2012) these specimens key to *Chrissia halyi* Ferguson 1969 from Sri Lanka, but we have not been able to obtain the description of that species for comparison. Most likely our specimens are a new species.

The darwinulid ostracod *Alicenula serricaudata*, is a largely groundwater associated species with a Gondwanan distribution and the records from four of the central Kimberley springs sampled by Bennelongia (2017), plus Bunda Bunda and three of the Victoria-Bonaparte springs in 2017, are the first records for Australia (and the Oceania region) (Martens & Rossetti, 2002).

There is also likely to be undescribed (and probably geographically restricted) species of *Cypretta* and *Ilyodromus* ostracods in this collection, with numerous morphospecies collected and both genera requiring substantial taxonomic research.

The diversity of cyclopoid copepods was notably high at these springs, with ten species recorded in the 2017 survey and twelve species recorded in total across the springs listed in Table 1. For comparison, only seven species have been collected from the mound springs at Walyarta (Storey, Halse & Shiel, 2011; Quinlan *et al.*, 2016), with only four in common. However, Walyarta is a more isolated and confined spring system whereas the springs in Table 1 are distributed over a much larger area and with more extensive surface water. *Microcyclops* sp. TP1 was collected from Long Spring and another wetland on the Victoria-Bonaparte coast by Halse et al. (1996) and was recollected at Long Spring and at King Gordon Spring in 2017. It is an undescribed species not known from elsewhere.

Big Spring had *Mesocyclops woutersi* which has rarely been collected in Australia but is widely distributed in south-east and east Asia (Holynska, 2000). This was collected from the same spring in 1999 and is known from Palm Island in Queensland (Holynska, 2000). The harpacticoid copepod *Canthacamptus grandidieri* is a pan-tropical species, but has rarely been collected in Australia (Hamond, 1987) but was present in Black Spring sampled by Bennelongia (2017) plus Big Spring and several Victoria-Bonaparte Springs in 2017. Hammond (1987) provides some records from north Queensland. Three other harpacticoid copepods are also likely to be undescribed and not previously collected. *Nitokra* '*lacustris*' B07 from Bunda Bunda Spring and three Victoria-Bonaparte Springs (Attack, Long and Potential Spring 9), all from 2017 samples, is part of a species complex. Two species of this complex were recently described from the Yilgarn region of Western Australia (Karanovic *et al.*, 2015) and sp. B07 is likely to be a new species[3]. Canthocamptus sp. B11 was collected from Attack, King Gordon and Enigma Springs (all Victoria-Bonaparte). *Schizopera* sp. B37 was collected only from Potential Spring 1. These last three species are known only from the Kimberley mound springs at present.

A new species of *Karualona* cladoceran (water flea) was collected from three of the Victoria-Bonaparte springs (Attack Spring, Long Spring and King Gordon Spring). This has been provided to an overseas taxonomist for description. This may be what Halse et al. (1996) called '*Alona* n. sp. B' from "Grassed Pool" which is also on the Victoria-Bonaparte coast and may receive some fresh groundwater discharge. Another cladoceran resembles the pan-

[3] Jane McRae pers. comm. Jan 2019.

tropical *Guernella raphaelis* Richard 1892 (Macrotrichidae). This was collected from Potential Spring 9, Long Spring, King Gordon Spring and Attack Spring and represents the first records of this species from Australia. However, as with other 'widespread' species, some cryptic diversity can be expected with greater endemism than the current taxonomy would indicate (Frey, 1988; Elmoor-Loureiro *et al.*, 2010). Halse et al. (1996) recorded two undescribed species of *Macrothrix* cladocerans (also Macrotrichidae), from Edge Swamp and Long Spring, but no undescribed members of this genus were collected in 2017. The *Picropleuroxus quasidenticulatus* from Big Spring, and four Victoria-Bonaparte springs is a new record for WA. There are few other Australian records, although it has a broader oriental/neotropical distribution (Kotov *et al.*, 2013).

The atyid shrimp *Caridina spelunca*, which is restricted to groundwater associated habitats in the central Kimberley, was found by Bennelongia (2017) from Middle Spring and Waterfall Spring. This has not been collected from the Victoria-Bonaparte Springs or the western Kimberley Springs.

The dytiscid beetle *Enochrus fuscatus* (syn. *Enochrus malabarensis*[4]) is widely distributed across coastal regions of northern and north-eastern Australia (plus a record from northern South Australia), but the only other published Western Australian records are those from the Walyarta springs ((Quinlan *et al.*, 2016). This species occurred at almost all of the Walyarta springs but the record from King Gordon Spring is the first for the Kimberley Region. Another beetle *Laccophilus seminiger* was collected by us at Potential Spring 9 and we are unaware of any rother records of this from Western Australia.

The above taxa were not evenly spread across the springs (**Error! Reference source not found.**) but this may be at least partly due to uneven sampling effort. Many of these species are microinvertebrates and smaller mites that will be disproportionately collected in surface water with fine mesh plankton nets which have not been used at any of the central springs or at Lollywell Spring. Attack Spring and Long Spring had disproportionate representation of these species (13 and 15 species respectively) and this was not entirely due to the fact that an extra plankton sample was collected at each of these springs in 2017, since the second plankton sample taken at each of these sites only added 1 additional species from this list.

4.4.5 Invertebrates associated with groundwater

Few clearly stygophilic species have been collected from Kimberley mound springs, but a some are known to be associated with interstitial habitats that are permanently saturated due to groundwater discharge.

The endemic shrimp *Caridina spelunca* is known from caves and springs in the central Kimberley and was recorded from two springs (Waterfall Spring and Middle Spring) by Bennelongia (2017).

[4] Chris Watts, South Australian Museum, pers. comm.

Table 5. Occurrence of rarer species across the Kimberley springs

	FAMILY	IDENTIFICATION	BundaBunda	Lolyywell	Big	Mt Elizabeth	Moon	Black	Drysdale 1a (Fern)	Gibb River	Waterfall Yard	Middle	Kangaroo	Kachana	Potential Spr 9	Attack	Long	Enigma	Potential Spr 1	King Gordon	Bamboo	Brolga	Edge
Protozoa	Difflugiidae	*Difflugia gigantea*														1				1	1		
Rotifers	Lecanidae	*Lecane* sp. nov. LS1															1						
Oligochaetes	Naididae	*Dero* WA5 (cf. *graveli*) KMS														1	1						
	Naididae	*Allonais* cf. *lairdi*														1							
	Naididae	*Haemonais waldvogeli*																			1		
Mites	Anisitsiellidae	*Mamersella* sp.														1							
	Anisitsiellidae	*Sigthoria nilotica*												1									
	Pionidae	*Australotiphys* sp. K1												1									
	Aturidae	*Austraturus* sp. K1												1									
	Aturidae	*Axonopsella* sp.	1																				
	Arrenuridae	*Arrenurus* sp. 29			1																1		
	Arrenuridae	*Arrenurus* sp. 27						1	1								1						
	Arrenuridae	*Arrenurus* sp. 28															1						
Crustacea	Chydoridae	*Picropleuroxus quasidenticulatus*			1										1	1	1		1				
	Chydoridae	*Karualona n. sp.*														1	1			1			
	Macrotrichidae	*Guernella raphaelis*													1	1	1		1	1			
	Cyprididae	*Tanycypris* sp.														1	1			1	1	1	1
	Cyprididae	*Chrissia* sp.			1			1								1	1	1			1		
	Cyprididae	*Strandesia* sp. 653			1															1			
	Cyprididae	*Strandesia* sp. 360															1						
	Darwinulidae	*Alcenula serricaudata*	1					1	1		1	1			1	1	1						
	Cyclopidae	*Microcyclops* sp. TP1															1			1			
	Cyclopidae	*Mesocyclops wouteri*			1												1						
	Canthocamptidae	*Canthocamptus grandidieri*			1			1							1	1	1	1		1			
	Canthocamptidae	*Canthocamptus* sp. B11														1		1		1			
	Diosaccidae	*Schizopera* sp. B37																	1				
	Ameiridae	*Nitokra* sp. B07	1												1	1	1						
	Atyidae	*Caridina spelunca*				1					1	1											
			3	0	6	1	0	4	2	0	2	2	0	3	5	13	15	3	3	8	5	1	1

Two rarely collected harpacticoid copepods, *Phyllognathopus volcanicus* and *Elaphoidella grandidieri*, are known only from Kimberley mound springs in Australia. The latter has been collected from western, central (Bennelongia Environmental Consultants, 2017) and Victoria-Bonaparte springs and is a pan-tropical species (Gaviria & Aranguren, 2007). The records of *Phyllognathopus volcanicus* from Big Spring and Potential Springs 6 and 9 are the first for Australia but the species is also known from interstitial habitats in New Zealand (Lewis, 1984). Both of these species are likely to require permanent interstitial habitats.

Darwinulid ostracods are generally collected from groundwater or from habitats maintained by groundwater or hyporheic flows. All DBCA records are from groundwater influenced sites such as river pool sediments and springs. The three darwinulid species, *Alicenula serricaudata*, *Penthesilenula braziliensis* and *Vestalenula marmonieri*, collected from Kimberley mound springs all have supra-Australian distributions. The *Alicenula serricaudata* records from the 2016 and 2017 mound spring samples are the first of this genus and pan-tropical species for Australia. Candonid ostracods also generally inhabit groundwater (Karanovic, 2007) and an unidentified (female) specimen was collected from Potential Spring 1.

The water mite family Anisitsiellidae tend to be associated with stygal and interstitial habitats in Australia and all DBCA records of this family are from springs. The Kimberley mound spring records of two anisitsiellids, *Sigthoria nilotica* and *Mamersella* sp. are the only records from DBCA projects. *Sigthoria nilotica*, another pan-tropical species (Harvey, 1998), was collected from Kachana Spring in 2003 and is known from a hot spring in the Northern Territory (Smit & others, 1998). There are records from other habitats in eastern Australia but the identity of those is uncertain (Harvey, 1990). *Mamersella* occur in 'streams, seepages and springs'

(Harvey, 1998) and the only described species from Australia, *Mamersella ponderi* Harvey 1990 is restricted to Great Artesian basin mound springs. The single specimen from Attack Spring is not *M. ponderi* and could be a new undescribed species.

Many other species, such as some of the cyclopoid copepods and oligochaetes, are regularly found in groundwater samples (e.g. from bores well away from wetlands) but are not restricted to subterranean waters.

The paucity of clearly stygal species does not detract from the critical importance of groundwater discharge for maintaining the nature of the wetlands (permanently saturated peat deposits and ponding water under tall tree canopies) and for the distinctive communities they support.

4.4.6 Composition in relation to other wetlands

Understanding distributions of aquatic invertebrates and the conservation significance of invertebrate communities in the Kimberley region is hampered by the fact that there have been very few published studies of the region that have involved species level identification (see Introduction) and published the data.

There is certainly significant pan-tropical, Oriental and Australo-papuan/Australasian elements to the fauna of these springs, as for the Kimberley and tropical Australian regions more generally. Examples are the copepod crustacean *Mesocyclops woutersi* (widespread in south-east and east Asia - Holynska (2000)), the cladoceran *Pseudosida szalayi* (south, south-east and east Asia - (Korovchinsky, 2010)), the water mite *Sigthoria nilotica* (otherwise Africa, South and South-east Asia – Harvey (1990)) and the aquatic earthworm *Allonais lairdi* (otherwise Neotropical and Oriental - Martin et al. (2008)).

The idea that many species are widespread does need to be tempered by the increasing understanding that there is significant genetic evidence for cryptic species with narrower ranges. For example, the aquatic annelid *Branchiodrilus hortensis* (Stephenson, 1910) was thought to be a pan-tropical species (with records in the Kimberley) but recent studies (Martin *et al.*, 2018) have shown this to be made up of several genetically distinct species with more limited distributions. Unfortunately no Kimberley specimens were included in that analysis. Recent work on ostracods is also showing much greater species diversity, partly through genetic analyses, than previously thought (Martens, Halse & Schön, 2013; Halse & Martens, 2019).

It is likely that most of the species collected from these springs will occur in other types of wetlands and rivers in the Kimberley and most (especially those from the Victoria-Bonaparte coast) are likely to have distributions that extend east into at least the Northern Territory. Most of the dragonflies and damselflies, for instance, have distributions that extend across at least tropical/subtropical Australia, although there are some exceptions: e.g. the damselfly *Nososticta koongarra* is known only from the Kimberley and the Northern Territory tropics (Theischinger & Endersby, 2009). Distributions of many other aquatic invertebrates are not so well documented.

Of the 581 species listed for 'northern tropical rivers' by Humphrey et al. (2008), 75 have been recorded from Kimberley mound springs, but many taxonomic groups are not included in Humphrey et al.'s (2008) list.

A project to provide baseline condition and biodiversity data at 44 significant wetlands in Western Australia included five wetlands in the Kimberley: Lake Eda, Airfield Swamp, Parrys Lagoon, a swamp at the Ngallagunda Community and Le Lievre Swamp (see references provided in the Introduction). These are primarily fed by rainfall/surface water sources rather than groundwater. A total of fifteen benthic samples were collected from these wetlands in 2008 (three per wetland). Together, samples from these sites had 155 distinct macroinvertebrate taxa (microinvertebrates were not identified due to time constraints). Of these, at least 40% have been collected from Kimberley Mound Springs, although some differences in taxonomic resolution hinder a full comparison at this stage. This shared component represents about 20% of the equivalent taxa from the mound springs.

Storey (2002) collected 171 macroinvertebrate taxa from 58 samples collected from the lower Ord River downstream of Kununurra to the river adjacent to Parry Lagoons. Only 16 (9%) of these have been recorded from Kimberley mound springs, though this will be a slight underestimate due to differences in taxonomic resolution. This component in common represents only about 5% of the equivalent range of invertebrates from the mound springs, which is not surprising given that the Ord sites were all riverine.

Figure 15 is a plot from a three-dimensional ordination with aquatic invertebrate data collected from Kimberley springs in 2017 (the six sites with both plankton and benthic data) and equivalent data from the Walyarta mound springs sampled in 1999 (Storey *et al.*, 2011) and 2015 (Quinlan *et al.*, 2016). This analysis used a dataset that was taxonomically aligned and consisted of 304 species. This shows that invertebrate communities of the Kimberley springs were distinct from those of the Walyarta springs. Interestingly, the plot suggests the difference between the Kimberley springs and those of Walyarta is no greater than the turnover in species between the 1999 and 2015 Walyarta samples. However, it can be seen from

Figure 16 that over two-thirds of species (within the taxonomically aligned joint dataset) collected from the Kimberley springs were not collected at Walyarta and that 60% of species collected from one or both Walyarta datasets were not collected from the Kimberley Springs. The actual number of species occurring in the Kimberley springs but not in the Walyarta springs would be even higher because the joint dataset excludes some speciose groups (due to taxonomic issues) likely to exhibit significant endemism (e.g. *Cypretta* and *Ilyodromus* ostracods). Also, a large proportion of the species collected from just one of the three datasets were singleton species (occurring in just one sample) so would not have influenced similarity between sites represented in Figure 15.

Although it is early days in terms of aquatic invertebrate survey in the Kimberley, the picture at present is that these springs support a high diversity of aquatic invertebrates and, while most of the individual species are likely to be widely distributed in at least the region, there is a suite of species that is rare and more likely to be represented in these springs than other wetland types in at least the Kimberley. Furthermore, the composition of the springs' aquatic invertebrate communities is unlikely to be replicated in other types of wetlands anywhere in Australia.

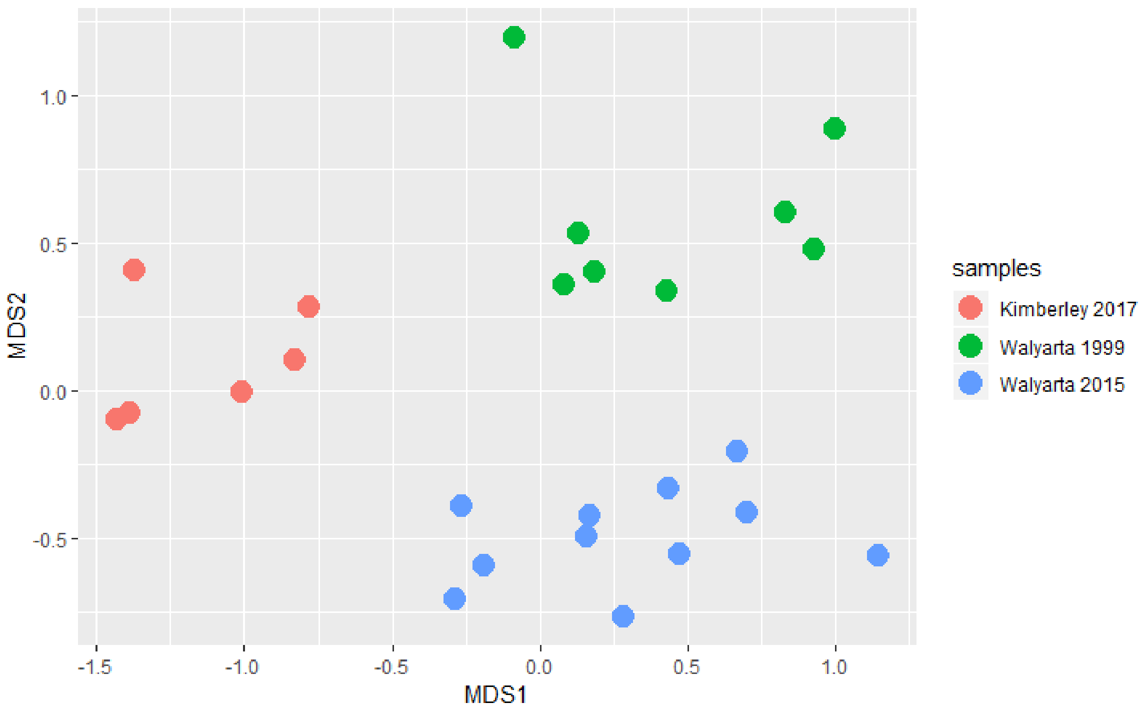

Figure 15. Axes 1 and 2 of a three-dimensional ordination of all surface water samples involving combined plankton and benthic samples collected from springs at Walyarta and in the Kimberley region. Stress = 0.1.

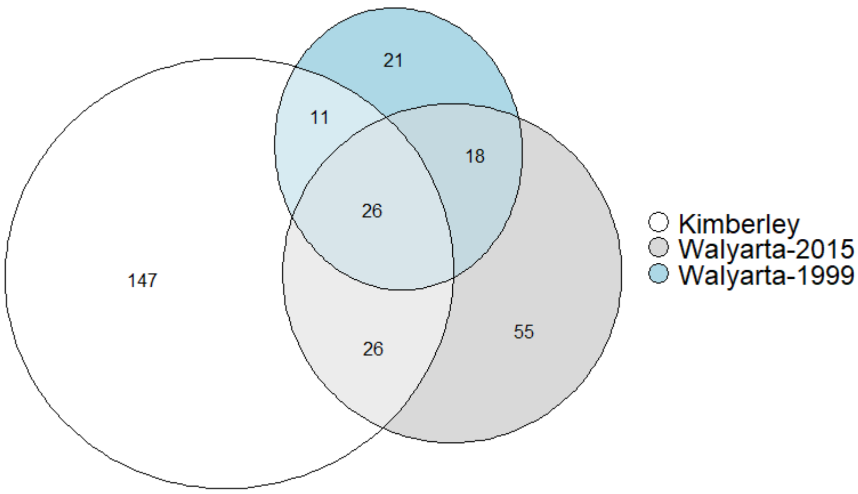

Figure 16. Relative proportions of the total species pool collected from Walyarta (1999 and 2015) and Kimberley mound springs. Circles are proportional to the total number of species within each of the three datasets (after taxonomic alignment). Drawn using the eulerr 5.0.0 R package by Larsson et al. (2018), with a test to confirm that the size of each segment is proportional to the number of species it represents.

4.5 Glossary

Benthic sample. A sample taken with a coarse mesh net (usually 250 μm) to sample invertebrates living amongst the mud, aquatic plants and organic detritus as well as those larger animals swimming in the water. The coarse mesh allows rapid sweeping through all habitats without the net becoming clogged up with fine particulate matter, but some smaller animals pass through the net. These samples primarily target macroinvertebrates.

Plankton sample. A sample taken with a very fine mesh net (usually 50 to 100um) used to sweep more slowly through the water to catch invertebrates in the water column or aquatic plants, including the microinvertebrate species such as rotifers and protozoans.

Interstitial. Referring to species that live within (as opposed to on or above) wetland substrates.

Microcrustacea. Species of ostracod, copepod and cladocera.

Microinvertebrates. Microcrustacea plus rotifers and protozoans

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5 Ecological Community Assessment of the Victoria-Bonaparte Springs

Jill Pryde

5.1 Introduction:

Individual mound springs have generally not been accurately mapped on the tidal flats of the Victoria-Bonaparte Bioregion, with the exception of Brolga Spring. The assemblages of wetlands associated with the organic mound springs were identified following the Kimberley Rainforests Australia survey in 1987 by McKenzie *et al.* (1991). In 2000, Sally Black nominated Point Spring and Long Swamp together as one community type. However, later discussions specified that the springs and their individual cohorts of assemblages should be split into two types (G.K. Keighery and N.L. McKenzie *pers comm*.). Other survey data includes Halse *et al*. (1996) who undertook a waterbirds and aquatic invertebrate survey at selected sites including two sites at Long Spring, one at Brolga Spring and one another located on the north-western extent of the wetlands. Other survey included one to monitor change in condition at Long Swamp (G. Graham 1994-1995) and Sally Black visited selected sites across the northern Kimberley to evaluate mound springs for their conservation value and proposed listing as threatened ecological communities (TECs).

A total of four occurrences are recorded on the TEC database including Brolga Spring, King Gordon Spring, Attack Spring and Long Swamp occupying a total of ~82.2ha and ranging over 13.5 km east-west. Prior to the August 2017 survey, a desk top study identified an additional seven wetlands as potential mound springs that could align with the priority ecological community (PEC) (Figure 19).

Assemblages of the wetlands with the organic mound springs on the tidal mudflats of the Victoria- Bonaparte bioregion have not been formally assessed by the WA Threatened Ecological Communities Scientific Committee (TECSC). The community is listed Priority 1 ecological community (PEC), recorded on the TEC database in 2008.

The key threats identified for the mound springs are pastoralism (impacts of cattle) including trampling of vegetation, soils and spring pools, and nutrient enrichment; altered fire regimes - too high intensity, and potential hydrological change. The springs are on aquifers that have operating bores on them and are potentially threatened by water abstraction (DEC 2008).

5.1.1 Setting

Vegetated peat mounds of numerous sizes occur over ephemeral freshwater springs and pools. The mound springs are generally surrounded by inundated moats containing *Typha*, sedges and grasses. The mound springs are distributed along the landward boundary on the coastal saline tidal flats. Smaller springs, (~0.02ha), manifest along the adjacent coastal flats, however many have become degraded. The coastal flats occur as a ~2 km wide band alongside the coast of Joseph Bonaparte Gulf, ~90 km north of Kununurra. The greater wetland area is occasionally inundated by fresh or saline water (Halse *et al*. 1996). The vegetation consists of dense forests of *M. leucadendra* with other tree species and rainforest patches that contain 50% or more of the crown cover including vines and climbing ferns over scattered-dense layers of ferns, sedges and grasses over leaf litter coverage of various depth. The springs and pools at each location vary in number, size and depth. The majority contained a thick cover of aquatic ferns and herbs, Typha, rushes and sedges with fallen logs and leaf litter.

The springs are located on unallocated Crown land (UCL), within the ex-Carlton Hill Pastoral Lease, which is awaiting outcome of S16 negotiations. Access to the springs is recommended during low tide.

5.1.2 Current description

Assemblages of the wetlands associated with the organic mound springs on the tidal mudflats (Figure 17) of the Victoria-Bonaparte Bioregion East Kimberley on Carlton Hill Station. Large wetlands with *Melaleuca* forest (Figure 18) with small patches of rainforest on central mounds. Rainforest and paperbark forest associated with mound springs and seepage areas of the Victoria Bonaparte coastal lands. The rainforest canopy height at Long Swamp is 30m, and the dominant tree species include *Nauclea orientalis, Terminalia microcarpa* and *Melicope elleryana*; the periphery of the patch is permanently moist and supports a *Melaleuca leucadendra* forest (McKenzie *et al*. 1991). Species richness at Long Swamp is 52 and perennial plant species richness is 20. Silty clay soil type at this swamp. Plants with very restricted distributions within the State include *Mucuna gigantea* (vine) and *Sterculia holtzei* P1 (tree). The lithology at Long Swamp is quaternary alluvium and the soil is a black soil plain.

5.1.3 2017 survey

A survey of the Victoria-Bonaparte organic mound springs, including an additional suite of potential mound spring sites, was undertaken between 1-4 August 2017 by a team with expertise in TEC identification and inventory, biological survey including flora and vegetation, aquatic invertebrate fauna identification and WA wetland inventory. The survey was coordinated by the East Kimberley District Nature Conservation Coordinator, with cooperation and assistance of Traditional Owners Miriuwung Gajerrong.

The aim of the survey was to update PEC baseline information, including description, condition and threats to the PEC, to establish permanent quadrats to record flora and vegetation, inventory aquatic invertebrates, soils and water chemistry, and to identify new occurrences and update boundaries of the wetland community as required. Over time it will be valuable to build up a uniform dataset for springs for a broader regional analysis.

Figure 17. View over the black cracking clay tidal flats – photo Kirsty Quinlan.

Figure 18. View over black soil plains with Melaleuca forest in background, Victoria-Bonaparte wetlands – photo Mike Lyons

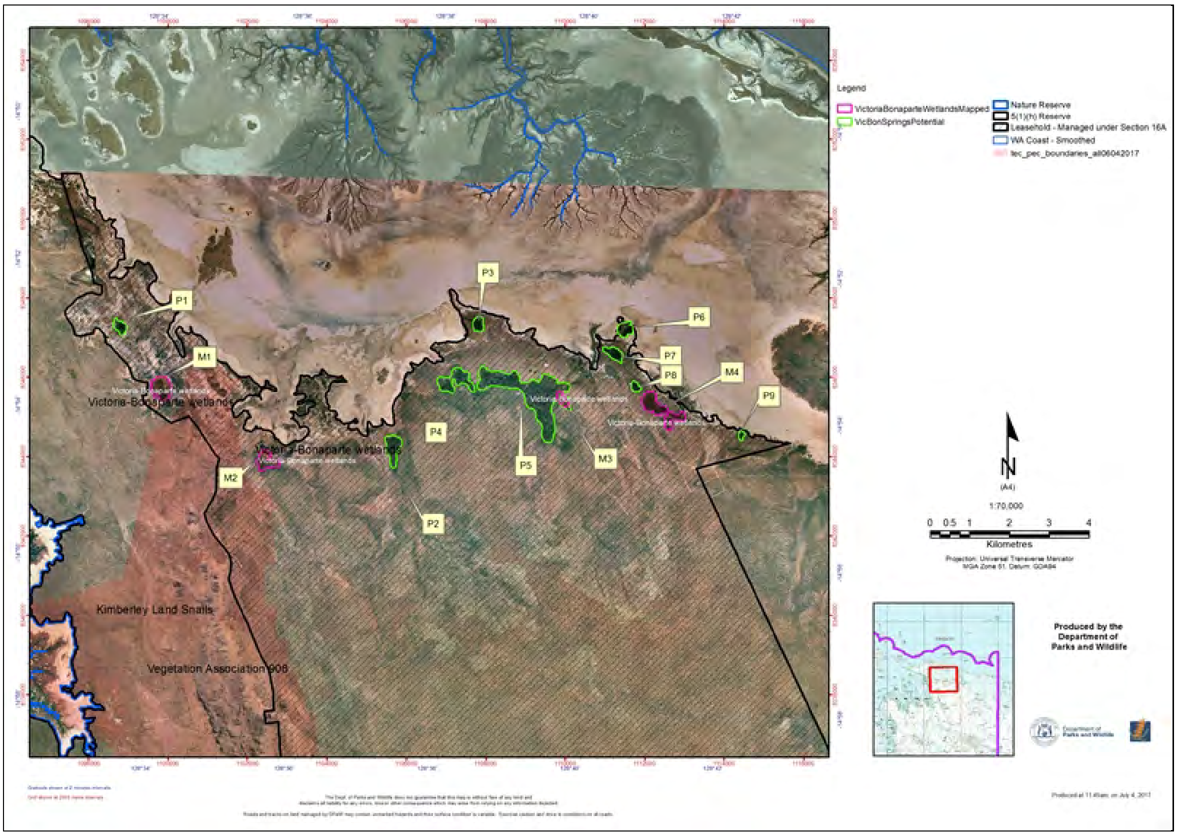

Figure 19. Currently mapped mound springs and potential springs

5.2 Methods

A total of eleven sites were surveyed, including all recorded occurrences and five additional sites, and the following recorded:

- general vegetation description, condition and structure across the mapped community.
- Flora list for vegetation within the quadrat and at adjacent locations throughout the mound spring community.
- threatening processes; and
- management recommendations compiled.

In conjunction with the above, six sites were selected in tall dense rainforest community and in a woodland community. Permanent 50x50^{2}m quadrats were installed. Each quadrat was marked with one 1.6m star picket at NE corner site. This will enable future scoring and analysis of change, for monitoring purposes. Quadrat data (held by M. Lyons) for site include:

- GPS location;
- vegetation description, stratum and structure;
- soil and landform;
- flora specimens were taken from the mound springs seepage areas and damplands surrounding the springs. Flora specimens were collected by Mike Lyons, with additional collections by Jill Pryde (Hayley's Spring) and M. Coote and A. Turnbull.

- Aquatic invertebrate survey, peat core and water chemistry in an area of standing water by A. Pinder and K. Quinlan.
- Assessment and mapping by the wetlands group (M. Coote and A. Turnbull) using a handheld GPS in conjunction with aerial photography.
- Photographs of occurrences and surrounding landscape.

These data will be added to the corporate TEC/PEC database when available.

5.3 Limitations:

Four days were allocated to survey the Victoria-Bonaparte wetlands and this limited the capacity to conduct a full assessment on status and condition across the suite of wetlands.

5.4 Results:

Survey of the Victoria-Bonaparte wetlands PEC was undertaken between 1-4 August 2016 to coincide with low tide. The PEC comprises four mapped occurrences that occur over a range of 14 km bordering the edge of the saline coastal flats. All recorded occurrences and most potential sites sampled are located on a raised central mound that contained a mix of peaty organic black soils and/or decayed organic material. Internal moats and pools occur at various depth and contained aquatic ferns and submerged herbs at various densities. The canopy vegetation comprised tall Melaleuca forest with other trees, including rainforest species of various stratum and density including thickets of vines, including climbing ferns over *Pandanus spiralis*, *Typha domingensis*, creepers, rushes, sedges, grasses and ferns. The surrounding alluvial flats and black soil plains support dense to scattered stands of *Melaleuca* spp., *Acacia* spp. and other shrubs and trees over *Cyperus* spp., *Sporobolus* spp. grasslands and patches of *Adansonia gregorii* (boab) and *Pandanus* thickets with scattered samphires over the outer saline areas. No Declared rare flora (DRF) were identified, however three priority flora species were recoded including *Sterculia holtzei* (P1), *Utricularia aurea* (P2) and *Adenostemma lavenia* var. *lanceolatum* (P3).

5.4.1 Brolga Spring (Occurrence 01)

(M1 on Figure 19)

Brolga Spring (Figure 20) occupies 23.3ha. A *Melaleuca* woodland surrounded by *Typha domingensis* with emergent *Ficus* spp. is a small permanent freshwater spring which lies on the margin of open coastal grassland plain towards the west and the red soils plains of open eucalypt woodlands to the east and south. The spring occurs at the extreme northern end of the Ningbing Range on the sandy margin flanked by tidal limit 3 km east and 4 km west. Brolga Spring lies directly adjacent Mijing Conservation Park (Crown reserve 49691).

Figure 20. Brolga Spring – photo Adam Turnbull

No comprehensive survey of Brolga Springs was undertaken in August 2017, however boundary reconnaissance and a brief edge survey to observe status and condition was conducted. Vegetation comprised a *Melaleuca* sp. forest within the central mound and open water with patches of duckweed *Lemna aequinoctialis*. Species co-occurring included *Cyperus javanicus*, sedges and *Typha domingensis*. The outer perimeter of the larger seepage area in the surrounding moat contained *T. domingensis* forming a dense barrier. The south and western peripheries were more open and comprised *Melaeuca viridiflora, Sesbania cannabina*, and occasional *Ficus* spp. with vines and creepers, including *Thespesia* sp. Based on records of previous survey and current survey, the degraded stands of *M. ?leucadendra* found on the southern side of the wetland are in poor condition and the vegetation surrounding the trees has become degraded, transitioning into a grassland. Along the western periphery, upland of the moat, soils are red-brown sandy-loam covered with deep litter of *P. spiralis*, dense *M. viridiflora* shrubs, *Sesbania cannabina* and *Adansonia gregorii* over *Cyperus* spp. and grasses. Although the brief survey limited the flora inventory, the flora taxa present in this occurrence appears to be diverse.

Previous observations by S. Black *et al*. (2000) noted the destructive impacts caused by cattle, particularly at the south east corner, which appears to be a major entry point into the wetland. McKenzie (*pers comm*. 2013) noted that a fence installed prior to visitation in 2013, appeared to have assisted in improving vegetation condition of the community. However, in August 2017 the fence was breached, and cattle were again causing significant damage to the community and resulted in trampling of vegetation, damaging soil structure and adding to the accumulation of nutrients. Some weeds in this area have potential of becoming a serious threat, including **Mesosphaerum suaveolens* (formerly *Hyptis*) located on the southern side. The community was partially burnt in the previous 12 months. Vegetation condition Good-Very Good (Bush Forever scales).

The key threats identified for the mound springs are trampling of vegetation, soils and springs by cattle, nutrient enrichment, high intensity fires and potential hydrological change.

5.4.2 Long Springs (Occurrence 04)

(M3 on Figure 19)

Figure 21. Cyclosorus interruptus patch with scattered rainforest trees, vines and creepers – photo Mike Lyons

Long Spring (Figure 21) is a large wetland with scattered pools and a mosaic of vegetation occupying ~110 ha. The combination of *Melaleuca* forest and *Typha domingensis* occurring in the moat and internal pools in the northern portion of the wetland is distinct from the internal rainforest and vine thicket patches with canopy height (>30m) occupying the southern portion of the spring. The south eastern periphery is permanently moist and supports a *M. leucadendra* forest transitioning to rainforest patches with groves of tall *P. spiralis* and dense cover of *Cyclosorus interruptus* with scattered rainforest trees, vines and creepers. The inner quaking mounds contain pools at variable depth (>50 cm) comprising dense leaf litter and thick layers of decayed vegetated matter suspended in fresh-brackish water. The pools and moats contain ferns, sedges, aquatic herbs and flowering *Nymphaea violacea*.

5.4.3 Site 01

(located on northeast edge of Long Spring (currently mapped as Occurrence04))

(P5 on Figure 19)

Following a reconnaissance to this location, it became apparent this was not the site of survey by McKenzie *et. al* (1991) which identified the site EK06. Vegetation comprised tall (>30m) forest of *Melaleuca leucadendra* ~75 % cover. Internal moats and pools at various depth (30-75 cm) with an external moat dominated by an impenetrable cover of *Typha domingensis* (>3 m) (Figure 22) with occasional *Acrostichum speciosum* and *Cyperus* sp. Internal pools contained mostly decayed aquatic herbs, sedges and *T. domingensis*. Approximately 150 m was traversed toward the centre of the spring with *M. leucadendra* and *T. domingensis* continuing to dominate this patch.

Figure 22. Long Spring (NE patch) dominated by *M. leucadendra* forest over *T. domingensis* – photo Mike Lyons

5.4.4 Site02 south east portion of Long Spring

(P5 on Figure 19)

Vegetation over the central mound contained dense *M. leucadendra* with a mixed rainforest canopy to a height (>30m). One permanent 50x50 m^2 quadrat (KMS013A) was established in the south-central section with vegetation cover 50-70%. Constituent tree species included the buttressed *Carallia brachiata, Sterculia holtzei* (P1), *Timonius timon, Nauclea orientalis* and *P. spiralis* with vines, including *Flagellaria indica*. Ferns included *C. interruptus, A. speciosum* and *Ceratopteris thalictroides. T. domingensis* and *C. javanicus* were also present in the understory. The pools of standing water (Figure 23) contained decayed organic material, roots, leaves, and aquatic herbs including golden bladderwort, *U. aurea* (P 2), and flowering *Nymphaea violacea* with soils of dark grey-silty clay. On higher ground, the sandy eastern periphery comprised scattered woodland of *Melaleuca* sp*., Corchorus* sp. and *Fimbristylis ferruginea.*

Figure 23. Long Spring (south) – photo Mike Lyons

General condition was Excellent (Bush Forever scales). Within the central mound, some evidence of cattle activity around the periphery of the wetland. Cane toads (*Bufo marinus*) were present. The establishment of cane toads is considered a future threat to wetlands across the Kimberley.

5.4.5 Potential Spring 01

(P1 on Figure 19)

Potential Spring 01 occurs on the north western extension of the saline coastal tidal flats of the Victoria-Bonaparte wetlands, 4 km north of Brolga Spring. It is a shallow, seasonally inundated open freshwater pool with dark grey peaty soils (Figure 24). It contains two bodies of open water. The larger wetland is relatively open, surrounded by sedges including *Cyperus conicus* and *C. javanicus* with grasses and herbs. On the south, western and northern edges of the wetland emergent on higher ground a woodland of trees including *Melaleuca alsophila* and mangroves over grasses. A dense stand of *Typha domingensis* surround the smaller wetland to the north of the main water body. The wetland provides a variety of habitat types for shorebirds, and many bird species were present during the August 2017 visit. An inventory of avian fauna was recorded by D. Chemello.

Figure 24. Potential Spring 01 – photo Mike Lyons

One permanent 50 m transect (KMS014A) was established along the northern edge of the central waterbody, 05 m inward of the highwater level (Figure 25). This level is likely to rise and fall with tidal movement. The vegetation comprised of *Melaleuca alsophila.* woodland and mangroves of *Avicennia marina* and *Lumnitzera racemosa* and *Thespesia populneoides*. There was little undergrowth in this location, mostly bare ground with occasional *Schoenoplectus subulatus, Fimbristylis* sp*., Panicum seminudum* var*. seminudum* and herbs. Vegetation was in condition Good (Bush Forever scales). Plant species considered useful indicators of rainforest communities and associated mound springs were not present at the site sampled or areas surveyed opportunistically. Therefore, based on the August 2017 survey this portion of the wetland may not align with the Victoria-Bonaparte wetlands PEC. However, a higher stand of vegetation which is located on the far western edge of the wetland was not surveyed. This area may contain rainforest indicator vegetation.

Figure 25. Potential Spring 01 Transect KMS014A – photo Mike Lyons

Cattle appear to be a major threat to this wetland (Figure 26). They were present at the time of survey and their impact on the vegetation and soils was evident. An inlet immediately to the north of the smaller wetland as well as the cleared edge on the eastern flank of the wetland appear be the primary entry points. Other threats include weed invasion, altered fire regimes, feral animals, potential hydrological changes (e.g. groundwater extraction) and tourism development.

Figure 26. Cattle, a major threat across the wetlands – photo Mike Lyons

5.4.6 Potential spring 09

(P9 on Figure 19)

This spring is the most easterly sampled in the survey, located ~500 m east of Attack Spring, on the edge of the coastal saline flats. A small (~0.8 ha), heavily vegetated mound, surrounded by a moat and internal pools of water at variable depth occurs. The substrate mostly contained partially decayed vegetated material.

Figure 27. KMS10 established in dense vegetation at potential spring 09 – photo Mike Lyons

One permanent 50x50 m^2 quadrat (KMS010) (Figure 27) was established within the dense closed-open tall forest with cover ~70% of *M. leucadendra* (>70m) and *Glochidion sumatranum* over *Sesbania formosa*, a broadleaf tree emergent. The understory contained *C. interruptus* and other ferns with submerged aquatic, *U. aurea* (P2) in standing water. On the periphery, some patches of vegetation were more open. Other patches were dense, containing thickets of *T. domingensis* and *Colocasia esculenta* (taro) with *Marsilea crenata, Corchorus* sp., *Cyperus* sp. and *Scleria lingulata.* No DRF was located however one Priority flora species was recorded. Plant species considered useful indicators of rainforest communities and associated mound springs were present. The total number of weeds species was low. Vegetation condition was Excellent (Bush Forever scales).

There was evidence of cattle activity. The key threats identified for the wetland include grazing, weed invasion, altered fire regimes, feral animals, potential hydrological changes (e.g. groundwater extraction) and possibly tourism development.

It is considered that this mound spring is likely to align with Victoria-Bonaparte wetlands Priority 1 ecological community.

5.4.7 Attack Spring (Occurrence 03)

(M4 on Figure 19)

Attack spring is an elevated quaking mound, which contains a thick layer of decayed vegetated matter suspended over fresh-brackish water. The 36 ha mound was encircled by a mosaic of standing pools and moats of water at variable depth (3-70 cm). Vegetation over the mound comprised a dense closed-open *Melaleuca* forest and other rainforest species canopy to a height of >30 m (Figure 28).

Figure 28. Quaking mound, Attack Spring – photo Mike Lyons

One permanent 50x50 m^2 quadrat (KMS011A) was established within the central mound containing *M. leucadendra* forest (>30m) and *Glochidion sumatranum* with 70% cover, over scattered *Sesbania formosa* and vines of *Flagellaria indica* with an understory of *T. domingensis, Cyperus platystylis* and ferns including *Cyclosorus interruptus* (Figure 28). Contiguous pools contained thick layers of fallen paperbark and decayed vegetated material and a dense coverage of aquatic herbs, including *Lemna aequinoctialis, Utricularia aurea* (P2) and *Ceratophyllum demersum*. The moat surrounding the mound contained an almost impenetrable barrier of *Phragmites karka* and *Typha domingensis*. On higher ground, the periphery of the wetland contained occasional *S. formosa* and dense *Melaleuca* spp. woodland with tufted perennial grass *Fimbristylis cymosa*. Vegetation condition was Excellent (Bush Forever scales). Within the central mound there was little evidence of cattle activity, however cattle impacts were noted on the outer surrounding *Melaleuca* woodland.

5.4.8 Enigma Spring (Potential spring 06)

(P6 on Figure 19)

A small densely vegetated mound located on the far northern edge of the saline coastal flats (Figure 29). The mound occupies ~6 ha and drained from the north west. A small number of internal pools and moats with water at variable depth were present. Substrate consists mostly decayed organic material with little soil.

Figure 29. Enigma Spring displaying the dense understory – photo Jill Pryde

One permanent 50x50 m^2 quadrat (KMS012A) was established within the densely closed to open *M. leucadendra* forest >70m with *Ficus racemosa, Glochidion sumatranum, Carallia brachiata* and *Hibiscus tiliaceus,* over a dense understory of shrubs containing, *Thespesia populneoides, Abutilon indicum* var. *australiense,* climbers, *Mucuna gigantea* subsp. *gigantea, Flagellaria indica, Decaisnina angustata* and *Adenostemma lavenia* var.

lanceolatum (P3) with ferns *Cyclosorus interruptus, Acrostichum speciosum* and *Ceratopteris thalictroides*. Around the periphery, thickets of *Typha domingensis* and *Colocasia esculenta* var*. aquatilis.* Other flora present include *Marsilea crenata, Cyperus haspan, Cyperus javanicus, Fuirena ciliaris* and *Fimbristylis* sp. Restricted to the outer edge were shrubs of *Melaleuca* spp. over grasses. Plant species within the central mound that are considered useful indicators of rainforest communities and associated mound springs were present at the site sampled. Total number of weeds was low, however the large shrub *Calotropis procera* was recorded. Vegetation condition was Excellent (Bush Forever scales). There was no sign of recent fire. There was some evidence of cattle entering the community, however impacts appeared to be low.

Two small vegetated patches to the west were briefly surveyed (Figure 30). The most northerly patch was degraded with the second patch located immediately south comprised a tall woodland of *Melaleuca* spp. over a dense understory of grasses and herbs. The patches contained few rainforest indicator species, and no peat mounding was evident.

Figure 30. Looking west to small vegetated patches and potential mound springs – photo Jill Pryde

5.4.9 Potential spring 07 (Hayley's Spring)

(P7 on Figure 19)

Hayley's spring (Figure 31) is located south of Potential Spring 06 and 1 km northwest of Attack Spring. No comprehensive survey was conducted; however a brief edge survey and boundary reconnaissance was undertaken to assess status and condition.

Figure 31. Internal pools covered with *L. aequinoctialis* – Photo Jill Pryde

The thickly vegetated mound occupies ~8.6 ha and rises (~2 m) above black cracking clays and surrounding saline coastal flats. Soils are peaty grey-black containing mostly organic material. Water appears fresh-brackish. Vegetation on the central mound comprised a tall-medium dense *Melaleuca leucadendra* forest with *Glochidion sumatranum* and vines including *Flagellaria indica* and *Vincetoxicum carnosum* but mostly lacking a mid-story. A suite of internal moats of various depths (~30-70 cm) contain a dense cover of *Lemna aequinoctialis, Utricularia aurea* (P2) with occasional *Ceratopteris thalictroides* (Figure 31*.* Ferns *Cyclosorus interruptus* and *Acrostichum*. sp. surrounded pools, often at the base of *Melaleuca* trees. Many fallen *Melaleuca* trees lay over the mound. Surrounding the central mound included a dioecious tree *Ficus hispida* var*. hispida* with shrubs*, Cathormion umbellatum, M. viridiflora* and *Plumbago zeylanica* and creeper*, Causonis trifolia* with a dense stand of *Schoenoplectus subulatus, Phragmites karka, T. domingensis* over *Marsilea* sp*. S. lingulata* and ferns. The dryer outer perimeter contained a woodland of *Melaleuca* spp. with *Acacia neurocarpa*. shrubs and mistletoe with *T. domingensis* and swathes of mixed sedges and grasses, including *C. javanicus* sp*.* and *Fimbristylis polytrichoides* and herbs, including *Ludwigia octovalvis*. Vegetation condition was Excellent (Bush Forever scales).

Based on observations from this partial survey, the mound appears to align with Victoria-Bonaparte wetlands Priority 1 ecological community.

The key threats identified to the mound springs are, grazing, weed invasion, altered fire regimes, feral animals and potential hydrological changes (e.g. groundwater extraction) and tourism development.

5.4.10 Potential spring08 (unnamed)

(P8 on Figure 19)

A small vegetated mound which occupies ~5.4 ha is located immediately west of Attack Spring. This site was not surveyed.

5.4.11 King Gordon Spring (Occurrence 02)

(M2 on Figure 19)

King Gordon spring is situated 2 km east of Brolga Spring and occupies ~18 ha. This is a large vegetated mound containing rainforest and vine thicket patches surrounded by moats, and standing pools of water at variable depth (Figure 32). The outlier saline mudflats comprise *Melaleuca* shrubland over sedges, vines and grasses.

Figure 32. High water levels within internal moats – photo Jill Pryde.

One permanent 50x50 m^2 quadrat (KMS015) was established within the central raised mound, containing closed-open rainforest, dominated by *M. leucadendra* (<30m) with *Carallia brachiata, Nauclea orientalis, Timonius timon* providing ~60-70% cover. The understory comprised scattered *P. spiralis* with dense layers of vines including *F. indica* and a rampant climbing vine *Luffa aegyptiaca* over *T. domingensis* and *Cyperus* sp. and ferns over a dense layer of fallen *Pandanus* branches and litter. Scattered internal pools of water (<75 cm deep) contained a thick layer of decayed vegetated material in combination with aquatic herbs *U. aurea* (P2) (Figure 33), *L. aequinoctialis*, and *Nymphaea violacea*, aquatic ferns, including *C. thalictroides*, vines and creepers and grasses including *Fimbristylis* sp. Soils were dark grey clay below a dense leaf layer. General condition was Excellent (Bush Forever scales). Average flora species richness was 10-25 and the number of weeds species was low. *M. leucadendra* trees showed signs of recent fire. was recorded No obvious sign of threats were noted however cattle are likely to utilise the springs.

Figure 33. Priority 3 aquatic herb *Utricularia aurea* found in majority of sites surveyed –photo Mike Lyons

5.4.12 Bamboo Spring (Potential spring02)

(P2 on Figure 19)

Bamboo Spring (Figure 34) is located 3 km east of King Gordon Spring and lies adjacent to inlets draining from the north west. The spring was elongated in shape and occupied ~23 ha. No comprehensive vegetation survey was undertaken due to highwater levels, however opportunistic flora specimens were collected (KMS016A). Peat and water were sampled and a partial boundary reconnaissance, focussing along the western periphery.

Figure 34. Bamboo Spring – photo D. Chemello

This spring was mostly inundated by water at various depths (20-75 cm) and dominated by *M. leucadendra* (~90% cover) perched on pockets of higher ground with the ferns including *A. aureum* in combination with *T. domingensis* and *Cyperus* sp. Internal pools contained the violet-white flowering *N. violacea* (Figure 35) and thick mats of decayed aquatic herbs including, *L. aequinoctialis, U. aurea* (P2) and a hornwort, *C. demersum*. An open moat (>75 cm) surrounded the central mound and contained *T. domingensis, N. violacea* (Figure 31) and aquatic herbs including, *L. aequinoctialis, U. aurea* (P2) and Indian water fern *C. thalictroides*. Soils were black organic peat. The surrounding shrubland contained *Melaleuca* spp. and *Acacia* spp. over mixed sedges of *Cyperus* sp. and grasses, including *S. lingulata*. Vegetation condition was Excellent (Bush Forever scales).

Figure 35. Flowering *Nymphaea* sp. present within internal and external moats – photo Mike Lyons.

5.5 Recommendations

- Determine whether additional springs surveyed align with the Victoria-Bonaparte Wetlands priority 1 ecological community. This would require further hydrological investigation and additional vegetation survey;
- Design and implement a project to determine the hydrological drivers of the mound spring ecosystem;
- Design and implement a monitoring program that utilises quadrats established during the current survey. This will probably require establishment of a more comprehensive network of quadrats, and should be designed to provide information about the success of land management in the sensitive environment of the mound spring ecosystem;
- Seek funds for fencing of the mound springs to restrict cattle access; and

- Determine whether weeds are likely to become a major threat and seek ways to management them.

5.6 Conclusions:

Based on observations from this partial survey, the majority of mound springs surveyed are likely to align with the Victoria-Bonaparte Wetlands priority 1 ecological community. Once all results of the August 2017 survey are reconciled, it is likely that additional occurrences will be added to the TEC database and boundaries will be delineated. Over time it will be valuable to build up a uniform dataset for springs for a broader regional analysis.

It is recommended that a full nomination be prepared and presented to the W.A. Threatened Species Ecological Communities Scientific Committee for formal assessment.

6 Ecological Community Assessment of the Bunda Bunda organic mound springs of the west Kimberley

Jill Pryde

6.1 Introduction

Assemblages of Bunda Bunda organic mound springs of the west Kimberley was endorsed as Vulnerable threatened ecological community (TEC) by the WA Minister for the Environment on 8 May 2002. There are two known occurrences totaling 27 ha that occur over a range of 1.2 km. They represent one of the most southerly occurrences of rainforest in Western Australia. The rainforest species of this community are common to rainforest patches across northern Australia, many of which have much greater species diversity, but are unusual in such a seasonally arid environment.

6.1.1 Setting

These coastal springs are located on tidal mudflats in Carnot Bay on the Dampier Peninsula north of Broome (Figure 36). The mound springs lie on a shallow aquifer of surficial sediments, over a major unconfined freshwater aquifer in the Broome Sandstone which meets a saltwater wedge along the coast. The mound springs were identified by Department of Water (2017) as ecosystems with high probability of groundwater-dependence.

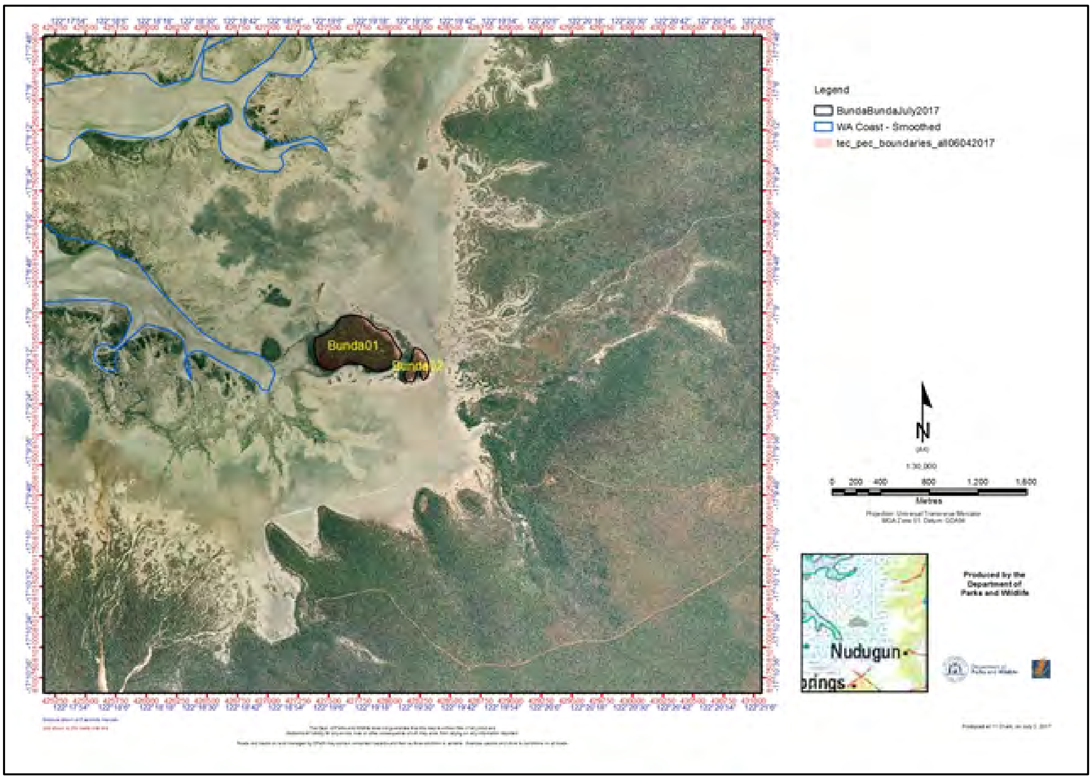

Figure 36. Current mapped boundaries of Bunda Bunda mound springs TEC.

6.1.2 Current description:

The two known occurrences of these peaty mounds rise above the surrounding tidal flats (Figure 37) and are composed of accumulated leaf litter and living vegetation, supporting a dense rainforest (closed forest - Figure 38) and a tall shrubland respectively, each with mangroves in concentriform arrangement. The smaller mound is dry in the centre, but encircled by a moat, fed by permanent freshwater seepage. The larger mound is wet and incompletely enclosed by a leptoscale channel or moat of variable depth which broadens to a microscale saline lake (300 m long, 50 m wide) on the north side. The moats and pools are saline and occasionally inundated during large tides.

Figure 37. View of mudflats mostly devoid of vegetation – photo Jill Pryde.

Figure 38.Edge of dense rainforest patch – photo Mike Lyons.

The western end of the larger mound is covered by a very dense (closed) forest dominated by evergreen *Carallia brachiata* trees to 20 m and a bracken-like layer of the fern *Cyclosorus interruptus* (to 1 m) (Figure 38). This is the most southerly population of *Carallia* in Western Australia. A few *Timonius timon* and dragon trees *Sesbania formosa* occur. The east end of the island is slightly lower, moister and the leaf litter forms a 'spongier' substrate. It is covered by tall closed forest (< 20m) of *Melaleuca cajuputi, T. timon, S. formosa* with fewer *C. brachiata* and an understory of *C. interruptus.* Creepers including *Cassytha filiformis* and the broadleaved *Secamone elliptica*, drape from trees, and climbing maidenhair ferns *Lygodium microphyllum* form a curtain which filters the light. In the moat-like channel surrounding the large mound are mangroves and the mangrove fern *Acrostichum speciosum*, with an occurrence of the uncommon mangrove *Lumnitzera racemosa* on the eastern side. An endemic (Kimberley) mistletoe, *Amyema dolichopoda* also occurs on the site. The two mounds differ from each other and there is considerable spatial variation in vegetation within each site. There is a clear zonation in the vegetation around the smaller south-western mound spring. It is fringed by a ring of mangroves, predominantly *Rhizophora stylosa* and *Avicennia marina*. Within this lies a band of *A. speciosum* and trees of *M. cajuputi* and *T. timon* to 12 m.

In the dry centre of the island is a tall shrubland dominated by *Acacia neurocarpa* (<5m), over grasses and sedges. The mudflats around the two mounds are mostly bare of vegetation, however a *Sporobolus* sp. grassland occurs closer to the shore.

6.1.3 2017 survey

A survey of the Bunda Bunda organic mound springs was undertaken on 7 August 2017 by a team with expertise in TEC identification and inventory, biological survey including flora and vegetation, aquatic invertebrate fauna identification and wetland inventory. The survey was coordinated by the Kimberley District Nature Conservation Coordinator, with cooperation and assistance of Traditional Owner group, Djaberadjabera and Nyul Nyul Rangers.

Bunda Bunda mound springs are surrounded by coastal tidal mudflats north of Broome on unallocated Crown land (UCL). Access to the springs is via Crown Reserve 22615 Carnot Bay, with permission of the Traditional Owners. Site visits are recommended during low tide at which time crocodiles are less likely to be present in the area.

The aim of the survey was to update TEC baseline information, including description, condition and threats to the TEC and to establish permanent quadrats to record flora and vegetation and inventory of aquatic invertebrates, soils and water chemistry and to update boundaries of the wetland communities as required.

This section covers the TEC aspect of the survey, will assist with the development of a recovery plan, and provides recommendations for management.

6.2 Methods

6.2.1 Bunda 01 (Occurrence 01)

The following was recorded:

- general vegetation description, condition and structure across the mapped community;
- A flora list (refer to Mike Lyons' lists) for vegetation within the quadrat and at random locations throughout the mound spring community;
- threatening processes; and
- management recommendations compiled.

In conjunction with the above, one site was selected to establish a permanent $50x50^2$ m quadrat upland from a seepage zone in the north west of the occurrence in tall dense rainforest community over a dense undergrowth of ferns, thick leaf litter, climbing vines and ferns. The quadrat was permanently marked with one 1.6 m star picket at NE corner site id KMS017A. Quadrat data (held by M. Lyons) for site include:

- GPS location;
- vegetation description, stratum and structure;
- soil and landform;
- flora specimens were taken from the mound springs seepage areas and damplands surrounding the springs. Flora specimens were collected by Mike Lyons and Jill Pryde. Additional flora collected by M. Coote and A. Turnbull;

and

- Aquatic invertebrate survey, peat core and water chemistry in an area of standing water, located in the south east portion of the occurrence by A. Pinder, K. Quinlan and T. Sonneman.
- Assessment and mapping by the Wetlands group (M. Coote and A. Turnbull) using a handheld GPS in conjunction with aerial photography.
- Photographs of occurrence and surrounding landscape.

These data will be added to the corporate TEC/PEC database when available.

6.2.2 Bunda 02 (Occurrence 02)

No survey undertaken of flora and vegetation, aquatic invertebrates, peat core or water chemistry, however

- A brief edge survey was undertaken to assess vegetation condition and threats.
- Photographs taken.

6.2.3 Potential new occurrence

A vegetated mound that lies 215 m west of Bunda01, not recorded on the TEC database, is likely to align with TEC database identifier Bunda02 (Occurrence2) and appears to have been incorrectly documented on TEC database.

Wetlands group assessed and mapped the “potential new” mound spring using a handheld GPS in conjunction with aerial photography.

6.3 Limitations

One day was allocated to survey Bunda Bunda organic mound springs TEC and as a result limited the capacity to conduct a full assessment on status and condition across the entire community.

6.4 Results

Survey at Bunda Bunda organic mound springs TEC was undertaken to coincide with low tide. The TEC comprised two mapped occurrences (Bunda01 and Bunda02) which are situated about 300 m from the shoreline, approximately 30 m apart. The larger mound (Bunda01) occupies (~22.8ha), with the smaller mound (Bunda02) (~3.6ha) and occurs lower in the landscape. The vegetated mound that lies west of Bunda01 was briefly surveyed for consideration of addition to the TEC database. This spring occupies ~3.8 ha.

6.4.1 Bunda01 (Occurrence01)

Bunda01 is a large vegetated mound surrounded by moats, stream channels and standing pools of water of variable depth. The outlier saline mudflats comprise occasional mangroves, sedges, grasses including *Sporobolus* sp. and chenopods. A shrubland-woodland that encircles the mound includes *Melaleuca cajuputi*, mangroves, and mangrove fern *A. speciosum* as well as the occasional *S. formosa*. In the north west portion of the mound, rising from the mudflats, vegetation transforms into a dense, closed rainforest, dominated by *C. brachiata* (>20m), *T. timon* and *Mallotus nesophilus* over a dense stratum of *C. interruptus* >1 m and thick accumulated leaf layer (Figure 39). The climbing fern, *Stenochlaena palustris* and climbers, *Gymnanthera oblonga* wrap around trees. The eastern and southern portion of the mound is lower in the landscape and has standing water <50 cm in depth, contains scattered leaf litter, aquatic herbs, and ferns. Saturated peaty black soils and thick leaf litter combine to form a quaking substrate. This portion of the community is covered by a tall closed forest (>20m) of *C. brachiata, T. timon, S. formosa* and *M. cajuputi* over *C. interruptus*, climbing maidenhair fern, *L. microphyllum* and vines.

Figure 39. Dense rainforest patch quadrat (KMS017A) site and Traditional owner Preston Cox – Photo Jill Pryde.

General condition was excellent (Bush Forever scales). The total number of weed species was low, however the stinking passion vine (*Passiflora foetida* var. *hispida*) is likely to become a major threat to the community (Figure 40). In exposed patches it has smothered native vegetation. In the quadrat it was recorded at low density. Introduced fruit trees, including bananas plants (*Musa acuminata*), which occur in the south east portion of the occurrence (Figure 41), are likely to spread if not contained and likely to outcompete native plant species. Damage by cattle is evident where they have encroached wetter areas of the mound springs, primarily in the seepages in the south east and north west.

Figure 40. The weed *Passiflora foetida* var. *hispida* is likely to become a major threat - photo Mike Coote.

Figure 41. Banana plants in south east portion of mound spring – photo Mike Lyons.

Findings of the August 2017 survey in regard to flora and vegetation description and component flora species is mostly consistent with the historical TEC database record. Flora species previously recorded were found across the mound springs, however additional flora recorded will be added to the TEC database. No DRF or Priority flora was found. Range extensions for flora taxa were documented. Plant species considered useful indicators of rainforest communities and associated mound springs were present. The key threats identified for the mound springs are grazing, weed invasion, altered fire regimes, feral animals, potential hydrological changes (e.g. groundwater extraction) and tourism development.

6.4.2 Bunda 02 (Occurrence 02)

(Bunda02 on Figure 19)

A brief edge survey of Bunda02 (Figure 42) recorded a vegetation community with open structure which appears much dryer with no apparent moat or standing water. Based on observations from this partial survey, no mounding was evident. Vegetation comprised a woodland of *M. cajuputi, T. timon* and *A. neurocarpa* with little understory. The periphery of the community contained mangroves, predominantly *Rhizophora stylosa* and *Avicennia marina*. Records indicate that this occurrence was burnt in October 1995, which may account for the open canopy and lack of peat mounds. Vegetation remained in Good condition (Bush Forever scales).

The key threats identified for the mound springs are grazing, weed invasion, altered fire regimes, feral animals and potential hydrological changes (e.g. groundwater extraction) and tourism development.

Following the survey, mapping of the Bunda Bunda organic mound springs boundaries will be refined. Based on records from previous surveys the area identified as Bunda02, located east of Bunda01 appears to be incorrect. S. Black (2002) noted this area as “*Melaleuca* island”. Survey is required to clarify if Bunda02 and the potential new occurrence constitute the TEC. This issue was raised by Environs Kimberley [email dated 22 May 2017].

Once all results of the August 2017 survey are available, the TEC database will be updated and include amendment and refinement of TEC boundaries, taxonomic flora list updates and other biota.

Figure 42. View of Bunda02. Photo Jill Pryde.

6.5 Conclusions

The most significant threats to the integrity of Bunda Bunda mound springs are disturbance from cattle, weed invasion and too frequent fire. Cattle utilise water surrounding the community and vegetation for protection. Damage can be seen in the understory, especially in the areas of ponding water and wetter sites where trampling impacts are evident (Figure 43). Cattle also cause damage to soil structure and provide unwanted nutrients affecting water quality. The stinking passion flower is likely to become a major threat if not managed. In some locations of the community the stinking passion flower is forming dense mats, smothering vegetation. This is likely to limit growth of native vegetation and modify the structure. The historically planted fruit trees, including banana plants, which occur in Occurrence01, should be removed. However, this action is likely to necessitate negotiation with Traditional Owners.

Figure 43. Trampling by cattle evident in the understory – photo Jill Pryde

6.6 Management Recommendations:

- Seek funds to fence the mound springs complex to restrict cattle entering the TEC;
- Map *Passiflora foetida* var. *hispida* across the community and seek ways to control or eradicate the highly invasive weed;
- Seek ways to remove fruit trees, particularly banana plants within Occurrence01;
- Design and implement a project to determine the hydrological drivers of the mound spring ecosystem;
- Design and implement a monitoring program that utilises quadrats established during the current survey. This will probably require establishment of a more comprehensive network of quadrats, and should be designed to provide information about the success of land management in the sensitive environment of the mound spring ecosystem;
- Determine whether Occurrence02 constitutes the TEC and if the vegetated mound to the west of Occurrence01 constitutes a new occurrence of the TEC. This would require hydrological investigation and vegetation survey.

7 Survey of Assemblages of Big Springs organic mound springs of the west Kimberley

Jill Pryde

7.1 Introduction

The assemblages of Big Springs organic mound springs were endorsed as Vulnerable threatened ecological community (TEC) by the WA Minister for the Environment on 8 May 2002.

7.1.1 Setting

Big Springs organic mound springs (Figure 44) are situated on the eastern shore of King Sound, adjacent to the boundary of Meda Station. They are situated 12 km east of the mouth of Meda River and 80 km north of Broome (Figure 45) and surrounded by saline coastal flats (Appendix 1). There are 23 occurrences covering a total of 62.7 ha recorded across a range of 3 km.

The occurrences are confined to unallocated Crown land (UCL) surrounded by Meda Pastoral Lease. Access overland to the TEC is through Meda Station.

Figure 44. Big Springs organic mound springs – photo J. Pryde.

Figure 45. Mapped occurrences of Big Springs Mound springs.

7.1.2 Current description

A complex system of freshwater seepages and peaty springs with internal moats with broad tidal flats on the seaward margin and cracking clay flats on the landward margin. A further feature is the scattered clusters of small outlying, densely vegetated mound springs. The main seepage area has an extensive outflow swamp on its north west side. Within the complex, the substrate varies from peat through to peaty grey clay to grey clay. The main seepage area supports well developed rainforest vegetation (Figure 46) dominated by forests of *Terminalia microcarpa*, a species not otherwise known south of Walcott Inlet, 90 km to the north east. Several mistletoe species (Loranthaceae) have been recorded in the *Terminalia* canopy, which reaches 20 m in places. Other trees present include cluster fig *Ficus racemosa,* banyan fig *F. virens,* the paperbark *Melaleuca leucadendra*, *Pandanus* sp., dragon tree *Sesbania formosa* and *Timonius timon*. Many fewer common species noted were *Antidesma ghaesembilla, Diospyros maritima* and Leichardt *tree Nauclea orientalis*. The understory varies from central open glades with turf of *Cyperaceae* to pure leaf litter under the *Terminalia* canopies. Internal moats support the mangrove fern *Acrostichum speciosum*. Patches of duckweed *Lemna aequinoctialis* and less commonly, hornwort *Ceratophyllum demersum* occur. One population of climbing swamp fern *Stenochlaena palustris* was noted. The outer perimeter of the large seepage feature is relatively dry in most places with this ring generally dominated by dense thickets of *Melaleuca alsophila* and/or *Acacia ampliceps* with scattered *Bauhinia cunninghamii*, Chinese lantern *Dichrostachys spicata* and occasional boabs *Adansonia gregorii* of small stature. In the north west there is a perimeter swamp with extensive beds of narrowleaf cumbungi *Typha domingensis* and the sedge *Schoenoplectus litoralis*, with the occasional white-flowered black mangrove *Lumnitzera racemosa*. Outlying mound spring islands on tidal flats vary markedly in size and diversity of vegetation. Some of the smallest islands consist solely of *Typha domingensis*. Larger examples often feature *Pandanus spiralis, Sesbania formosa, Acacia neurocarpa* and occasionally *Terminalia microcarpa* and *Ficus* sp., with a range of *Cyperaceae*. Several islands were noted with unusual associations such as *Typha* growing with the mangrove *Lumnitzera* sp.

Figure 46. Diverse overstorey of Big Springs mound springs - photo M. Lyons.

7.1.3 2017 survey

A survey of Big Springs organic mound springs was undertaken on 9 August 2017 by a team with expertise in TEC identification and inventory, biological survey including flora and vegetation, aquatic invertebrate fauna identification and wetland inventory. The survey was coordinated by the Kimberley District Nature Conservation Coordinator, with collaboration of Traditional Owner group, Warwa and Meda Pastoral Station management.

The aim of this survey was to update TEC baseline information, including description, condition and threats to the TEC, to establish permanent quadrats to record flora and vegetation, inventory of aquatic invertebrate and water chemistry and soils, and to update boundaries of the wetland communities as required.

This section covers the TEC aspect of the survey, will assist with the development of a recovery plan and provides recommendations for management.

7.2 Methods

7.2.1 Big Springs (Occurrence 01)

BigS01a and BigS01b

- general vegetation description, condition and structure across the mapped community were recorded;
- A fora list for vegetation within the quadrat and at random locations throughout the mound spring community;
- threatening processes noted; and
- management recommendations compiled.

In conjunction with the above, one site was selected to establish a permanent 50x50^2 m quadrat in the north west of occurrence in the well-developed, tall, dense rainforest community, in main seepage area. The quadrat was permanently marked with one 1.6 m star picket at NE corner, site id KMS018A (Figure 47). Quadrat data (held by M. Lyons) for site include:

- GPS location;
- vegetation description, stratum and structure;
- soil and landform;
- flora specimens were taken from the mound springs seepage areas and damplands surrounding the springs. Flora specimens were collected by Mike Lyons and Jill Pryde. Opportunistic collections by M. Coote and A. Turnbull.

and

- Aquatic invertebrate survey, peat core and water chemistry in areas of standing water (Figure 48) by A. Pinder, K. Quinlan and T. Sonneman.
- Assessment and mapping by the Wetlands group (M. Coote and A. Turnbull) using a handheld GPS in conjunction with aerial photography.
- Photographs taken of occurrence and surrounding landscape.

These data will be added to the corporate TEC/PEC database.

Figure 47. Location of Quadrat KMS018A – photo J Pryde.

Figure 48. Core samples taken within central mound – photo T. Sonneman.

7.2.2 All remaining occurrences BigS03-BigS23

Smaller outlying occurrences that are recorded on the TEC database and potential new occurrences investigated:

No survey undertaken of flora and vegetation; aquatic invertebrate, peat core or water chemistry.

Wetlands assessed and mapped boundaries of mound spring occurrences that met criteria of a mound spring, using a handheld GPS in conjunction with aerial photography. Photographs taken of vegetated mounds.

7.3 Limitations

One day was allocated to survey Big Springs organic mound springs TEC and as a result limited the capacity to conduct a full assessment on status and condition across the entire community.

7.4 Results

Survey of Assemblages of Big Springs organic mound springs TEC was undertaken on 9 August 2017 to coincide with low tide. The TEC is comprised of one large densely vegetated mound which occupies (~8.5 ha), ~128 m offshore, with 22 outlying mounds, much less developed and considerably smaller in area, ranging between ~0.20 ha -1.3 ha (Figure 49). These occurrences extend northward for approximately 3 km, along salt flat margins.

Figure 49. One of the smaller vegetated mounds to the north – photo M. Coote.

7.4.1 Big Spring (Occurrence 01)

The largest occurrence of Big Springs organic mound springs is a heavily vegetated mound to an elevation (~8m). The mound contains a mosaic of freshwater seepages, peaty springs and pools. Internal moats surround peaty mounds supporting large mature trees. Soils are brown peaty loam, mostly damp with light to very heavy leaf litter and decaying vegetation (Figure 50).

Figure 50. Dense leaf litter with aquatic herbs within extensive internal moats – photo M. Lyons.

The community structure is a tall dense rainforest (Figure 51). occurring on rises and comprising *Melaleuca. leucadendra* (>20m) with *Terminalia microcarpa, Timonius timon, Sesbania formosa, Nauclea orientalis, Carallia brachiata, Ficus virens* and *F. aculeata* var. *indecora*. Patches of understory vegetation are more open and dryer, containing *Pandanus spiralis* over small grasses and herbs including *Fimbristylis* spp. and *Eleocharis spiralis*. Below the densely covered rainforest canopy include climbers, *Gymnanthera oblong,* climbing swamp ferns, *Stenochlaena palustris* which surround trees and form dark impenetrable barriers.

Mistletoes (*Amyema* spp.) are present high in the overhanging canopy. Internal moats across the mound ranged in water depth (> 0.75 m) (Figure 52). Dominant in the moats are stands of *Acrostichum speciosum*, a large fern spreading to 3 km (Figure 53). Moats were covered with leaf litter, aquatic herbs of *Lemna aequinoctialis, Ceratopteris thalictroides* and an aquatic submerged hornwort, *Ceratophyllum demersum* forming a thick mat below the surface of the water (Figure 54). Present but not dominant was *Typha domingensis* and *Cyperaceae* spp.

Figure 51.Dense rainforest patch – photo M. Lyons

Figure 52. Woodland and moats surround the internal mound – photo K. Quinlan

Figure 53. Aquatic herbs and ferns form dense layers within internal moats – photo J. Pryde.

Figure 54. Submerged aquatic herbs – photo M. Lyons.

A woodland emerging into a shrubland encircled the mound and included dense stands of *Melaleuca* spp. with occasional stands of *Pandanus spiralis*, together with *Sesbania formosa*, *Terminalia. microcarpa, Acacia* spp. *and Fuirena umbellata.*

General condition of Big Springs was Excellent (Bush Forever scales). The number of weed species was low, however two that have potential to become a threat, including date palms located adjacent to the quadrat (Figure 55) and *Passiflora foetida* var. *hispida*. A fence that was installed in 2016 by the Kimberley District appears to have controlled cattle access (Figure 56).

Figure 55. Introduced date palms located within mound spring – photo J. Pryde.

Figure 56. Looking north along cattle exclusion fence with smaller occurrences in the distance – photo J. Pryde.

Partial survey of the remaining outlier occurrences specified less developed mounds, mostly with no standing water. All mounds lacked well-developed vegetation structure and appeared low in floral species diversity. Mounds were restricted to one or combinations of *Melaleuca* spp. *P. spiralis*, *S. formosa*, *A. neurocarpa, T. microcarpa, Ficus* sp*., Lumnitzera* spp., *T. domingensis and Schoenoplectus subulatus*. General condition of these occurrences ranged from Very Good-Degraded (Bush Forever scales). Dead tree stands and vegetation destroyed or impacted by cattle trampling was evident at some of the mounds.

The cracking clay tidal flats, surrounding these mounds is mostly devoid of vegetation at the time of survey. Stands of *Melaleuca* spp. *Acacia* sp. *P. spiralis*, *Bauhinia cunninghamii, Adansonia gregorii,* mangroves and *Sporobolus* sp. were occasionally present. A tall grassland flanks Occurrence01 and is flourishing because of the fencing that excludes cattle. There is potential for the established grassland to increase fire risk to the mound springs. Management of the grass requires consideration.

Preliminary findings of the August 2017 flora and vegetation survey is mostly consistent with the TEC database record. Flora species previously recorded were found across the mound springs, however additional flora recorded will be added to the TEC database in future. No DRF or Priority flora were found, however range extensions for flora taxa were documented. Plant species considered useful indicators of rainforest communities and associated mound springs were present. The key threats identified for the mound springs include grazing, weed invasion, altered fire regimes, feral animals and potential hydrological changes (e.g. groundwater extraction) and tourism development.

For most occurrences recorded on the TEC database, source locations were derived using aerial photography and therefore often inaccurate. Following the August 2017 survey, point location of occurrence and boundary mapping will be updated. Occurrences that do not constitute the TEC will be deleted and newly identified occurrences will be added to the TEC database.

Once all results of the August 2017 survey are available, the TEC database will be updated including amendment and refinement of TEC description and boundaries and updated flora lists and records of other biota.

7.5 Recommendations

- Design and implement a project to determine the hydrological drivers of the mound spring ecosystems and further investigate historical report that the spring is man-made.
- Design and implement a monitoring program that utilises quadrats established during the current survey. This will probably require establishment of a more comprehensive network of quadrats, and should be designed to provide information about the success of land management in the sensitive environment of the mound spring ecosystem
- Map weeds across the community and seek ways to control of the most invasive weeds.
- Devise management of the grassland occurring between Occurrence01 and the cattle exclusion fence to limit fire risk to the adjacent mound spring.
- Determine whether the small mounds constitute the TEC. This would require vegetation survey and hydrological investigation

7.6 Conclusions

The most significant threat to the integrity of Big Springs organic mound springs is disturbance from cattle. Other threats include weed invasion, too frequent fire, and potential hydrological change. Fencing was constructed in 2016 to control impacts of cattle disturbance in Occcurrence01 and as a result the vegetation in this occurrence is in Excellent condition. Date palms are likely to become a major threat if not removed.

The newspaper reports from around 1993 that stated that the spring was man made, having arisen from water seeping from a bore installed in the 1960s, and that this requires investigation. It was considered that this was very unlikely to be the case however, based on observations during the August 2017 survey, such as the presence of the large peat-rich mound, providing a stable, permanently moist suite of microhabitats that would have taken many years to form and the age of plants present. Water continues to penetrate the increasingly elevated peat layers that are likely to be the result of pressure created by local and regional hydrological forces.

7.7 References

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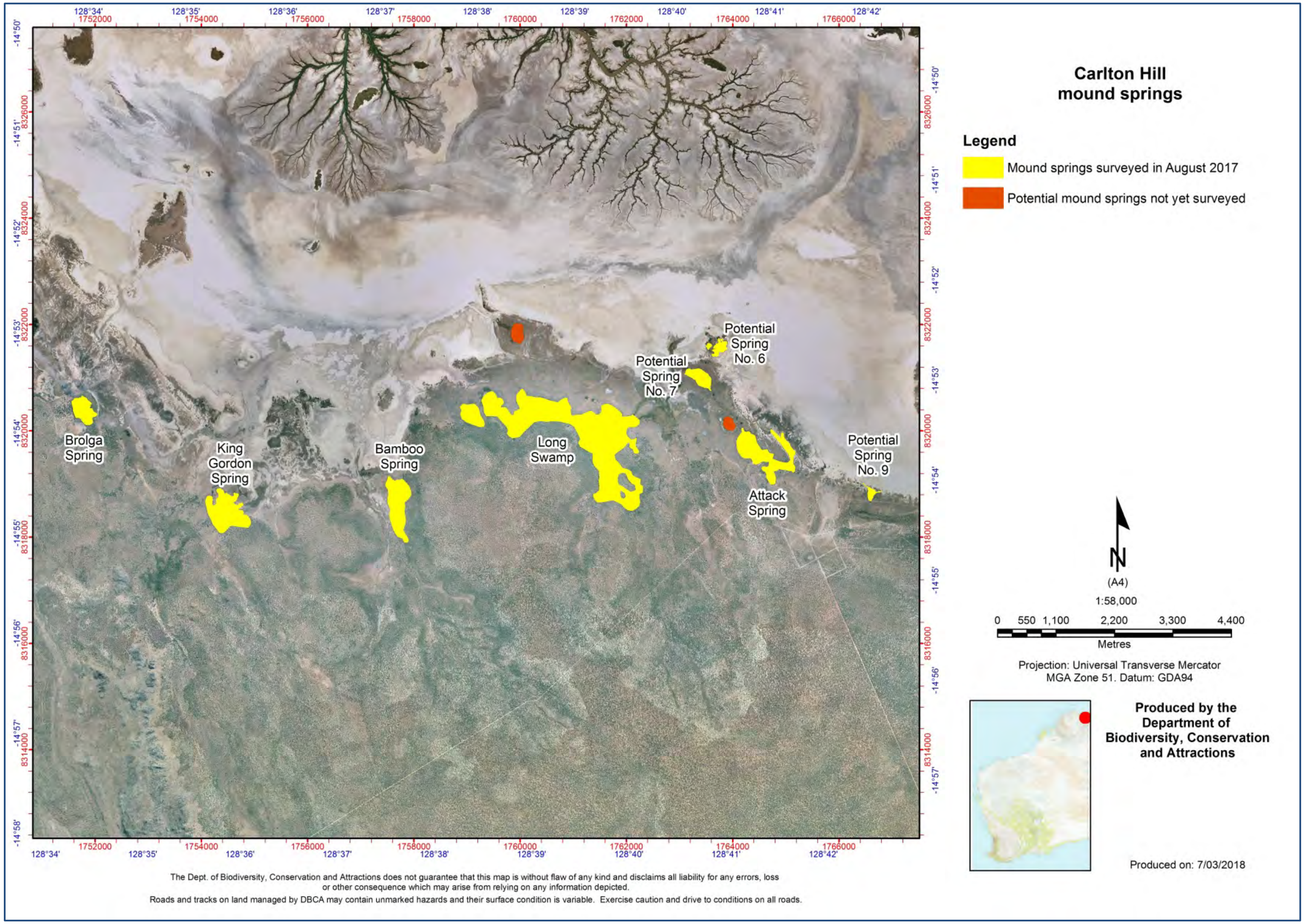
8 Mapping

Michael Coote and Adam Turnball

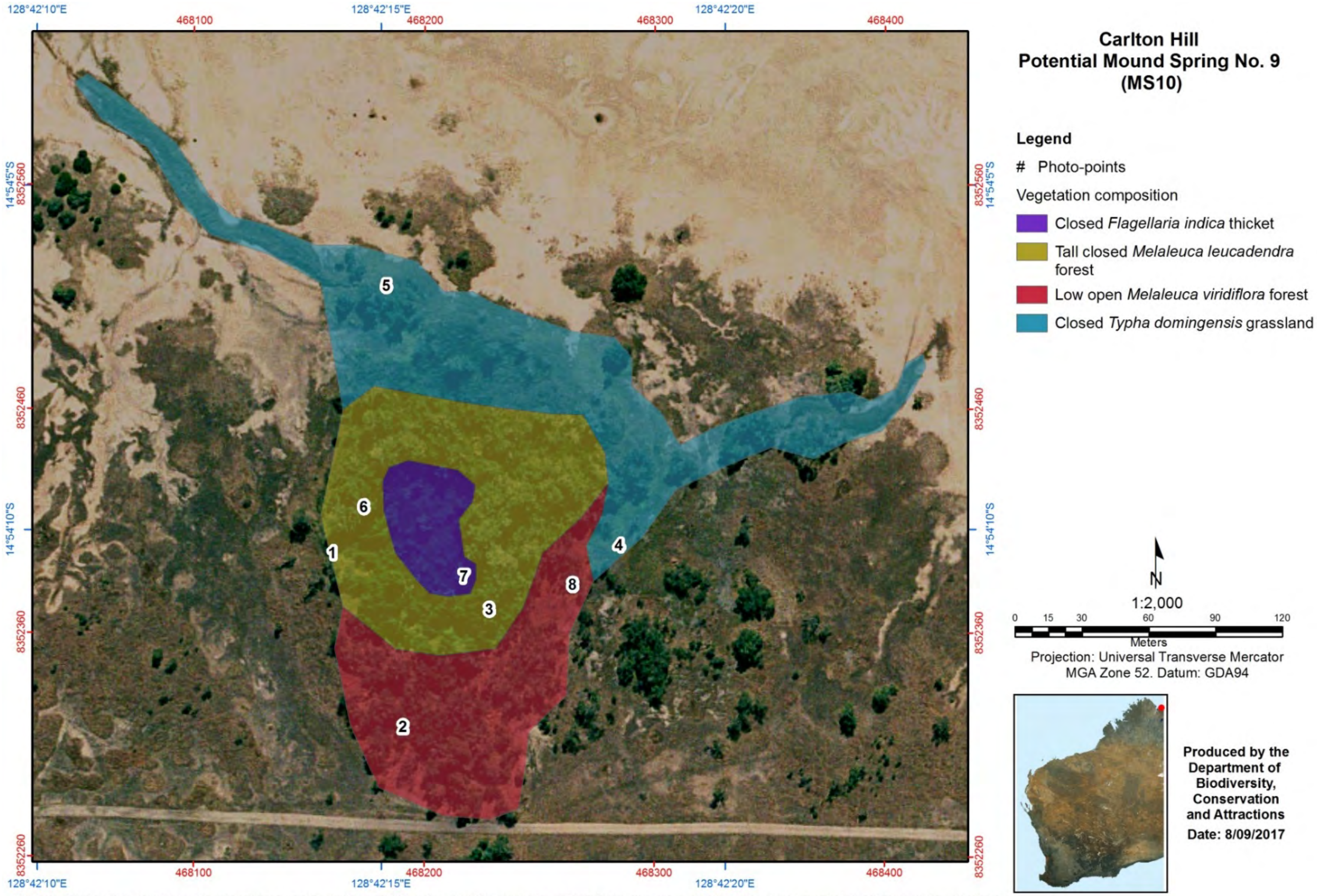
Note: At photo points depicted on the following maps, four photographs facing in the four cardinal directions were taken. They are not reproduced here but are available from Michael Coote and Mike Lyons, DBCA.

The following vegetation maps were based on foot traverses and photo point descriptions. They are necessarily preliminary given the field time available and difficulty in accessing all areas of the various springs.

Carlton Hill Mound Spring Survey – August 2017



Potential spring 9 photo-points and vegetation structure



The Dept. of Biodiversity, Conservation and Attractions does not guarantee that this map is without flaw of any kind and disclaims all liability for any errors, loss or other consequence which may arise from relying on any information depicted.
Roads and tracks on land managed by DBCA may contain unmarked hazards and thier surface condition is variable. Exercise caution and drive to conditions on all roads.
If applicable this map is based on information provided by and with the permission of the Western Australian Land Information Authority (Landgate 2017).

Potential Spring 9 - Additional notes for vegetation descriptions (see map legend for vegetation unit).

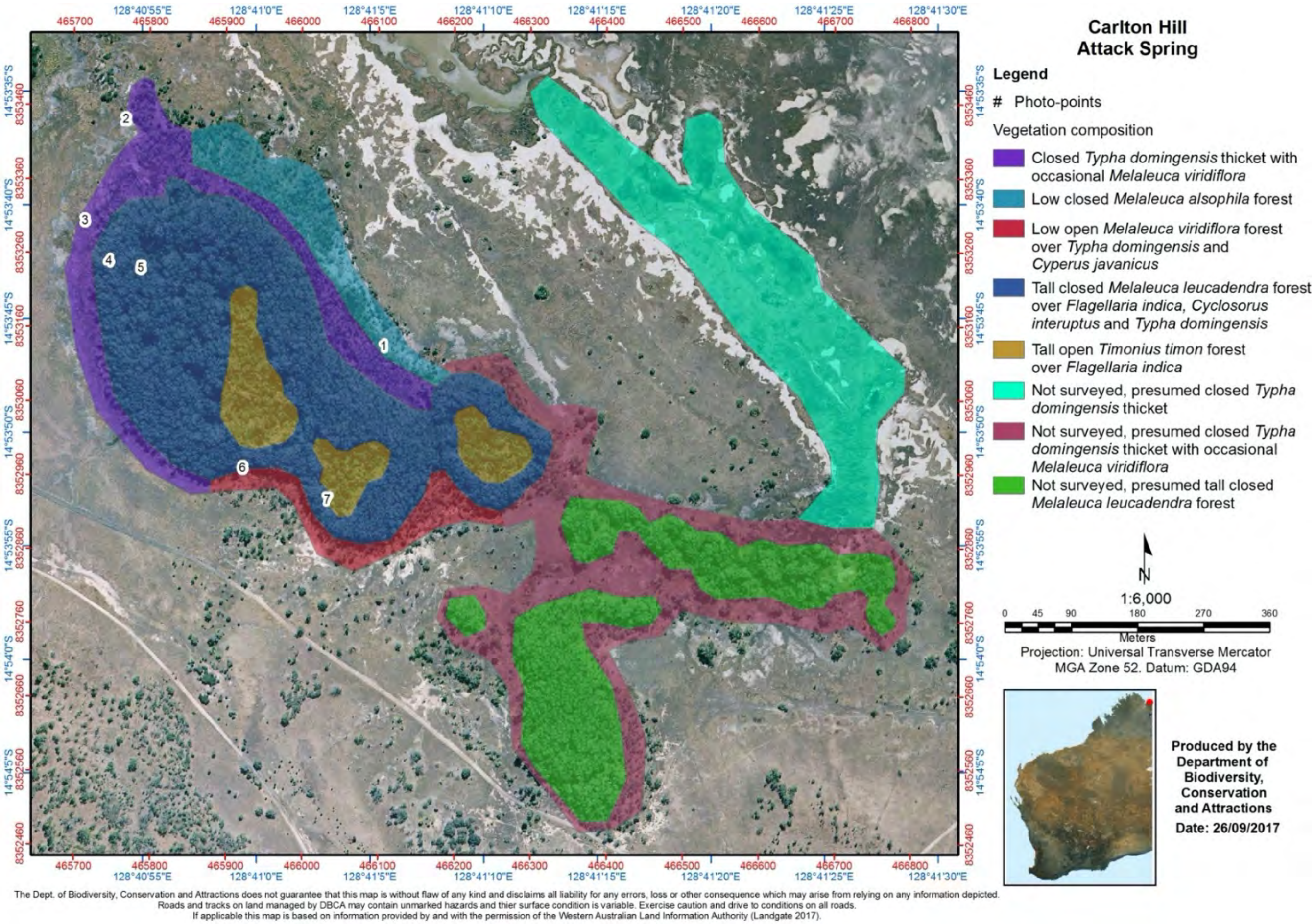
Closed *Flagellaria indica* thicket - *Flagellaria indica*.

Tall closed *Melaleuca leucadendra* forest – *Melaleuca leucadendra*; over *Flagellaria indica*, *Timonius timon* and *Sesbania formosa* in the midstorey; over *Colocasia esculenta* var. *aquatilis*, *Cyclosorus interruptus* and *Typha domingensis*. Additional taxa at boundary (photo-point 1) included *Acacia neurocarpa*, *Corymbia bella, Cyperus conicus,* and *C. javanicus*.

Low closed *Melaleuca viridiflora* forest – *Melaleuca viridiflora*, *Pandanus spiralis* and *Timonius timon* over *Acacia neurocarpa* and *A. ampliceps*, *Corymbia bella* over *Cyperus javanicus* , *Melochia corchorifolia*, *Colocasia esculenta*, *Ceratopteris thalictroides*, *Utricularia aurea* and *Marsilea* spp.; Heavy cattle pugging was noted at photopoint 2.

Closed Typha domingensis grassland – *Melaleuca viridiflora* over *Typha domingensis*.

Attack Spring photo-points and vegetation structure



Attack Spring – Additional notes for vegetation descriptions (see map legend for vegetation unit).

Closed Typha domingensis thicket with scattered Melaleuca viridiflora – Typha domingensis, Melaleuca viridiflora, Utricularia aurea and Acrostichum speciosum .

Low closed *Melaleuca alsophila* forest – *Melaleuca alsophila* , *Cyclosorus interruptus, Lemna* spp. Pugging evident.

Low open *Melaleuca viridiflora* forest over *Typha domingensis* and *Cyperus javanicus* – *Pandanus spiralis* also present in canopy with scattered *Acacia neurocarpa* and *Corymbia bella*.

Tall closed *Melaleuca leucadendra forest* over *Flagellaria indica, Cyclosorus interruptus* and *Typha domingensis*

Tall open *Timonius timon* forest over *Flagellaria indica*.

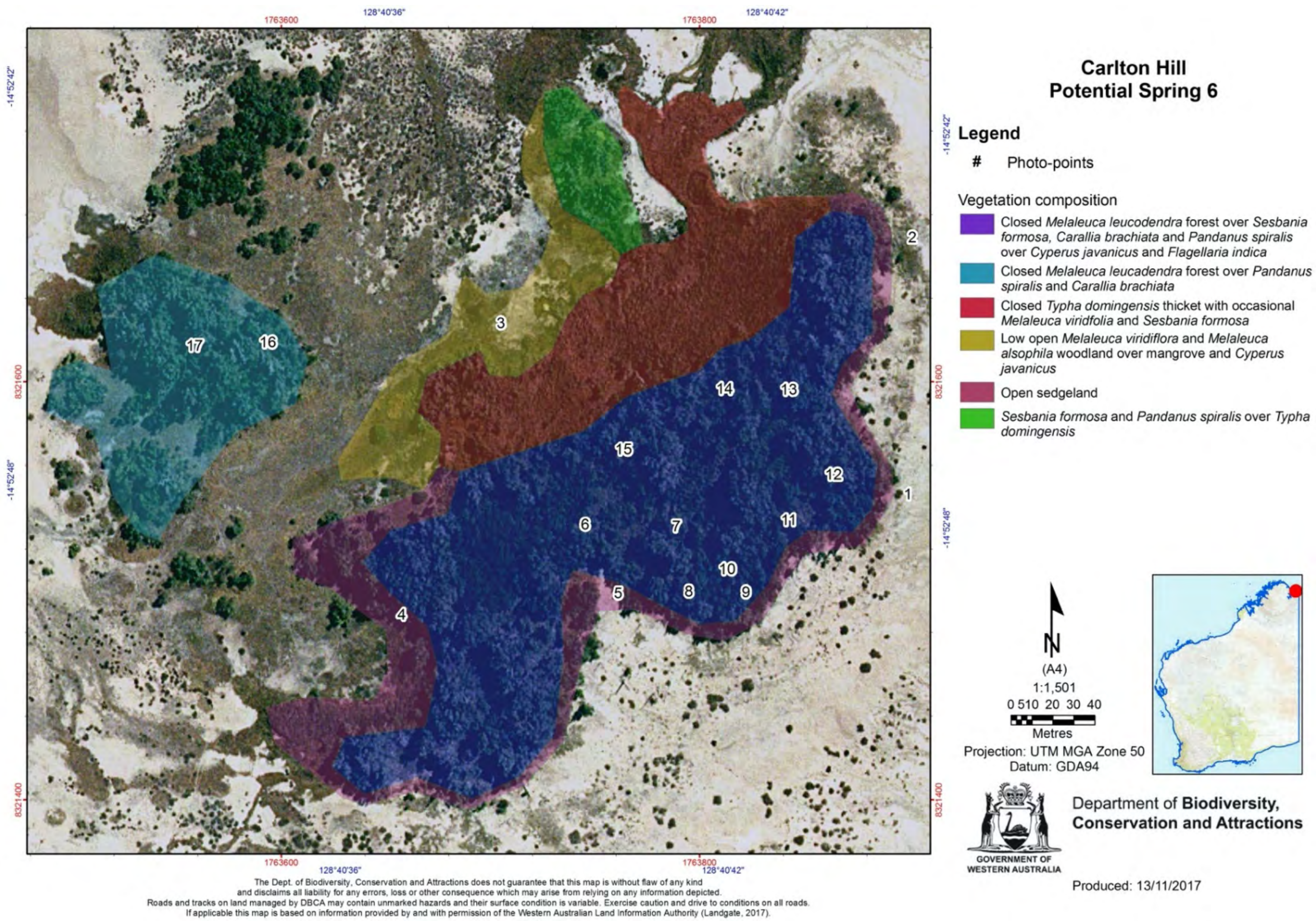
Not surveyed, presumed closed *Typha domingensis* thicket.

Not surveyed, presumed closed *Typha domingensis* thicket with occasional *Melaleuca viridiflora.*

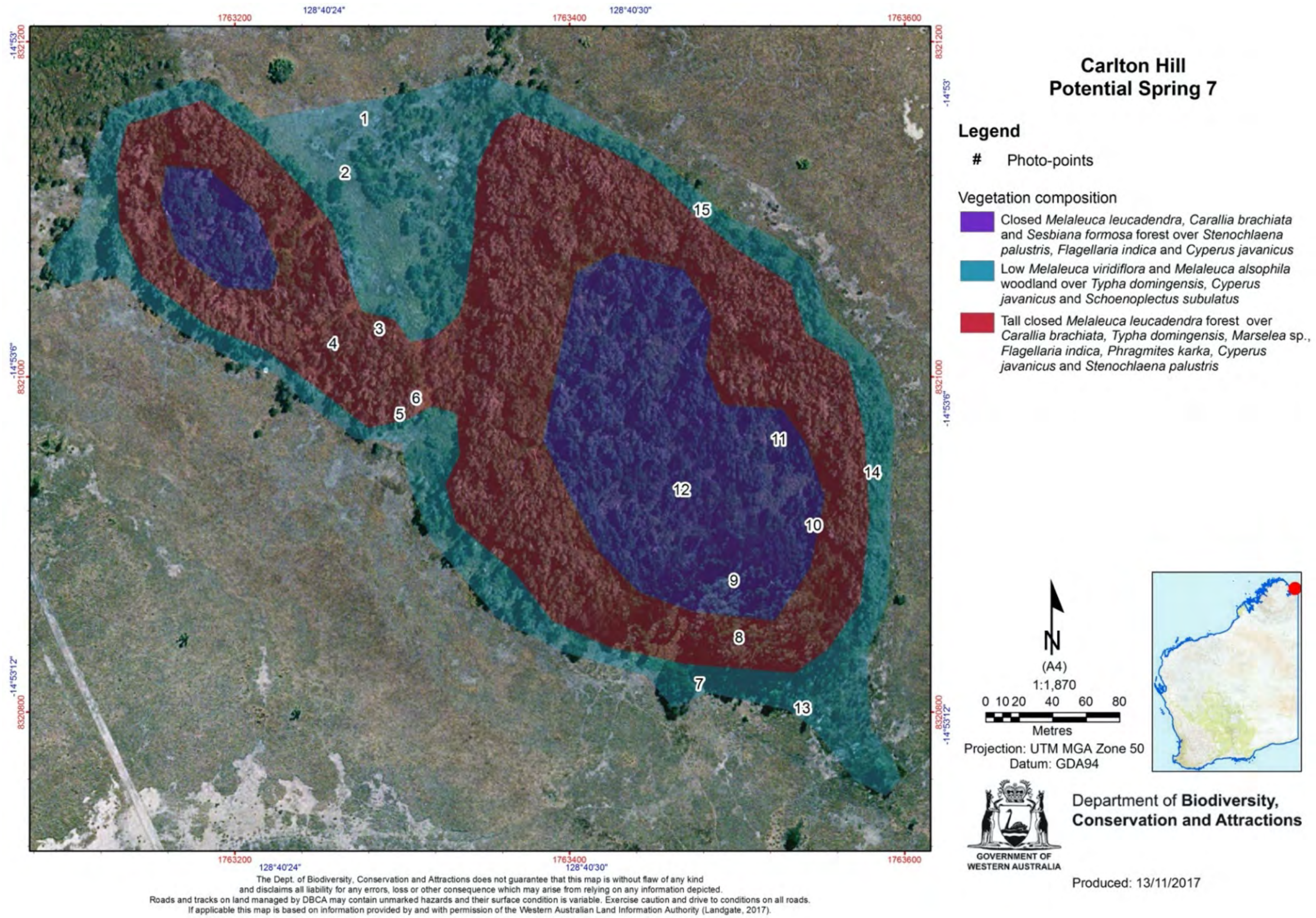
Not surveyed, presumed tall closed *Melaleuca leucadendra* forest.

Attack Spring – photographs

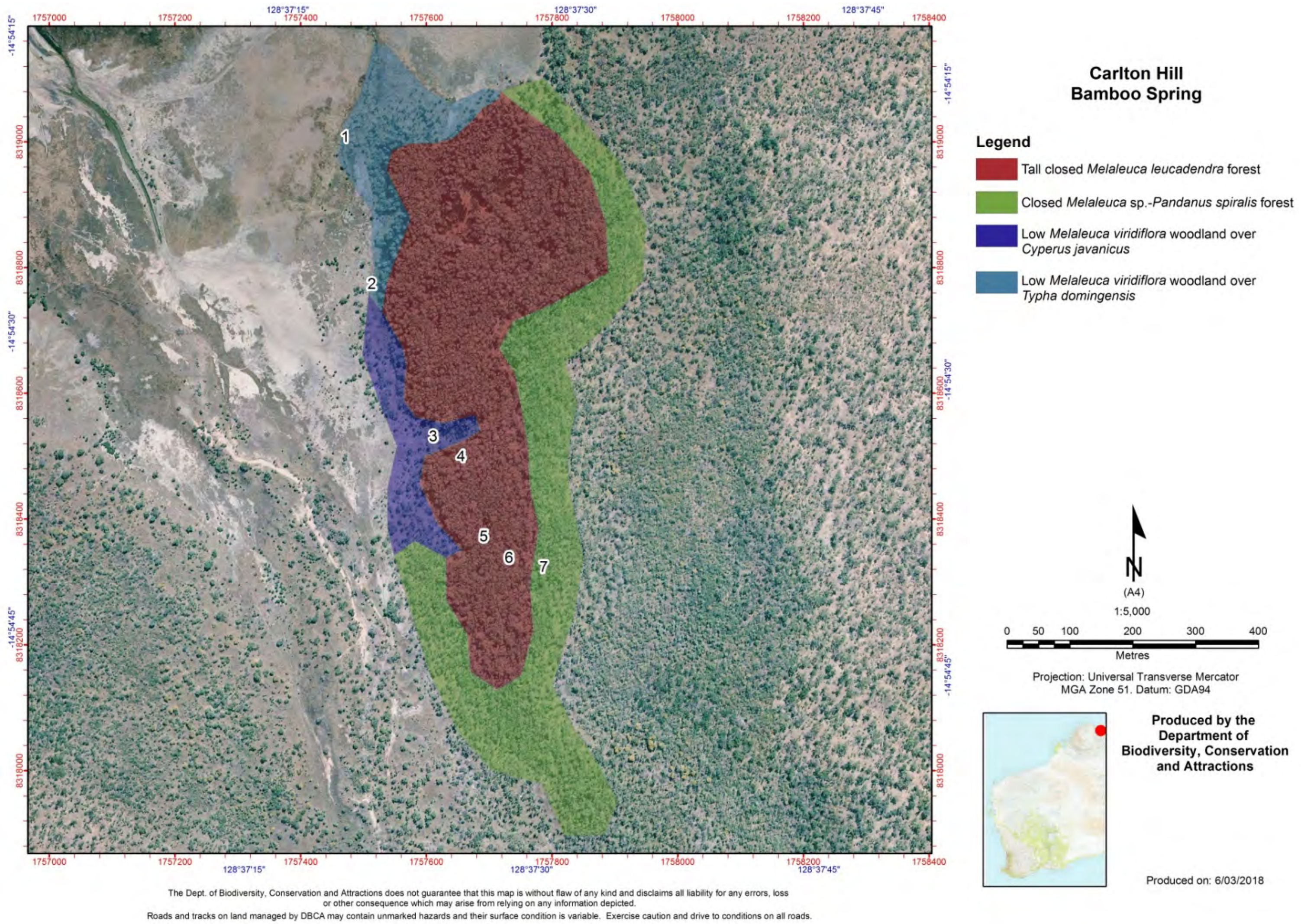
Potential spring no. 6 photo-points and vegetation composition.



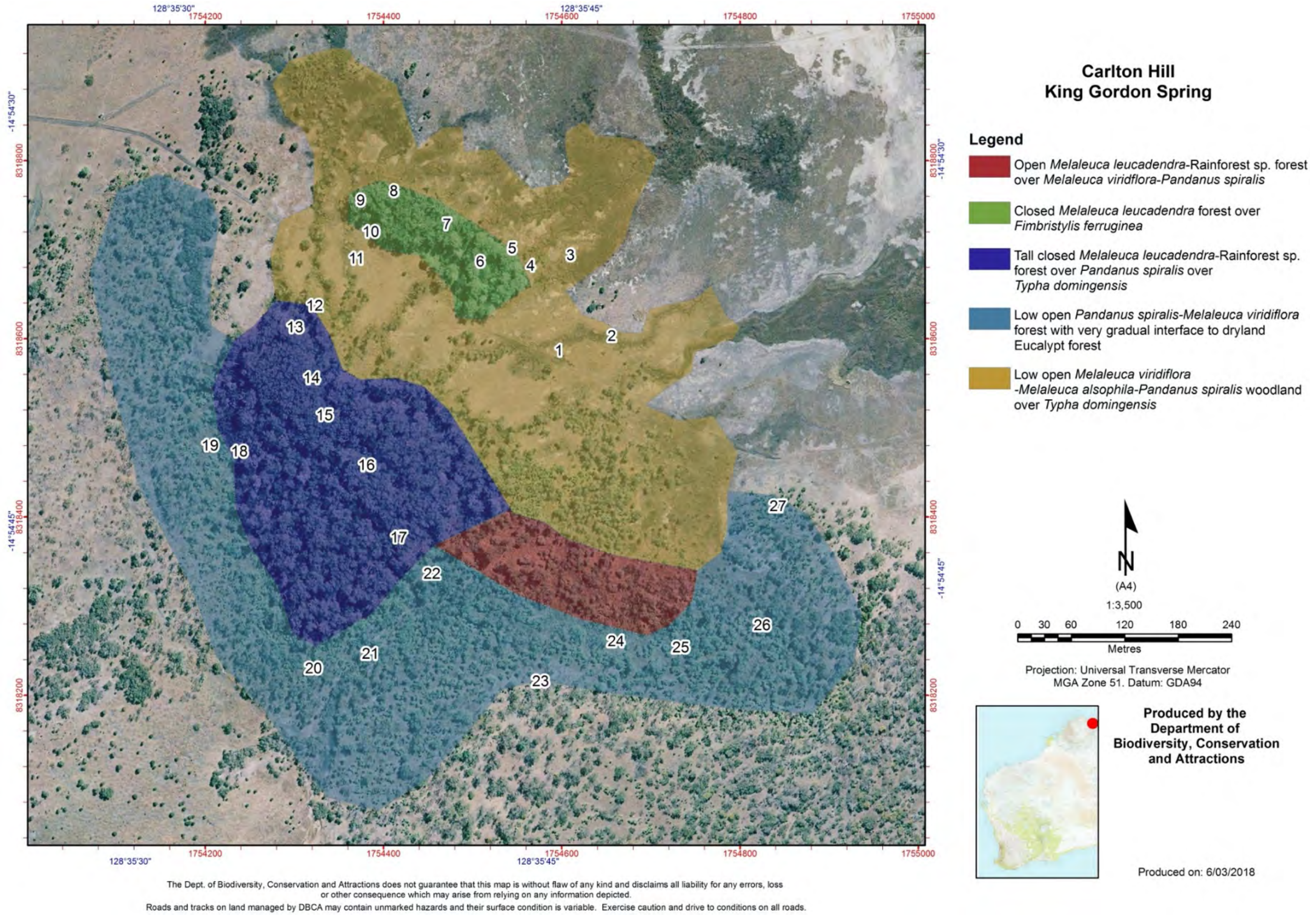
Potential spring no. 7 photo-points and vegetation composition



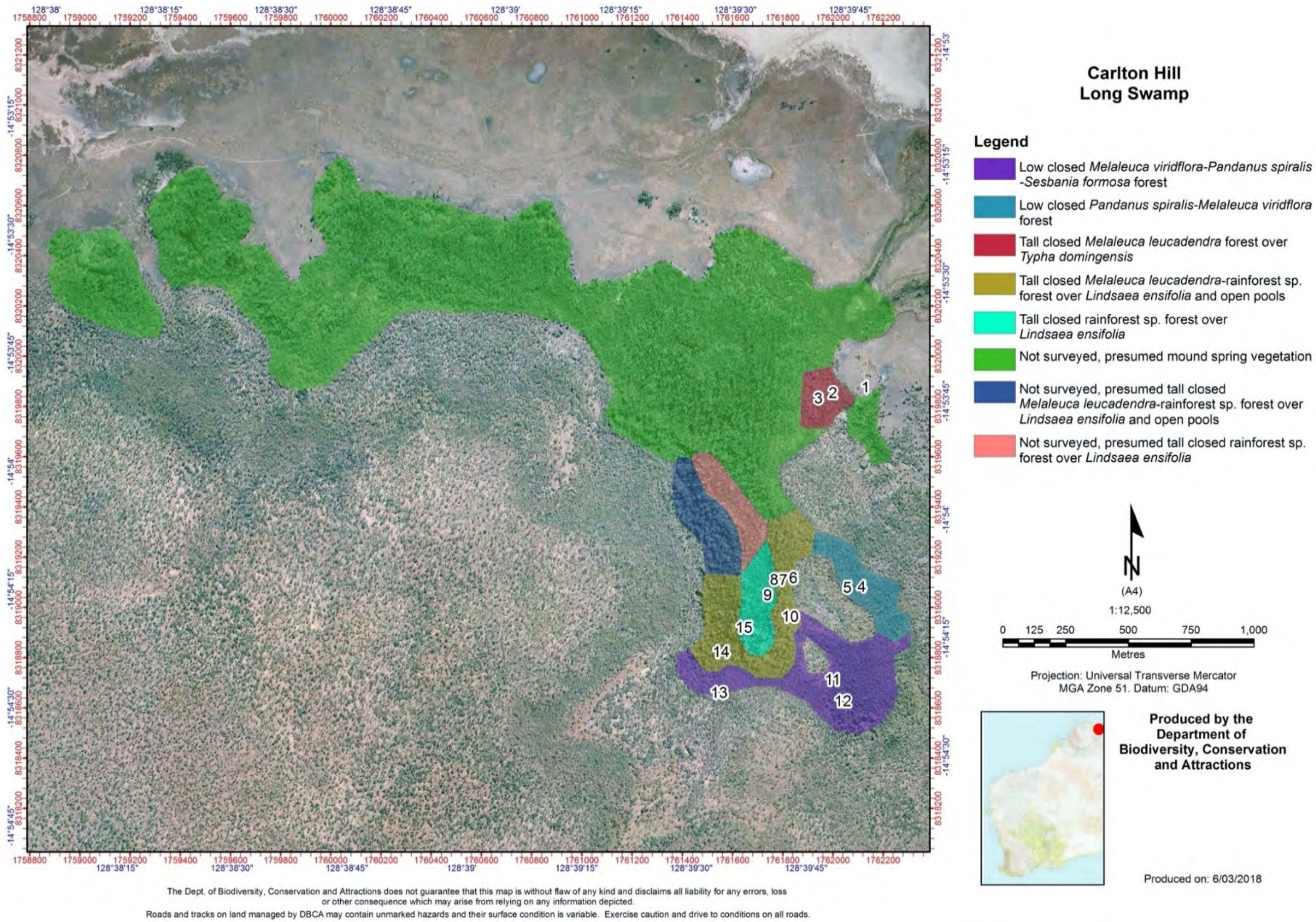
Bamboo Spring photo-points and vegetation composition



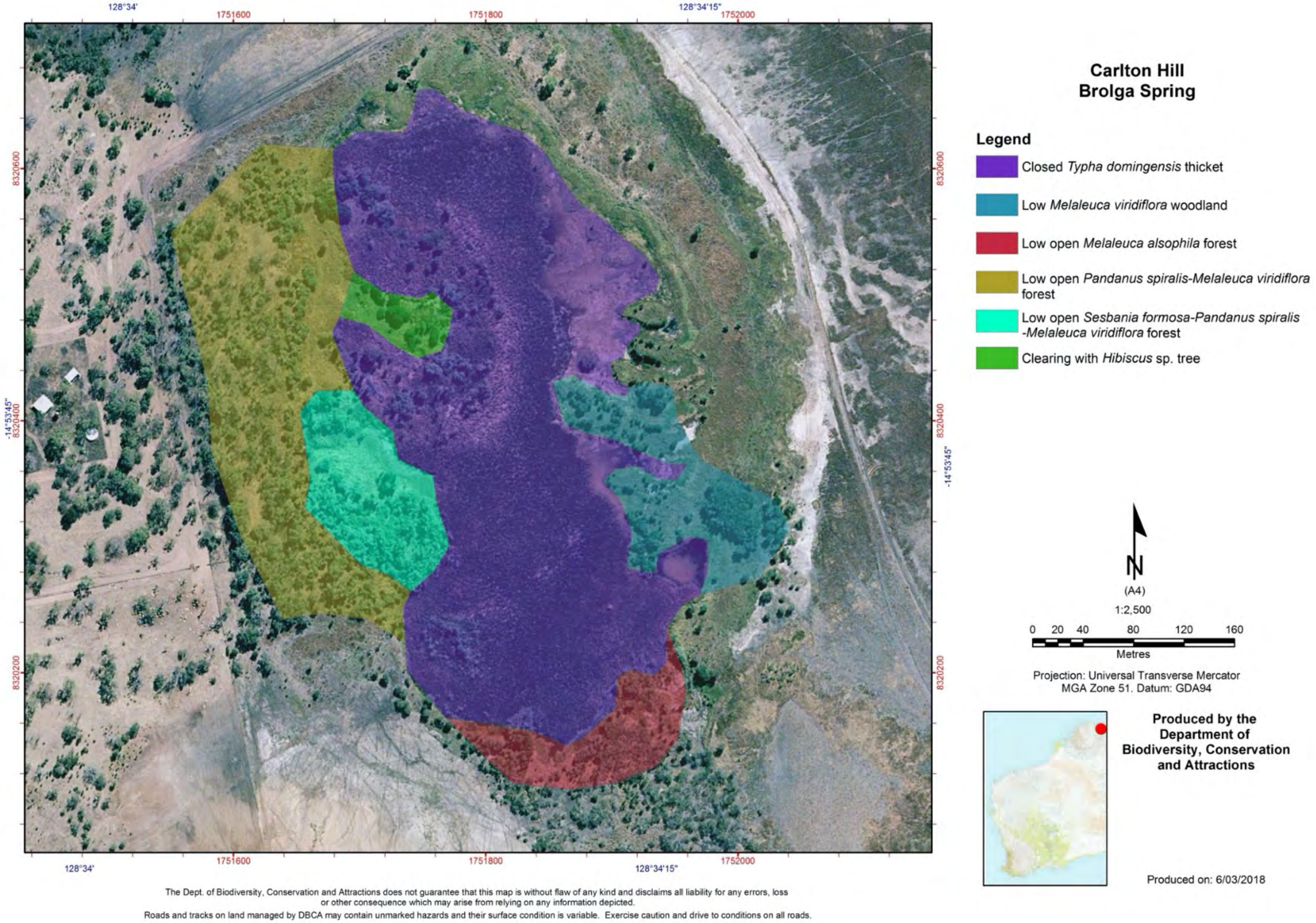
King Gordon Spring photo-points and vegetation composition



Long Swamp photo-points and vegetation communities



Brolga Spring vegetation communities



Appendix 1. Project report Invertebrate surveys 1993-2003. CALM, Species and Communities unit.

Department of Conservation and Land Management
Wetlands Conservation Project 2000 Final Report:
Conserving organic mound springs of the Kimberley Region.

1. Where the project as described in the funding application has been completed:-
   - have all of the objectives stated in the project proposal been met? - **Yes**
   - if not, which objectives have not been met and why? - **NA**
   - have you achieved more than intended? Give details. - **No**
   - did you meet the timelines indicated in the application? If no, give details. **Yes, all subcontracted flora and fauna taxonomic work completed by 30 June 2001**

2. If the project as described in the funding application has not been completed:- **NA**
   - why has the project not met the timeline your proposal put forward?
   - what changes to the proposal, if any, have occurred or will occur?
   - will all of the stated objectives be met, if not, which will not be met and why?
   - do you intend to carry any project funds over to next financial year, give details of how and how much?
   - when do you expect the project to be completed? Provide a revised timeline showing both works complete and planned.

3. Has there been any media coverage of the project (including in CALM News)? Give details and copies of articles. Where there has been no media coverage, what is planned and when?

As requested an article was written and forwarded to Nigel Higgs for publication in media of his choice. It is anticipated that an article on conserving the States' organic mound springs as threatened ecological communities will be drafted for publication in Landscope in early 2002.

4. Please provide a description of the work that has been carried out. Where possible, please include quantitative information such as metres of fencing completed, area of weeds treated, samples taken and identified, reports written etc. Where appropriate provide photographs of the work, diagrams, maps and/or reports produced.

The goal of the project was to identify the organic mound springs of the Kimberley Region as threatened ecological communities in order to conserve them. This necessitated obtaining sufficient biological data to clarify the taxonomy and distribution of poorly known groups of flora and fauna considered to be ecologically important (eg rushes and sedges, crustaceans, aquatic insect larvae, diatoms, rotifers). Specific actions were the sorting and identification of sedge plants and invertebrate fauna collected by the Project Officer during field survey. Contracts were let to sort and identify 8 invertebrate samples, and plant collections from eleven sites. Annotated species lists (Attachments 1 and 2) and a report 'Comments on Kimberley Springs sampled by Sally Black' (Attachment 3) are attached.

This data has been used to classify, define and describe the organic mound springs of the Kimberley Region as community types, so they could be added to the Threatened Ecological Communities Database and formally assessed by the WA Threatened Ecological

Communities Scientific Committee. As a result of the work the following communities have been databased and formally assessed:

- **Black Spring organic mound spring community (Endangered) (Attachment 4)**
- **Organic mound spring communities of Big Springs (Vulnerable) (Attachment 5)**
- **Organic mound spring communities of Bunda Bunda (Vulnerable) (Attachment 6)**
- **Organic mound spring community of the southern North Kimberley Bioregion (Mt Elizabeth and Drysdale River Stations) (Vulnerable –near Endangered, to be reassessed within 5 years) (Attachment 7)**
- **Lolly Well Springs organic mound spring wetland complex (Priority 1) (Attachment 8)**
- **Closed canopy rainforest on freshwater swamps on alluvial floodplain soils in the east Kimberley (Point Spring and Long Swamp) (Priority 1 – to be reassessed subsequent to further analysis of floristic survey data) (Attachment 9)**

Listing as threatened ecological communities gives these wetlands priority conservation status and the implementation of management actions has commenced with the Project Officer conducting onsite liaison with pastoral managers, lessees and LCDC members. The results of this WCP Project also provide baseline data required for monitoring purposes.

5. An itemized account of the total expenditure of the project funds **provided by CALM** is required. Please state the flexfields that have been used with a description and the amount spent against each flexfield. See below for an example.

Example of expenditure details required. (Please only include the relevant items, add or remove items as required).

Flexfield	**Description**	**Amount**
145-01-24-017-1621-0000-113	Contracts for invertebrate fauna identification	$7780
145-01-24-017-1621-0000-113	Contract for flora identification	$720
	Total Expenditure	**$8500**

6. Where another organisation has contributed to the project:

   - what has their contribution been?

CALM WATSCU is a major contributor to this WCP project which has been conducted as part of the project 'Conserving threatened ecological communities throughout the State, especially outside the southwest' (jointly funded by CALM WTSCU and an NHT grant). The WATSCU contribution is as follows:
(1)Salary and oncosts for Project Officer for 2000/2001 to coordinate project, to conduct field survey and sampling, to identify, describe, classify and database threatened ecological communities, and to nominate and present the communities for formal assessment by the WA Threatened Ecological Communities Scientific Committee)
(2)Cost of travel, field surveys and sampling.

   - please provide details of funding (how much and used for what) and resourcing (what resources and used for what).

(1)Salary and oncosts: $9743 (equivalent of 2 months)

(2)Field survey: $ 5000
Total: $14743

7. Have volunteers, community groups or CALM Bushrangers etc. been used in the project? Please provide details of the number of volunteer hours/days, number of volunteers involved, name of groups involved, tasks completed etc. Please provide any photographs of these groups carrying out the work.

Yes – the Broome Botanical Society provided assistance during field survey and sampling.

Comments on Kimberley Springs sampled by Sally Black

Stuart Halse (*2 October 2001*)

Seven springs were sampled in 2000 for aquatic invertebrates by Sally Black using a pondnet with 250μm mesh. This biased sampling against micro-invertebrtaes, which usually comprise about half the invertebrate species in a wetland. Nevertheless, a total of 122 species were collected, of which 96 were macro-invertebrates and 26 micro-invertebrates.

A table listing the species collected at each site is attached. Species richness varied from 40 at Big Spring to 12 at Moon Spring. This compares quite favourably with the richness of springs of Mandora Marsh, northern wheatbelt and eastern Gnangara Mound (36-22, 35-9 and 23-19 species, respectively), given that a fuller range of micro-invertebrates was collected from these sites (Jasinska 1998; Pinder and Pennifold 2001; Storey *et al* 2001).

The richness of the springs sampled by Black compares less favourably with Edge swamp, Rainforest swamp and Brolga Spring sampled by Halse et al (1996) on the Victoria-Bonaparte mudflat but the differences are entirely attributable to the large micro-invertebrate lists compiled by Halse *et al*. Detailed comparisons of the Victoria-Bonaparte springs and those sampled by Black are not made in this report but the Victoria-Bonaparte work has been used to provide additional context for interpreting the significance of springs sampled by Black (referred to as Kimberley springs in the remainder of the report).

Two differences were observed between the fauna of the Kimberley springs and those elsewhere in Western Australia. Firstly, there is a strong Indo-Pacific or Asian element in the Kimberley spring fauna, especially in the micro-invertebrates despite under-collecting. The three *Mesocyclops* species collected all have an Indo-Pacific distribution, as do the ostracods *Stenocypris malcolmsi* and *Cyprinotus kimberleyensis* and the hydrophilid beetle *Regimbarta attenuata* (see attached table). A similar pattern was found in the swamps of the Victoria-Bonaparte mudflat (Halse *et al*. 1996).

Secondly, almost one-fifth of the fauna collected in both the Kimberley and Mandora springs were beetles, compared with <10% at Gnangara and in the wheatbelt. The hemipteran fauna exhibited a similar, comprising approx. 10% of the Kimberley and Mandora faunas and being absent from the southern springs. This was repeated for most other insect groups and probably reflects the greater availability of free water at the Kimberley and Mandora sites.

Several of the described species collected in the Kimberley springs were first records for Western Australia, although this probably reflects the fact that many of the species are restricted to northern partsof the State where there has been little previous northern collecting, rather than implying rarity of the fauna and high conservation significance of the Kimberley springs. Among the first records were the ostracod *Stenocypris malcolmsi*, the cyclopoid copepods *Mesocyclops papuensis* and *M. woutersi*, the hemipteran *Naucoris australicus*, the dragonflies *Hemicordulia australiae* and *Orthetrum villsovittatum*, and the worm *Pristina probiscidae*.

Many of the species found in the Kimberley springs are restricted to northern Australia (see attached table). This trend is not as pronounced at the Mandora springs, where a greater proportion of species occur across the continent or have southern affinities (see Storey *et al*. 2001). Together with the Indo-Pacific faunal element, however, it suggests that the Kimberley springs do contain a different community from that at Mandora.

In terms of biogeography and conservation significance, the following can be hypothesised:

- Despite unevenness in collecting effort and taxonomic treatment, there appears to be a gradation in species composition of springs from south to north, with distinct Kimberley (including Victoria-Bonaparte), Mandora and southern communities.
- The amount of free water at a site affects species richness and faunal composition (free water increases richness and the proportion of surface water macro-invertebrates, especially larger

flying insects) and this may be largely responsible for the different types of animals (as opposed to species) in the northern and southern springs.

- Kimberley springs appear to be relatively rich aquatic habitats. Big Spring and Black Spring stand out as important because of their richness and the high proportion of northern species they contain and warrant conservation. Based on the particular taxa present and their importance, Mt Elizabeth Spring is probably the next most worthy of protection.

The above comments are preliminary because of the lack of work on springs in Western Australia, the different sampling methods employed in different studies and the fact that no site has a complete list. Further work may change our perceptions of the importance of sites. In particular, it will be interesting to see how collections recently made by Halse, Scanlon and Cocking, at flowing spring sites in the Pilbara, fit into the picture above. It would also be rewarding to undertake micro-invertebrate sampling with finer mesh nets at the Kimberley Springs.

References

Halse, S.A., Shiel, R.J. and Pearson, G.B. 1996. Waterbirds and aquatic invertebrates of swamps on the Victoria Bonaparte mudflat, northern Western Australia. *Journal of the Royal Society of Western Australia* 79, 31-38.

Jasinska, E.J. 1996. Monitoring of tumulus spring invertebrates. Unpublished report to WATSCU and WRC.

Pinder, A.M. & Pennifold, M.G. 2001. A survey of the aquatic invertebrates of some organic mound springs in the Shire of Three Springs, Western Australia. Unpublished report to WATSCU.

Storey, A.W., Halse, S.A. & Shiel, R.J. 2001. Aquatic fauna and water chemistry *in* A land assessment of Mandora Marsh and its immediate surrounds - October 1999. Unpublished report, department of Conservation and Land Management.

Communities Scientific Committee. As a result of the work the following communities have been databased and formally assessed:

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   - please provide details of funding (how much and used for what) and resourcing (what resources and used for what).

(1)Salary and oncosts: $9743 (equivalent of 2 months)

.

Appendix 2. Quadrat descriptions for floristic survey

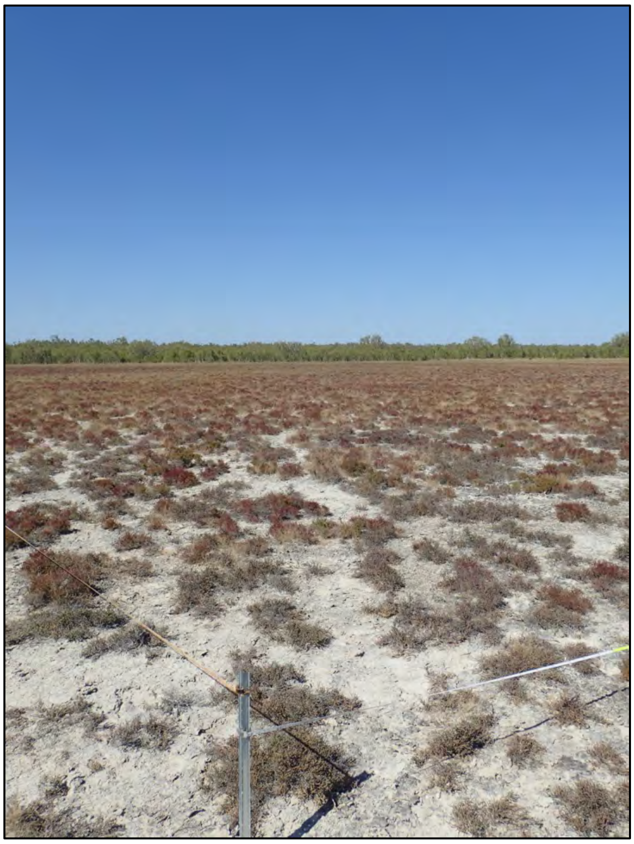
Vegetation quadrats sampled in 2017 & 2018 vegetation and flora surveys. Note quadrats NCP 1, 2 & NCP 4-6 are quadrats sampling vegetation peripheral to core spring habitats at Nimalarragun Wetland

Site: NCP01

Lat/Long (WGS 84): -17.773439°S 122.256313°E **Sample date:** 08-Mar-18

Region: Dampier peninsular. **Locality:** Nimalarragun claypan **Habitat:** Supra tidal flat

Vegetation: Low chenopod shrubland of *Tecticornia indica* subsp. *julacea* and *Tecticornia halocnemoides* subsp. *tenuis* over very open low grassland *of Eragrostis falcata*.



Species
Eragrostis falcata
Fimbristylis rara
Sporobolus virginicus
Tecticornia halocnemoides subsp*. tenuis*
Tecticornia indica subsp*. julacea*
Xerochloa imberbis

Site NCP02

Lat/Long (WGS 84):-17.773916°S 122.253968°E **Sample date:** 08-Mar-18

Region: Dampier peninsular **Locality:** Nimalarragun claypan **Habitat**: Supra tidal flat

Vegetation: Sparse tussock grassland of *Panicum decompositum* over low closed heathland/low closed shrubland of *Tecticornia indica* subsp. *julacea*, *Vincetoxicum carnosum* and *Hibiscus apodus*, over low sparse sedgeland of *Fimbristylis cymosa* and *Fimbristylis rara*.

Species
**** Chloris barbata***
Vincetoxicum carnosum
Dactyloctenium radulans
Ectrosia danesii
Euphorbia* aff. *hassallii
Fimbristylis cymosa
Fimbristylis rara
Flaveria trinervia
Gymnanthera oblonga
Hibiscus apodus
Melaleuca alsophila
Panicum decompositum
Phyla nodiflora
Pluchea rubelliflora
Portulaca pilosa
Sesbania cannabina
Sesuvium portulacastrum
Stemodia florulenta
Tecticornia* indica subsp. *julacea

Site: NCP04

Lat/Long (WGS 84):-17.768746°S 122.256750°E **Sample date:** 09-Mar-18

Region: Dampier peninsular **Locality**: Nimalarragun claypan **Habitat:** Spring margin

Vegetation: Low woodland of *Melaleuca alsophila* over low isolated trees of *Timonius timon* over low sedgeland of *Fimbristylis cymosa* and a low grassland of *Sporobolus mitchellii*.

Species
Ammannia baccifera
Bergia ammannioides
Eragrostis cumingii
Euphorbia hirta
Ficus aculeata* var. *indecora
Fimbristylis cymosa
Fimbristylis polytrichoides
Flueggea virosa* subsp. *melanthesoides
Gymnanthera oblonga
Hibiscus apodus
Melaleuca alsophila
Panicum mindanaense
Phyllanthus maderaspatensis
Sesbania cannabina
Sporobolus australasicus
Tamarindus indica
Vincetoxicum carnosum

Site: NCP05

Lat/Long (WGS 84):-17.781169°S 122.259328°E **Sample date:** 09-Mar-18

Region: Dampier peninsular **Locality:** Nimalarragun claypan **Habitat:** Upland spring margin

Vegetation: Low woodland of *Melaleuca alsophila* over tall sparse shrubland of *Acacia colei* var. *colei* over low isolated shrubs of *Hibiscus panduriformis, Vincetoxicum carnosum* and *Gymnanthera oblonga* over isolated grasses and sedges of *Panicum mindanaense* and *Fimbristylis* sp.

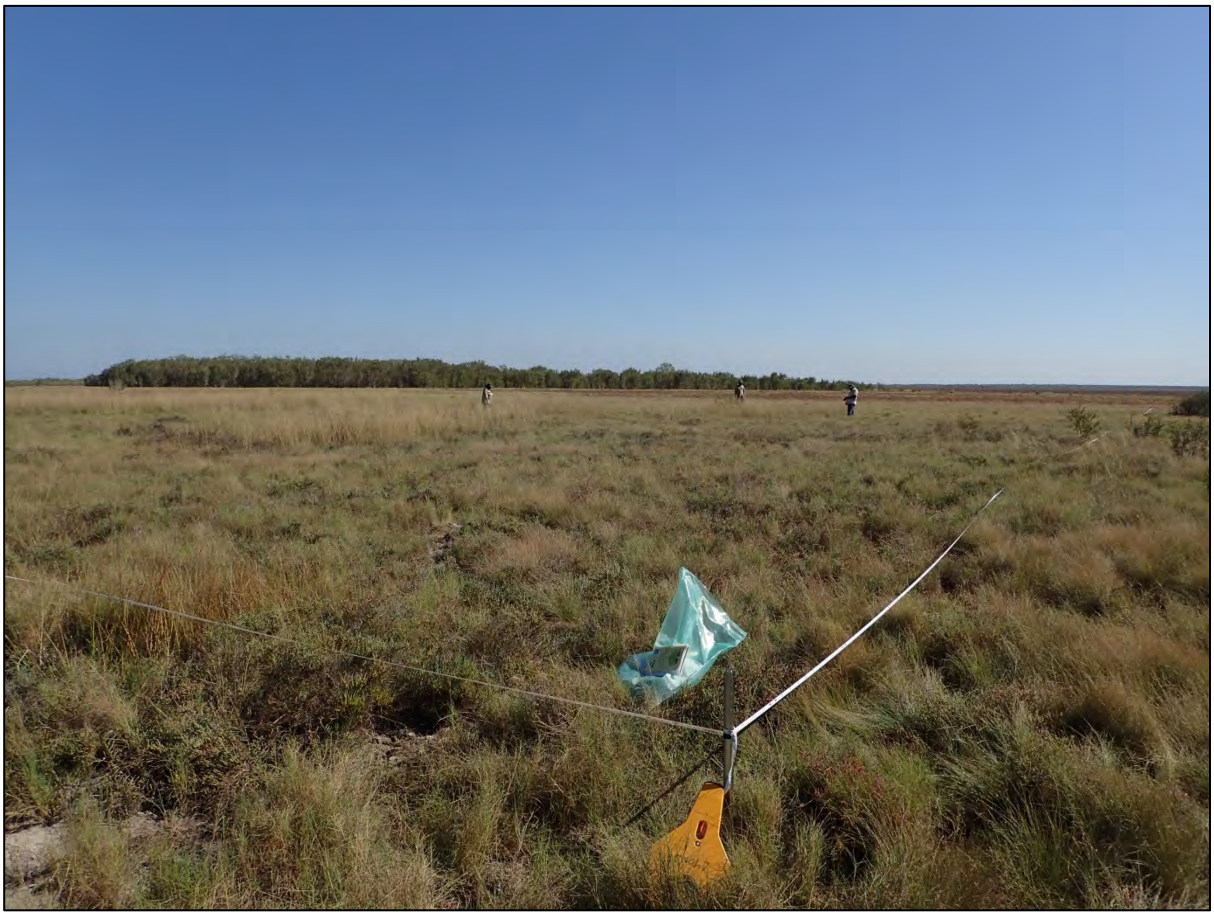
Species
Acacia colei* var. *colei
Atalaya hemiglauca
****Azadirachta indica***
Blumea sp. indet.
Brachychiton diversifolius
Calandrinia tepperiana
***Chrysopogon sp.* indet.**
Corchorus aestuans
Digitaria bicornis
Eragrostis cumingii
Euphorbia hirta
Fimbristylis polytrichoides
Grewia breviflora
Gymnanthera oblonga
Hibiscus apodus
Melaleuca alsophila
Panicum mindanaense
****Passiflora foetida var. hispida***
Phyllanthus maderaspatensis
Rhynchosia minima
Sesbania cannabina
Setaria surgens
Sporobolus australasicus
Thaumastochloa pubescens
Timonius timon
Tinospora smilacina
Vincetoxicum carnosum

Site NCP06

Lat/Long (WGS 84): -17.780197°S 122.249588°E **Sample date:** 10-Mar-19

Region: Dampier peninsular **Locality:** Nimalarragun claypan **Habitat:** Supra-tidal flat

Vegetation: Isolated clumps of grasses of *Panicum decompositum* with emergent *Melaleuca alsophila* over low sparse chenopod shrubland of *Tecticornia indica* subsp. *julacea*.



Species
Diplachne fusca subsp. fusca
Fimbristylis cymosa
Fimbristylis polytrichoides
Fimbristylis rara
Gymnanthera oblonga
Hibiscus apodus
Melaleuca alsophila
Panicum decompositum
Phyla nodiflora
Pluchea rubelliflora
Schoenoplectus subulatus
Sesbania cannabina
Sesuvium portulacastrum
Sporobolus virginicus
Tecticornia indica* subsp. *julacea
Vincetoxicum carnosum

Site NCP03

Lat/Long (WGS 84): -17.781576°S 122.263149°E **Sample date:** 08-Mar-19

Region: Dampier peninsular. **Locality:** Nimalarragun claypan **Habitat:** Spring riparian margin.

Vegetation: Open forest of *Melaleuca cajuputi* over sparse fernland of *Acrostichum speciosum*, over low sparse sedgeland of *Fimbristylis cymosa*, *Fimbristylis polytrichoides* and *Sporobolus mitchellii*.

Species
Ceratophyllum demersum
Chloris barbata
Eragrostis cumingii
Fimbristylis cymosa
Fimbristylis ferruginea
Fimbristylis polytrichoides
Gymnanthera oblonga
Hibiscus apodus
Landoltia punctata
Melaleuca alsophila
Melaleuca cajuputi
****Passiflora foetida var. hispida***
Sporobolus mitchellii
Vincetoxicum carnosum

Site NCP07

Lat/Long (WGS 84): -17.781518°S 122.268472°E **Sample date:** 08-Mar-19

Region: Dampier peninsular. **Locality:** Nimalarragun claypan **Habitat:** Mound Spring

Vegetation: Open forest of *Melaleuca cajuputi* over woodland of *Timonius timon*, over fernland of *Acrostichum speciosum*

Species
Acacia colei **var.** ***colei***
Acrostichum speciosum
Fimbristylis ferruginea
Gymnanthera oblonga
Melaleuca cajuputi
Pandanus spiralis
****Passiflora foetida*** **var.** ***hispida***
Schoenoplectus subulatus
Timonius timon

Site KMS10A

Lat/Long (WGS 84): -14.902755°S 128.704084°E **Sample date:** 04-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** Un-named spring **Habitat:** Mound spring

Vegetation: Tall open forest of *Melaleuca leucadendra* over vineland of Apocynaceae spp. and *Flagellaria indica*, over low open vines of *Flagellaria indica* over low open fernland of *Cyclosorus interruptus*.

Species
Colocasia esculenta* var. *aquatilis
Cyclosorus interruptus
Flagellaria indica
Glochidion sumatranum
Marsilea crenata
Melaleuca leucadendra
Merremia gemella
Mucuna gigantea* subsp. *gigantea
Scleria lingulata
Sterculia holtzei

Site KMS11A

Lat/Long (WGS 84): -14.896823°S 128.684779°E **Sample date** 01-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** Attack Spring **Habitat:** Mound spring

Tall open forest of *Melaleuca leucadendra* over low isolated vines of *Flagellaria indica* over tall isolated sedges of *Typha domingensis* over isolated clumps of sedges and ferns of *Cyperus platystylis* and *Cyclosorus interruptus*.

Species
Ceratophyllum demersum
Cyclosorus interruptus
Cyperus platystylis
Fimbristylis cymosa
Flagellaria indica
Fuirena ciliaris
Glochidion sumatranum
Lemna aequinoctialis
Melaleuca leucadendra
Persicaria subsessilis
Scleria lingulata
Typha domingensis
Utricularia aurea

Site KMS11B

Lat/Long (WGS 84): -14.896382°S 128.685083°E **Sample date:** 02-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** Attack Spring **Habitat:** Supra-tidal margin of mound spring

Low isolated trees of *Melaleuca alsophila* over tall shrubland of *Melaleuca alsophila* over low open sedgeland of *Cyperaceae sp.* indet.

Species
Melaleuca alsophila
Sporobolus sp. indet.
Xerochloa imberbis

Site KMS12A

Lat/Long (WGS 84): -14. 880484°S 128. 676647°E **Sample date:** 02-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** Un-named spring **Habitat: M**ound spring

Vegetation: Open forest of *Melaleuca leucadendra* over low woodland of *Timonius timon* and *Melochia* sp. over low sparse vineland of *Flagellaria indica* and sparse sedgeland of *Cyperus haspan* and *Cyperus javanicus* over low isolated clumps of ferns of *Cyclosorus interruptus*.

Species
Abutilon indicum* var*. australiense
Acrostichum speciosum
Adenostemma lavenia* var*. lanceolatum
Calotropis procera
Cayratia trifolia
Ceratopteris thalictroides
Cyclosorus interruptus
Cyperus haspan* subsp*. juncoides
Cyperus javanicus
Decaisnina angustata
Ficus racemosa
***Fimbristylis sp.* (PERTH - M.N. Lyons & J. Pryde KMS 039)**
Flagellaria indica
Fuirena ciliaris
Glochidion sumatranum
Hibiscus tiliaceus
Ludwigia octovalvis
Luffa sp.
Melaleuca leucadendra
Mucuna gigantea* subsp*. gigantea
Vincetoxicum carnosum

Site KMS13A

Lat/Long (WGS 84): -14. 902392°S 128. 660870°E **Sample date:** 03-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** Long Spring (Swamp) southern extension.

Habitat: Mound spring

Vegetation: Tall open forest of *Melaleuca leucadendra* over low open woodland of *Sterculia holtzei* and *Nauclea orientalis* over low isolated palms of *Pandanus spiralis* over tall isolated sedges of *Typha domingensis* over emergent ferns and isolated aquatics of *Cyclosorus interruptus* and *Nymphaea violacea.*

Species
Carallia brachiata
Ceratopteris thalictroides
Cyclosorus interruptus
Cyperus javanicus
Eleocharis geniculata
Flagellaria indica
Glochidion disparipes
Hygrophila angustifolia
Melaleuca leucadendra
Nymphaea violacea
Pandanus spiralis
Sterculia holtzei
Timonius timon
Typha domingensis
Utricularia aurea

Site KMS13B

Lat/Long (WGS 84): -14. 896122°S 128. 661569°E **Sample date:** 03-Aug-17

Region: North Kimberley - Carlton Hill**.** **Locality:** Un-named spring **Habitat**: Mound spring

Vegetation: Woodland of *Melaleuca leucadendra* over tall rushland of *Typha domingensis*.

Species
Cyperus platystylis
Melaleuca leucadendra
Paspalum scrobiculatum
Typha domingensis
Vincetoxicum carnosum

Site KMS14A

Lat/Long (WGS 84): -14. 881075°S 128. 559330°E **Sample date:** 04-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** Un-named spring **Habitat:** Brackish wetland on supra-tidal flat.

Vegetation: Low open forest of *Melaleuca alsophila, Lumnitzera racemosa* and *Thespesia populneoides* over low isolated clumps of sedges of *Fimbristylis* sp. and Malvaceae sp., over low isolated tussock grassland of *Panicum seminudum* var. *seminudum*

Species
Vincetoxicum carnosum
Excoecaria ovalis
Lumnitzera racemosa
Melaleuca alsophila
Panicum seminudum* var. *seminudum
Schoenoplectus subulatus
***Sporobolus sp.* indet.**
Thespesia populneoides
Vincetoxicum carnosum

Site KMS15A

Lat/Long (WGS 84): -14. 912050°S 128. 593906°E **Sample date:** 04-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** King Gordon Spring **Habitat:** Mound spring

Vegetation: Tall woodland of *Melaleuca leucadendra* over low woodland of *Nauclea orientalis* and *Pandanus spiralis* over low isolated vines of *Flagellaria indica* over isolated clumps of forbs of *Adenostemma lavenia* var. *lanceolatum* over low sparse sedgeland of *Fimbristylis* sp. (M.N. Lyons & J. Pryde KMS 039).

Species
Acacia neurocarpa
Adenostemma lavenia var. lanceolatum
Carallia brachiata
Ceratopteris thalictroides
Cyperus sp. indet.
*Fimbristylis sp. (*M.N. Lyons & J. Pryde KMS 039*)*
Flagellaria indica
Hygrophila angustifolia
Ludwigia octovalvis
Luffa aegyptiaca
Melaleuca leucadendra
Monochoria vaginalis
Nauclea orientalis
Nymphaea violacea
Pandanus spiralis
Timonius timon
Typha domingensis
Utricularia aurea

Site KMS16A

Lat/Long (WGS 84): -14. 907897°S 128. 622158°E **Sample date:** 04-Aug-17

Region: North Kimberley - Carlton Hill. **Locality:** Bamboo Spring **Habitat:** Mound spring

Vegetation: Tall open forest of *Melaleuca leucadendra* over low isolated vine clumps of *Flagellaria indica* over low isolated clumps of ferns of *Acrostichum aureum* and *Typha domingensis* over isolated clumps of aquatics *Nymphaea violacea* and *Ceratophyllum demersum*.

Species
Acrostichum aureum
Ceratophyllum demersum
Lemna aequinoctialis
Melaleuca leucadendra
Nymphaea violacea
Scleria lingulata
Typha domingensis

Site KMS17A

Lat/Long (WGS 84): -17.151627°S 122.318308 **Sample date** 07-Aug-17

Region: Dampier Peninsular **Locality:** Bunda Bunda Spring **Habitat:** Mound spring

Vegetation: Closed forest of *Carallia brachiata* and *Sesbania formosa* over isolated trees of *Sesbania formosa* over low isolated trees of *Timonius timon* over low fernland of *Cyclosorus interruptus*, *Acrostichum speciosum* and *Lygodium microphyllum*.

Species
Acrostichum speciosum
Carallia brachiata
Cassytha filiformis
Cyclosorus interruptus
Gymnanthera oblonga
Lumnitzera racemosa
Lygodium microphyllum
Mallotus nesophilus
Melaleuca cajuputi
Musa acuminata
**Passiflora foetida* var. *hispida*
Sesbania formosa
Timonius timon

Site KMS18A

Lat/Long (WGS 84): -16.978531°S 123.952859°E **Sample date:** 08-Aug-17

Region: Dampier peninsular **Locality:** Big Spring **Habitat:** Mound spring

Vegetation: Tall woodland of *Melaleuca leucadendra* over woodland of *Terminalia microcarpa*, *Sesbania formosa* and *Nauclea orientalis* over tall sparse fernland of *Lygodium microphyllum* over low woodland of *Pandanus spiralis* over tall sparse fernland *of Acrostichum speciosum*.

Species
Acrostichum speciosum
Bauhinia cunninghamii
Carallia brachiata
Ceratophyllum demersum
Ceratopteris thalictroides
Echinochloa colona
Eleocharis spiralis
Ficus aculeata* var. *indecora
Ficus virens
Ficus virens* var. *virens
Fimbristylis cymosa
Fimbristylis ferruginea
Fimbristylis littoralis
Fuirena umbellata
Gymnanthera oblonga
Lemna aequinoctialis
Lygodium microphyllum
Marsilea hirsuta
Melaleuca cajuputi
Nauclea orientalis
Pandanus spiralis
****Passiflora foetida* var. *hispida***
Schoenoplectiella mucronata
Stenochlaena palustris
Sesbania formosa
Terminalia microcarpa
Vincetoxicum carnosum

Appendix 3. Flora species list tabulated to show taxa occurrences by region and habitat.

List includes quadrat records and non-quadrat collections. Non-native taxa are annotated with *

Family		Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
Acanthaceae		Hygrophila angustifolia			1		1	
Aizoaceae		Sesuvium portulacastrum				1		1
Apocynaceae		Calotropis procera			1	1	1	1
		Gymnanthera oblonga			1	1		1
		Vincetoxicum carnosum				1		1
Araceae		Colocasia esculenta var. aquatilis		Wild population (diminutive solitary tuber).	1		1	
		Landoltia punctata			1		1	
		Lemna aequinoctialis			1			1
Arecaceae	*	Phoenix dactylifera		Population recorded at Big Spring (KMS18A).	1			1
Asteraceae		Adenostemma lavenia var. lanceolatum	P3	Scattered distribution across northern Australia in springs and rainforest patches	1		1	1
		Blumea integrifolia				1		1
		Blumea saxatilis				1		1
	*	Flaveria trinervia				1	1	
		Pluchea rubelliflora				1		1
		Pterocaulon intermedium				1		1
Blechnaceae		Stenochlaena palustris				1		1
Boraginaceae		Heliotropium curassavicum				1	1	
Byblidaceae		Byblis filifolia				1	1	
Capparaceae		Capparis lasiantha				1	1	

Family	Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
Celastraceae	Stackhousia intermedia				1		1
Ceratophyllaceae	Ceratophyllum demersum			1		1	
Chenopodiaceae	Tecticornia halocnemoides subsp. tenuis				1		1
	Tecticornia indica subsp. julacea				1	1	
	Tecticornia indica subsp. leiostachya				1	1	
	Tecticornia pergranulata subsp. elongata				1	1	1
Combretaceae	Lumnitzera racemosa			1	1		1
	Terminalia microcarpa			1		1	1
Convolvulaceae	Merremia gemella			1		1	1
	Merremia gemella				1		1
	Xenostegia tridentata				1	1	
Cucurbitaceae	Cucumis melo				1	1	1
	Luffa aegyptiaca			1			1
	Luffa saccata			1			1
Cyperaceae	Bulbostylis barbata				1		1
	Cyperus bifax				1		1
	Cyperus conicus				1	1	
	Cyperus cunninghamii subsp. cunninghamii				1	1	
	Cyperus haspan				1	1	1
	Cyperus haspan subsp. juncoides			1			1
	Cyperus javanicus			1		1	1
	Cyperus platystylis		3rd WA record, at western distributional limit near Kununurra and Carlton Hill	1	1	1	
	Eleocharis geniculata			1			1
	Eleocharis spiralis			1		1	1
	Eleocharis sundaica				1		1
	Fimbristylis cymosa			1	1		1

Family	Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
	Fimbristylis ferruginea			1			1
	Fimbristylis littoralis			1			1
	Fimbristylis polytrichoides			1	1	1	
	Fimbristylis rara				1		1
	Fimbristylis sp. (M.N. Lyons & J. Pryde KMS039)		matches PERTH Colln. (AA Mitchell 7822)	1			1
	Fuirena ciliaris			1			1
	Fuirena umbellata			1		1	
	Schoenoplectiella mucronata			1			1
	Schoenoplectus subulatus			1	1		1
	Scleria lingulata			1		1	
Droseraceae	Drosera broomensis				1		1
Elatinaceae	Bergia ammannioides				1		1
Euphorbiaceae	Euphorbia aff. hassellii				1	1	
	Euphorbia hirta				1		1
	Excoecaria agallocha				1	1	
	Excoecaria ovalis				1	1	1
	Mallotus nesophilus			1		1	1
Fabaceae	Acacia ampliceps				1		1
	Acacia colei var. colei			1	1	1	
	Acacia holosericea				1	1	1
	Acacia neurocarpa			1	1		1
	Bauhinia cunninghamii			1			1
	Canavalia papuana				1	1	
	Cathormion umbellatum subsp. moniliforme				1		1
	Chamaecrista absus				1		1
	Desmodium filiforme				1		1
	Dichrostachys spicata				1		1

Family		Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
		Indigofera colutea				1	1	
		Mucuna gigantea subsp. gigantea			1		1	
	*	Parkinsonia aculeata				1	1	
		Rhynchosia minima				1		1
		Sesbania cannabina				1		1
		Sesbania formosa			1			1
	*	Stylosanthes hamata				1	1	1
	*	Stylosanthes scabra				1	1	
	*	Tamarindus indica				1	1	
		Vigna radiata var. sublobata				1		1
		Zornia muelleriana subsp. congesta				1	1	
Flagellariaceae		Flagellaria indica			1		1	
Hydrocharitaceae		Najas tenuifolia			1		1	
Lauraceae		Cassytha filiformis			1		1	
Lentibulariaceae		Utricularia aurea	P2	At western limit of distribution in Kimberley with unconfirmed Pilbara outlier	1			1
Loranthaceae		Decaisnina angustata			1			1
Lygodiaceae		Lygodium microphyllum			1			1
Lythraceae		Ammannia baccifera				1		1
Malvaceae		Abutilon indicum var. australiense			1		1	
		Brachychiton diversifolius				1		1
		Corchorus aestuans				1	1	
		Grewia breviflora				1		1
		Hibiscus apodus			1	1	1	
		Hibiscus tiliaceus			1		1	
		Melochia corchorifolia				1		1
		Sida acuta var. acuta				1		1

Family	Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
	Sterculia holtzei	P1	Only WA occurrence, core distribution in NT	1			1
	Thespesia populneoides				1		1
	Urena lobata				1	1	1
	Waltheria indica				1	1	1
Marsileaceae	Marsilea crenata			1		1	
	Marsilea hirsuta			1		1	
Meliaceae	* Azadirachta indica		On the margins of Nimalarragan wetland		1		1
Menispermaceae	Tinospora smilacina				1		1
Montiaceae	Calandrinia tepperiana				1		1
Moraceae	Ficus aculeata var. indecora			1	1		1
	Ficus hispida var. hispida				1		1
	Ficus racemosa			1			1
	Ficus virens			1			1
	Ficus virens var. virens			1			1
Musaceae	* Musa acuminata		Recorded at Bunda Bunda likely historical planting.	1			1
Myrtaceae	Corymbia bella				1	1	1
	Corymbia opaca				1		1
	Corymbia paractia	P1	Margin of Nimalarragan wetland at interface with Pindan		1	1	
	Eucalyptus microtheca				1		1
	Melaleuca alsophila			1	1		1
	Melaleuca cajuputi			1			1
	Melaleuca dealbata				1		1
	Melaleuca leucadendra			1	1	1	
	Melaleuca nervosa				1		1

Family		Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
		Melaleuca viridiflora				1		1
Nymphaeaceae		Nymphaea violacea			1		1	1
Onagraceae		Ludwigia octovalvis			1		1	
Orobanchaceae		Buchnera asperata				1		1
		Buchnera linearis				1	1	1
		Buchnera ramosissima				1	1	1
Pandanaceae		Pandanus spiralis			1	1		1
Passifloraceae	*	Passiflora foetida var. hispida			1	1	1	
Phrymaceae		Uvedalia linearis var. lutea				1		1
Phyllanthaceae		Flueggea virosa subsp. melanthesoides				1	1	1
		Glochidion disparipes			1			1
		Glochidion sumatranum			1			1
		Phyllanthus maderaspatensis				1		1
Picrodendraceae		Petalostigma pubescens				1	1	
Plantaginaceae		Stemodia florulenta				1		1
Plumbaginaceae		Plumbago zeylanica				1		1
Poaceae		Aristida hygrometrica				1	1	
		Arundinella nepalensis				1		1
	*	Cenchrus ciliaris				1	1	
	*	Cenchrus setigera				1		1
	*	Chloris barbata			1	1	1	
		Chrysopogon pallidus				1	1	
		Cynodon dactylon				1	1	1
		Dactyloctenium radulans				1		1
		Digitaria bicornis				1	1	
		Diplachne fusca subsp. fusca				1	1	
		Echinochloa colona			1			1
		Ectrosia danesii				1		1

Family		Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
		Eragrostis cumingii			1	1	1	
		Eragrostis falcata				1	1	
		Eriachne obtusa				1		1
		Panicum decompositum				1		1
		Panicum mindanaense				1	1	
		Panicum seminudum var. seminudum				1		1
	*	Paspalum distichum				1	1	1
		Paspalum scrobiculatum			1	1	1	
		Phragmites karka			1		1	
		Schizachyrium fragile				1		1
		Setaria surgens				1		1
		Sorghum stipoideum				1	1	
		Sporobolus australasicus				1	1	
		Sporobolus mitchellii			1			1
		Sporobolus virginicus				1		1
		Thaumastochloa pubescens				1	1	1
		Xerochloa imberbis				1	1	1
Polygonaceae		Persicaria subsessilis			1			1
Pontederiaceae		Monochoria vaginalis			1		1	
Portulacaceae	*	Portulaca pilosa				1	1	
Pteridaceae		Acrostichum aureum	P1	Recorded at Bamboo Spring (KMS16A) with a previous collection from Big Spring (KMS18A)	1		1	
		Acrostichum speciosum			1			1
		Ceratopteris thalictroides			1		1	1
Rhizophoraceae		Carallia brachiata			1		1	1
		Rhizophora stylosa				1		1
Rubiaceae		Nauclea orientalis			1		1	1

Family		Taxon	Conservation code	Taxon comments	Mound Springs	Peripheral to Mound Springs	North Kimberley - Carlton Hill	West Kimberley – Dampier Peninsular and King Sound
		Oldenlandia mitrasacmoides				1		1
		Spermacoce dolichosperma				1	1	
		Timonius timon			1	1	1	1
Sapindaceae		Atalaya hemiglauca				1		1
Solanaceae	*	Physalis angulata				1		1
Stylidiaceae		Stylidium pindanicum	P3	Pindan fringing coastal flats		1		1
Thelypteridaceae		Cyclosorus interruptus			1			1
Typhaceae		Typha domingensis			1	1		1
Verbenaceae		Phyla nodiflora		Northern Australian clade regarded as native	1	1		1
Vitaceae		Cayratia trifolia			1		1	

Appendix 4. Aquatic invertebrate data.