Geography Monograph Series No. 14

Pungalina Wetlands Scientific Study Report

The Royal Geographical Society of Queensland Inc.
Brisbane, 2017

The Royal Geographical Society of Queensland Inc. is a non-profit organisation that promotes the study of Geography within educational, scientific, professional, commercial and broader general communities. Since its establishment in 1885, the Society has taken the lead in Geographical education, exploration and research in Queensland.

Published by:
The Royal Geographical Society of Queensland Inc.
237 Milton Road, Milton Qld 4064, Australia
Phone: (07) 3368 2066; Fax: (07) 3367 1011
Email: admin@rgsq.org.au
Website: www.rgsq.org.au

ISBN 9780949286184
ISSN 1037 7158

Desktop Publishing: Kevin Long, Page People Pty Ltd, Noosa, Australia

Other titles in the Geography Monograph Series:

No 1. Technology Education and Geography in Australia Higher Education (ISBN 0-949286-01-X)

No 2. Geography in Society: a Case for Geography in Australian Society (ISBN 0-949286-02-8)

No 3. Cape York Peninsula Scientific Study Report (ISBN 0-949286-04-4)

No 4. Musselbrook Reserve Scientific Study Report (ISBN 0-949286-06-0)

No 5. A Continent for a Nation; and Dividing Societies (ISBN 0-949286-07-9)

No 6. Herald Cays Scientific Study Report (ISBN 0-949286-08-7)

No 7. Braving the Bull of Heaven; and, Societal Benefits from Seasonal Climate Forecasting (ISBN 0-949286-09-5)

No 8. Antarctica: a Conducted tour from Ancient to Modern; and, Undara: the Longest Known Young Lava Flow (ISBN 0-949286-10-9)

No 9. White Mountains Scientific Study Report (ISBN 0-949286-11-7)

No 10. Gulf of Carpentaria Scientific Study Report (ISBN 0-949286-12-5)

No 11. Safe, Sustainable and Secure Communities: a Geographer's Perspective (ISBN 0-949286-13-3)

No 12. Queensland Geographical Perspectives (ISBN 0-949286-14-1)

No 13. Cravens Peak Scientific Study Report (ISBN 0-949286-16-8)

This publication has been prepared by Hayley Freemantle and Bernard Fitzpatrick of The Royal Geographical Society of Queensland Inc.

Contents

Acknowledgments

The Royal Geographical Society of Queensland Inc. very much appreciates the support given by individuals and groups, who played a vital role in the success of the 2012 Pungalina Wetlands Scientific Study Report.

Volunteers

The following have made it possible to ensure that the project was a success: Tony Hillier, Mary Comer, Paul Feeney, David Flood, Gerry Keates, Brian and Heather McGrath, John and Mary Nowill, Laylee and Stephen Purchase, Kay and Graham Rees, Patricia and Wayne Spearritt, Kev Teys, Bruce Urquhart, Digby and Gavin Warren and our Chef Rolf Roduner. The time and efforts of Stuart Watt and Margaret Keates are acknowledged for their work in following up paper reviews and preparation of the report for publication.

Scientific Advisory Committee

The Scientific Advisory Committee is a body comprising people suitably accredited to advise the Society on its Scientific Expedition programme. This committee which consisted of Mr Tony Hillier (Convenor), Hayley Freemantle (Project Officer), Em Prof. John Holmes, Dr Bob Johnson, Dr John Kanowski (AWC), Dr Alex Kutt, Dr Geoff Monteith, Dr John Nelder and Professor James Shulmeister suggests possible locations for research attention, selects a site following survey reports, makes a selection of projects to be included in the expedition and oversees the refereeing of papers following the expedition. This work, much of it taking place 12 months or more prior to the actual fieldwork, is very important for the overall success of the project. The success of each of the seven expeditions conducted so far and the enthusiasm with which the reports have been received indicates the value of the work of this Committee.

Reviewers

Dr Stephen Balcombe, Prof Gerry Cassis, Prof Simon Haberle, Dr John Kanowski (AWC), Dr Alex Kutt, Dr Geoff Montheith, Assoc Prof Christian Nansen, Dr Tim New, Dr Chris Pavey, Dr Gilbert Price, Dr Cassie Read and Prof James Shulmeister provided valuable assistance in refereeing the papers published in this volume.

RGSQ Office Staff

Projects such as the expedition series rely very much on a competent ‘office’ back up. Our staff of Hayley Freemantle and Keith Smith gave their unstinting support. Keith, as on previous expeditions, provided financial support, while Hayley Freemantle handled the day-to-day communication with researchers, committees and suppliers. Hayley was instrumental in organising people, travel, reporting, reviewing and the early stages of compiling this publication.

Australian Wildlife Conservancy

Our thanks go to the Australian Wildlife Conservancy for allowing the use of Pungalina for the RGSQ’s seventh scientific expedition. Initially, there was some debate about going to Pungalina due to its remoteness, possible supply problems and also it was the first time an expedition had been run outside of Queensland. After our initial survey trip in 2011, the committee was confident that these issues were small compared to the huge diversity of ecosystems thus making it a logical choice for the wide variety of scientists and bird surveyors.

Australian Wildlife Conservancy’s North East Regional Ecologist, Dr John Kanowski who was our point of contact with the organisation, and who made all the approvals and arrangements a painless exercise should also be thanked.

Hermann Mouthaan and Sharyn Yelverton, the Australian Wildlife Conservancy managers at Pungalina, we thank you for your friendliness, advice, and physical assistance which contributed substantially to the success of the expedition and made the whole atmosphere comfortable and welcoming.

Finally, we must also extend our sincere thanks to the manager and staff at the Redbank Mine, located approximately 14 kilometres from the Pungalina entrance on the Doomadgee-Borroloola Road. The entrance track to Pungalina is 4WD only and not suitable for road trains. So all fuel, supplies, and equipment had to be offloaded from Ringrose Transport’s road trains at the mine site and reloaded onto station or volunteer vehicles for transport to the homestead. This could not have been achieved without the use of the mine forklift and cooperation of their staff.

Organisation of the Pungalina Wetlands Scientific Study

The Royal Geographical Society of Queensland Inc.

The Pungalina Wetlands Scientific Study was a project of the Royal Geographical Society of Queensland. The fieldwork component took place from June to August 2012, with a multi-disciplinary team of scientists and assistants (Table 1, page 2) on site to undertake fieldwork and surveys. Data collected during the scientific study will provide the Australian Wildlife Conservancy with onsite inventories and valuable baseline data for undertaking on-going monitoring and further site surveys and fieldwork. Analysis of the data will assist the Australian Wildlife Conservancy in developing management plans to secure the conservation of the Pungalina Seven Emu region.

Background

The Royal Geographical Society of Queensland Inc. is a not for profit organisation that promotes the study of all aspects of geography within the scientific, professional, educational and broader general community. Since the Society's inception in 1885, it has supported geographical exploration, research and education in Queensland.

Since J.P. Thomson, the Society's founder, pronounced his dream that "a society would grow in Queensland with the strength to supply geographical science, encourage exploration and contribute to the acquisition and dissemination of geographical knowledge about Queensland", the society has initiated a succession of noteworthy research activities which has provided beneficial information on the geography of Queensland, for perusal by many across the globe.

The 1990s saw a renewed dedication by the Society to continue the legacy set before. The organisation of studies to the Northern part of the Cape York Peninsula, during the wet season in 1992, Musselbrook Reserve in 1995, North East Cay, Herald Cays in 1997, White Mountains National Park in 2000 The Gulf of Carpentaria in 2002 and Craven Peak, 2007, verified the Society's responsibility to support geographical and environmental research and education in Queensland.

Australian Wildlife Conservancy—Pungalina Seven Emu

The Australian Wildlife Conservancy (AWC) is a non-profit organisation whose mission is the effective conservation of Australia's animal species and their habitats. AWC currently manages 21 wildlife sanctuaries across Australia, covering over 2.5 million ha. AWC's management activities are underpinned by a science programme, which includes inventory, monitoring and targeted research projects.

Pungalina Seven Emu is located (see map, Figure 1, page 3) within the traditional homelands of the Garawa who also have native title claims over the Pungalina and Seven Emu sanctuaries which are pastoral leases: AWC has acquired Pungalina outright, and has entered into a partnership with Frank Shadforth, a Garawa man, to establish a conservation reserve over half of the Seven Emu property. AWC conducts fire management on Pungalina Seven Emu in collaboration with the Garawa Rangers and Frank Shadforth, and both have participated in AWC's ecological survey work.

Pungalina Seven Emu is located in the Northern Territory, adjacent 16º 44' S, 137º 25' E, in the Gulf Coastal Bioregion. The Sanctuary covers more than 3000 km² in the catchments of the Calvert and Robinson Rivers. The underlying geology comprises Proterozoic sandstones and dolomite (with extensive caves) and Tertiary sediments. Major ecosystems include savannah woodlands, rocky escarpments and freshwater springs in the upper reaches of the catchments, riverine habitats, and cypress pine woodlands, grasslands, saline flats and monsoon forests on the coastal plains. The Calvert River and its main tributaries are listed as 'Regionally Important Wetlands' (National Land and Water Resources Audit, 2002). Seven Emu has extensive swamp and dune areas, flanked on either side by the Robinson and Calvert Rivers.

The mean annual rainfall is 975 mm, with a wet season from December to March. Mean maximum temperatures range from 29–38º C; mean minimum temperatures range from 12–24º C (BoM, Wollogorang Station).

Table 1: Researchers, with their projects, in the Pungalina Scientific Study.

Project	Researcher	Institution
A Rainfall History of the Australasian monsoon tropics	Dr Russell Drysdale, Dr Isabelle Couchoud, Dr Michael Griffiths and Prof Jonathan Woodhead	University of Melbourne
Survey of Soil Fauna focusing on Collembola of the Pungalina and Seven Emus Sanctuary	Penny Greenslade	University of Ballarat
Baseline studies of the Dung beetles of the Pungalina-Seven Emu area with focus on the genus *Lepanus*	Dr Nicole Gunter and Tom Weir	Australian National Insect Collection, CSIRO Ecosystem Sciences, ACT 2601
Baseline study of the weevils (Coleoptera: Curculionoidea) of the Pungalina-Seven Emu area, with particular emphasis on the *Melanterius* weevils associated with Acacia species	Dr Sara Pinzón-Navarro and Dr Rolf G. Oberprieler	CSIRO Ecosystem Sciences, Canberra, ACT
The nature and distribution of jumping spider (Aranaea: Salticidae) diversity on Pungalina and Seven Emu Stations	Dr Barry Richardson	Division of Ecological Sciences CSIRO, ACT
Survey of the aquatic macrophytes and algae of the wetlands of Pungalina Seven Emu Wildlife Sanctuary	Prof Peter Saenger	School of Environment, Science and Engineering, Southern Cross University, Lismore, NSW
Holocene Paleoecology and Paleoclimatology of Pungalina from lake cores	Prof James Shulmeister, Mr Joel Murphy and Dr Kevin Welsh	School of Geography, Planning and Environmental Management, University of Queensland School of Earth Sciences, University of Queensland
Vertebrate fauna survey of Pungalina Seven Emu: fauna patterns and refuges	Dr Eric Vanderduys, Mr Justin Perry, Ms Genevieve Perkins and Anders Zimny	CSIRO Ecosystem Sciences, Aitkenvale
Semi-aquatic and Aquatic Bugs (Hemiptera: Heteroptera: Gerromorpha and Nepomorpha) of the AWC Pungalina Seven Emu Sanctuary, Gulf Coastal Bioregion, Northern Territory	Tom Weir	Australian National Insect Collection, CSIRO Ecosystem Sciences, Canberra
Victorian Speleological Association Cave and Karst Studies of Pungalina Station, NT	Dr Nicholas White and Dr Susan White	Victorian Speleological Association Inc and Environmental Geoscience, Latrobe University, Bundoora
Bird Survey of Pungalina Seven Emu Scientific Study	Dezmond Wells	BirdLife Australia Southern Queensland
Ecological roles and diversity of biological rock and soil crusts at Pungalina-Seven Emu	Dr Wendy Williams, Mr Stephen Williams, Mr Colin Driscoll, Mrs Leanne Ezzy	University of Queensland, Gatton Campus Qld

Origins

Following the success of the Royal Geographical Society's previous six expeditions, the Scientific Advisory Committee decided in 2010 that another expedition could be run. Several earlier expeditions had been run in Cape York and the Queensland Gulf Area and the last one in the far west at Cravens Peak. Due to structural changes in Queensland National Parks it had become too difficult and most had been well researched, whereas the not for profit groups, Bush Heritage Australia and Australian Wildlife Conservancy who had been acquiring a number of properties across Australia were very welcoming of any extra scientific surveys. After further analysis it was decided to conduct a survey of two Australian Wildlife Conservancy properties, Piccaninny Plains in Cape York and Pungalina Seven Emu just inside the Northern Territory.

The trip was planned for May–June 2010 and was to include visits to 16 Queensland-by-degrees sites that remained to be visited in central and northern Queensland. Several days were spent at each location and we only just managed to get through to Pungalina, as the roads were still flooded after that year's extremely heavy wet season.

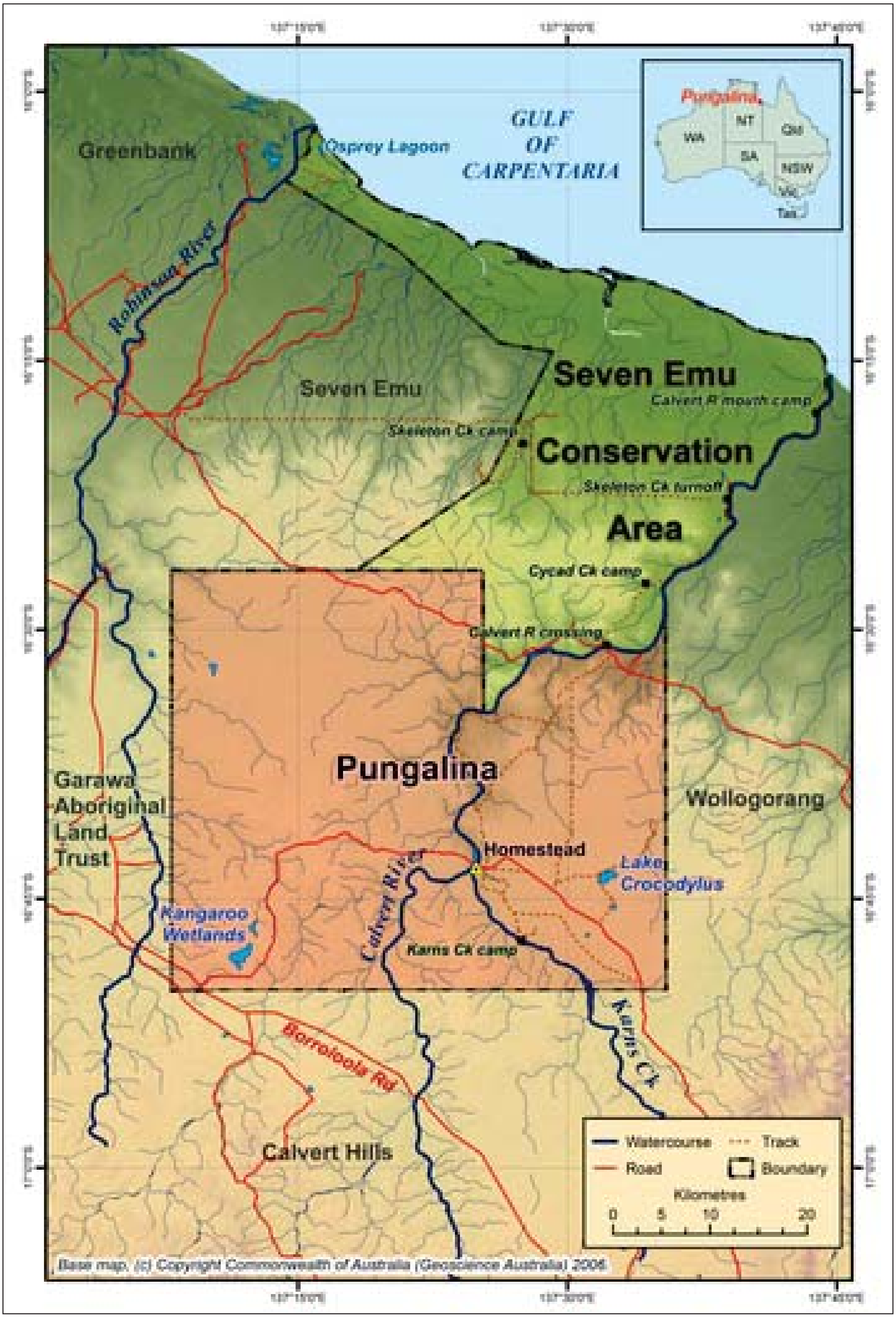


Figure 1. Map: Location of Pungalina Seven-Emu. Cartography: B. Fitzpatrick, The Royal Geographical Society of Queensland Inc Map Group

Figure 2. The Big Stinking Lagoon camp site.

After the trip, the "pros and cons" of each location were evaluated. Piccaninny Plains was logistically much easier but a lot of research had already been done in the area, whereas Pungalina was more difficult logistically, but there had been minimal research carried out in the area prior to Australian Wildlife Conservancy acquiring the property. After discussions with a number of scientists who would be likely to attend, it was decided to go to Pungalina.

The Northern Territory property "Wollogorang" borders the NT–Qld border and extends west to the Calvert River. Pungalina adjoins Wollogorang to the west of the Calvert River. It does not actually front the Doomadgee–Borroloola road but is accessed through the north eastern part of Calvert Hills property which lies to the south west. The combined area of Pungalina and Seven Emu is 306,000 ha and encompasses over 55 km of pristine coastline and more than 100 kilometres of the Calvert River. The property contains a very large diversity of ecosystems and many endangered species of birds and mammals.

Preparation

A relatively new homestead has been erected on the property and this serves as the manager's residence and the needs of visiting AWC staff. A large barn alongside had previously been used as the homestead but was not in good repair and could not cater for the needs of a large party of scientists and volunteers so in July 2011 a party of nine volunteers proceeded to Pungalina and repaired and extended the facilities. This work included completely rewiring and extending the electrical system, and building and installing from the ground up two toilets and a septic system and an additional shower.

Provision was also made to take with us in 2012 two extra washing machines and a pressure pump for the water supply. Also taken up in 2012 and installed were extra gas hotplates, a gas oven, and extra refrigerator and freezer. Combined with a walk-in cold room already on the property, this provided adequate cooking, washing and toilet facilities for the number of volunteers and scientists on site over a six-week period.

Plans were put in place to enable supplies of fuel, food, and any necessary equipment to be brought in and some repairs were carried out to the station 6x6 ex-Army truck to ensure it was useable when required. Surveys of the station tracks were carried out and locations selected for out-camp.

It was recognised from the outset that the large distances involved and the travel times required, maximum travel speed is an average 20 kph, would require the setting up and manning of at least three out-camps. Three sites were selected, one at Karns Creek approximately 15 km from the homestead to the southwest, another one at Cycad Creek about 40 km to the north and the furthest one at Big Stinking Lagoon 65 km to the north. A boat-launching site

Figure 3. Another local resident on the track.

Figure 4. Sitting on the bank of the Calvert River birdwatching.

was cleared on the river another 15 km north and this was about 15 km from the river mouth.

A plan was developed which would see the establishment of a base area with three outstations. This would give researchers four locations from which to operate with each location offering different environmental opportunities. The outstations would be set up to accommodate about six researchers who would be supported by two volunteer staff. The base area would accommodate the bulk of the volunteer staff and up to eight researchers. Communication between base and outstations would be by satellite phone.

During this time also a re-supply system was set up. This utilised an existing supply system out of Mt Isa to the nearest town of Boulia. Orders placed with suppliers in Mt Isa were trucked to Boulia then brought to Cravens Peak by volunteer drivers. Fuel for the expedition use was brought in to the property in the usual pre-wet season dump.

One afternoon, towards the end of the fortnight that was allocated for this work, when the

Figure 5. The main tent at Big Stinking Lagoon camp.

buildings were clean and a bit of fresh paint had been applied here and there the sky suddenly took on an unusual appearance. A strange coloured cloud appeared on the western horizon. This cloud grew and moved rapidly towards the homestead. It developed into a classic dust storm cloud—a moving wall of dust about 700m high and stretching the length of the western horizon. The storm hit late in the afternoon and raged for several hours. The winds were similar to those experienced in a cyclone, visibility was about one hundred metres and the air inside buildings was thick with dust. Next morning revealed a 5 mm layer of the finest dust over every surface in every building. Vehicles, which had been securely closed, had dust inside them. There was no option but to begin cleaning again. This preliminary work put us in a good position to get the expedition on the ground as soon as possible after the next wet season.

The expedition

The first members of the advance party left Brisbane on 02 June 2012 expecting to arrive at Pungalina on 05 June 2012 in time to meet the first truckload of supplies and equipment due on 07 June 2012. However a flooded road at Tambo due to a damaged bridge not being repaired held us up for 24 hours, the supply truck did not arrive until 08 June 2012 so no problems were created. The remainder of the advance party arrived progressively over the next few days.

The next few days were very busy unloading and sorting supplies and equipment and then installing the camp equipment needed to cater for everyone. As might be expected a few

Figure 6. Another local coming for a look at the visitors.

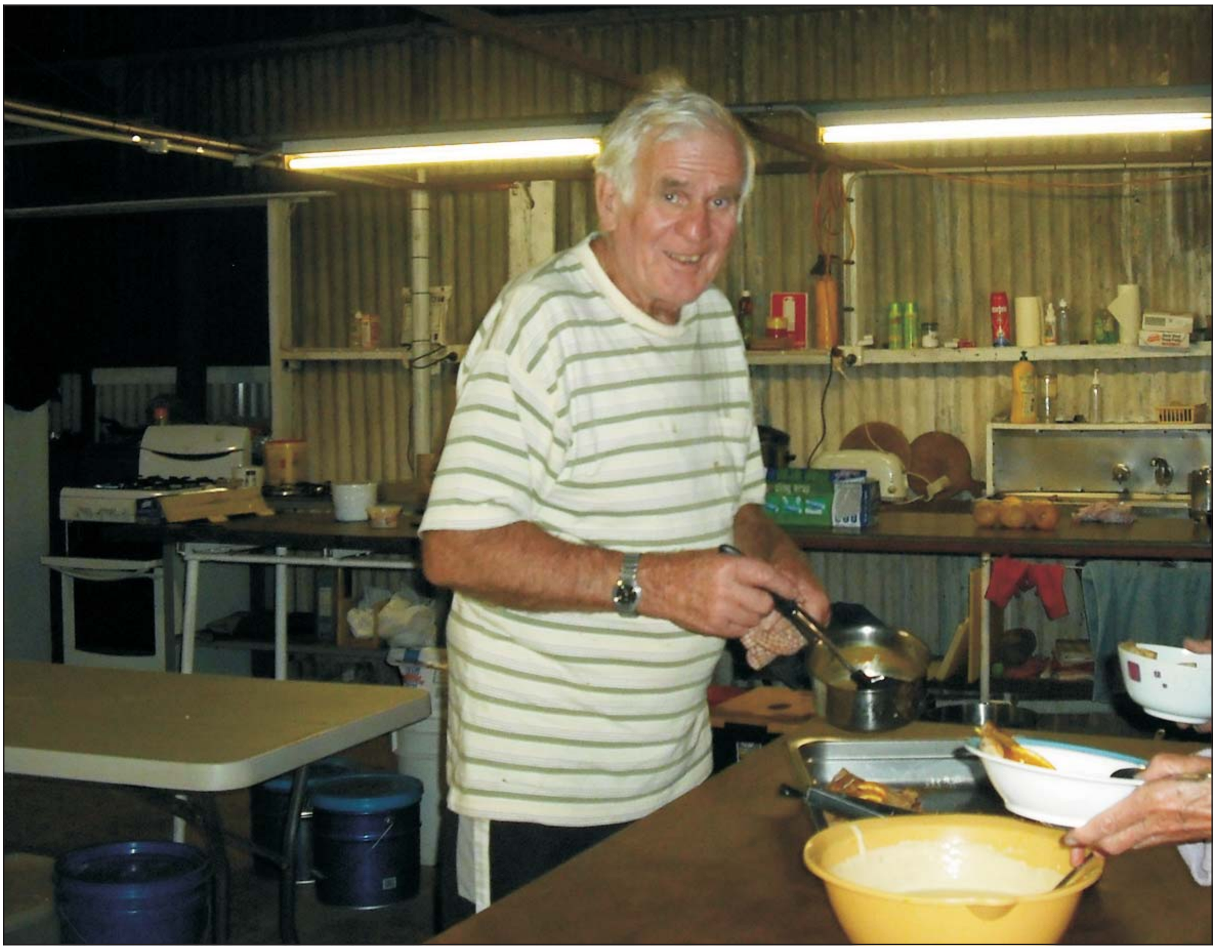


Figure 7. Our wonderful head chef, Rolf Roduna, hard at work in the main camp kitchen.

unexpected problems arose which tested the combined skills of several members and various innovative solutions were found to get everything operational.

We had been fortunate in securing the services of a highly experienced and retired chef, Rolf Roduner, who quickly set about providing us with first class meals, which continued throughout the expedition. Tragically, Rolf passed away only four months later but we know he really enjoyed the time he spent at Pungalina.

We then turned our attention to preparing the sites for out-camps prior to erecting them.

Much of the track to the north along the river had not been used since the previous year and had become so overgrown with hiptus weed that they could not be found or penetrated with a utility so we needed the considerable help of Hermaan and the station grader to find and re-open them so that we could get to the northern campsites.

We also opened up a number of other tracks to facilitate the movement of the bird surveyors who would like to have gone as far as the mouth of the Robinson River which is about 170 km from the Pungalina homestead but this was logistically impossible in the time span they had.

As soon as we had the sites cleared we erected the camps and had everything in place for the arrival of the first scientists over the weekend of 24 June 2012. Unlike the Cravens Peak expedition we were not hampered by rain or wet tracks, having only one shower of about 12 mm during our stay. All of the many creek crossings including the Calvert River were at easily trafficable levels.

The remainder of the expedition progressed well. All out-camps were equipped with satellite phones and called in each morning with orders for any supplies needed and to be advised of the movements of scientists between the camps for catering purposes.

A couple of minor injuries were capably dealt with by Mary Comber, a volunteer and retired nurse, however a bird surveyor suffered an injury to his eye from a wayward tent pole and was advised by his eye specialist to seek attention in case the retina had become detached.

Figure 8. A local resident sunning himself on the Calvert River bank.

Figure 9. Wayne and Pat Spearritt and guests at Big Stinking Lagoon camp.

This resulted in a call to the Mt Isa Flying Doctor who, after some consideration decided the patient should be evacuated. This occurred at 1230 am and required us to set up a flare path for the pilot and then extinguish the flares in case they caused a bushfire near the homestead.

Once the camps were set up and working ok, volunteers turned their attention to carrying out any repairs and maintenance needed on the station vehicles and equipment, and restoring some old equipment that had not been in use but was not beyond giving some more service.

Volunteers

The society is fortunate in having a group of volunteers with a very wide range of practical experience and skills; many of these have supported the previous expeditions and did so again at Pungalina. Given that their average age is past 70 this is a remarkable achievement.

It is appropriate to mention some who made a substantial contribution to the smooth running of the expedition. Firstly, the camp administration was kept running smoothly by Brian McGrath, with supplies moved around and people's movements controlled and accounted for and orders placed on time. With up to 50 people spread over 100 km of remote country this was no mean feat.

Paul Feeney, leader of the previous six expeditions, with his vast knowledge and skills, was also a valuable member of this team. Our plumbing expert Digby Warren again came to the fore with some very curly plumbing and hot water system problems and Graham Rees and Bruce Urquhart dealt with our electronics and computer problems. Wayne Spearritt ably supported our chef. John Nowill again lent his wide practical experience and mechanical ability to almost everything ably supported by Mary Nowill who assisted in the kitchen, helped run out-camp, and was the official photographer. Finally, no expedition has been complete without the presence of Kevin Teys. He has been at all seven expeditions and his lifetime of practical bush experience, and his unequalled mechanical knowledge and enquiring mind are priceless on such an undertaking. Many thanks to the eight volunteers who gave their time to support the expedition.

Projects

The projects accepted for study are shown in Table 1, page 2. Some scientists have prepared more than one paper. There are twelve papers published in this volume.

Collembola and other ground living invertebrates from Pungalina–Seven Emu Wildlife Sanctuary, Northern Territory

Penelope Greenslade

Environmental Management, School of Science, Information Technology and Engineering, Federation University, Mt Helen Campus, Ballarat, Victoria 3352

Abstract Collembola and other invertebrates were collected using a number of methods from three main locations in the Pungalina–Seven Emu survey area between 09 July and 21 July 2012. Specimens were identified to Order except for Collembola which were identified to species or morphospecies. Most invertebrates collected belong to highly dispersive taxa such as *Diptera*, *Hemiptera* and *Coleoptera*. Invertebrates were collected from two caves in the survey area; in the caves invertebrates were fairly abundant and species rich and included new species. Thirty-three collembolan species were collected, a third of which were found only on sites protected from fire such as rocky outcrops and creek banks. Symphypleona genera such as *Corynephoria*, *Prorastriopes* and *Temeritas*, normally abundant on native grasses and in leaf litter of forests and woodlands of the dry/wet savannah tropics were totally absent. It is suggested that the increased frequency of planned burns in the region are the cause.

Introduction

No Collembola have been recorded before from the survey area. The nearest documented records known were made in the early 1970s from localities along the McArthur River, 100 km west of the Pungalina–Seven Emu survey area and more recently from the same sites in July 2012 (Greenslade 2012 unpublished report). The recent McArthur River collection was made using a single method, that of a custom made suction sampler as well as by sweeping from grassy habitats so only epigaeic species were represented in the collection. Sweers Island, 500 km to the east, was sampled in 2004 using a wider range of methods (Greenslade 2005) and the only other collections reported for north east of Australia were from Chillagoe and Undara caves in northern Queensland (Moulds & Bannink 2012; Greenslade 2002).

It was expected that terrestrial Collembola in the survey area would be fairly abundant, widespread and diverse based on collections made in the 1970s and 1980s in similar vegetation types in northern parts of Australia (Greenslade 2013). These collections indicate that up to 60 or more species could occur in the survey area. In particular, species in the grass-living *Corynephoria* and leaf litter and soil living *Folsomides* would be expected to be present with up to ten species in each genus. These high numbers of species have only been found in fairly humid conditions after the wet season and also in areas not subject to recent flooding or fire.

For background on Australian Collembola in general as well as ecology see Greenslade (1991, 2014).

Aims

- To collect soil fauna, focusing on Collembola, as comprehensively as possible from relictual habitats such as caves, moss, fungal fruiting bodies and deep leaf litter around water bodies of various types.
- To sample the main landscape units and vegetation types so that a faunal list can be obtained for the survey area.
- To offer recommendations as to management of species and areas of conservation interest and for sustainability of landscapes.

Detailed objectives

- To search for relictual species and those of phylogenetic significance from habitats protected from short term impacts.

Table 1. Localities sampled on Pungalina–Seven Emu stations, collection methods, dates and notes on habitat

Site	Coordinates	Vegeta-tion	Date	Soil leaf litter, sand or guano	Pitfalls	Sweeps	Yellow Pans	Baits	Suction samples	Hand collec-tion
Tank hill transect (see Table 2, page 13)	16° 43.304' 137° 24.876'	varied	9.vii	2	10	1	10		1	
Pungalina camp grassland 1	16° 40.323' 137° 24.864'	exotic grass	9.vii						3	
Green Swamp edge	16° 43.479' 137° 29.471'	exotic grass	10.vii			1				
Mystery Shovel Creek	16° 41.319' 137° 30.168'	exotic grass	10.vii			1				
Lake Crocodylus edge	16° 43.789' 137° 31.748'	exotic grass	10.vii			1				
Fern Spring	16° 42.573' 137° 34.141'	exotic grass	10.vii			1				
Jabiru Swamp edge	16° 45.078' 137° 32.374'	exotic grass	10.vii			1				
Big Stinking Lagoon bank	16° 21.723' 137° 38.805'	bare ground	11 to 12.vii		10		10			
Big Stinking Lagoon woodland	16° 21.723' 137° 38.805'	bare ground	12.vii			1				
Calvert River nr mouth, river bank	16° 20.854' 137° 38.823'	tree cover	13-14.vii	1	5					
Calvert River nr mouth, woodland	16° 20.854' 137° 38.823'	wood-land	13-14.vii		5					
Beach at Fisherman's Camp	16° 20.686' 137° 44.008'	marine littoral	14.vii	1						
Cycad camp, water surface	16° 27.402' 137° 34.374'	algae	14.vii							1
Ballroom Cave	16° 47.589' 137° 27.589'	none	17-18.vii	1				5		1
Totem Cave	16° 47.589' 137° 27.589'	none	17-18.vii	1				5		1
Pungalina camp grassland 2	16° 43.255' 137° 24.858'	exotic grass	19.vii						1	
Creek nr Pungalina camp 1	16° 43.255' 137° 24.858'	pandanus	20.vii	1	5		5			
Creek nr Pungalina camp 2	16° 43.282' 137° 24.857'	wood-land	20.vii	1	5		5			1
Pungalina camp grassland 3	16° 43.282' 137° 24.857'	wood-land	19.vii			1			1	
Bracket fungus (dead)	16° 43.282' 137° 24.857'		17.vii	1						
Karns Creek bank	16° 47.589' 137° 27.589'	wood-land	18.vii	1						

• To provide a species list of Collembola for the Pungalina–Seven Emu region with information on distribution between habitats, vegetation types and landscape units.
• To collaborate with speleologists and with any other invertebrate specialists on the survey and identify Collembola collected by other members of the survey.
• To distribute other ground invertebrates collected during the survey to any interested specialists.
• To deposit all collections made in a relevant institution after completing a report to the RGSQ.

Hypotheses

- Faunas of habitats subject to short term impacts will harbor widely distributed species.
- Faunas of specialised habitats will harbour species of greater phylogenetic and conservation significance.

Methods

Because Collembola live in a range of microhabitats, a range of different sampling methods was used. A standard protocol was used as far as possible so that faunas could be compared between landscape units and vegetation types.

Table 2. Details of transect sites from base to top of Tank hill

Variables	Site 4	Site 3	Site 2	Site 1
Elevation (m)	52	52	54	62
Latitude	16° 43.307'	16° 43.305'	16° 43.304'	16° 43.297'
Longitude	137° 24.871'	137° 24.893'	137° 24.876'	137° 24.883'
Soil Temperature (°C)	25.9	29	28.8	
Photographs	x 3	x 3	x 3	x 3
% Grass cover to 0.5 m	90	0	0	0
% Grass cover to 1 m	0	10	10	5
% bare ground	2	0	trace	0
% leaf litter	8	5	trace	2
% rocks	5	40	60	70
Tree cover	few trees to 15m	sparse 2	1 only	1 fig
Shrubs to 2 m	0	30	trace	20
Shrubs to 3 m	0	trace	trace	
% cover ground timber	0	trace	trace	2
% cover herbs	sparse	0	0	10
Collection method	**Number of samples**			
Sweeps	1	0	0	0
Pitfalls	2	2	2	2
Yellow pans	2	2	2	2
Leaf litter and humus samples	Leaf litter and humus absent			2

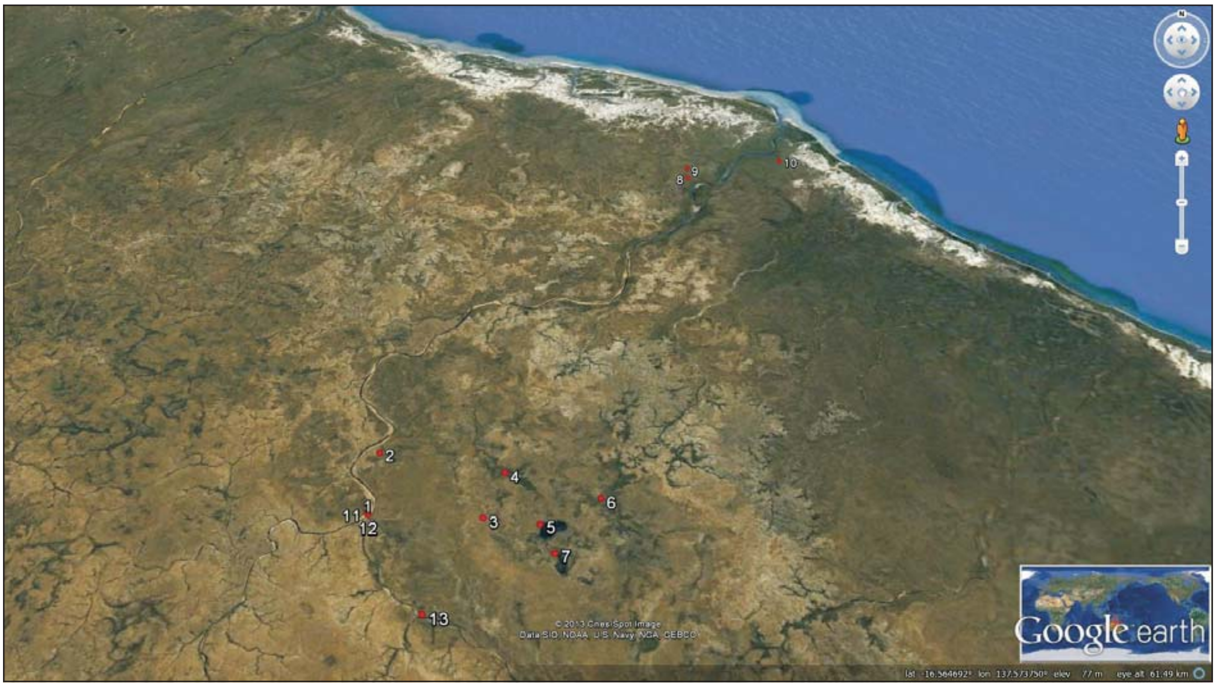


Figure 1. Map of Pungalina–Seven Emu showing sites sampled.

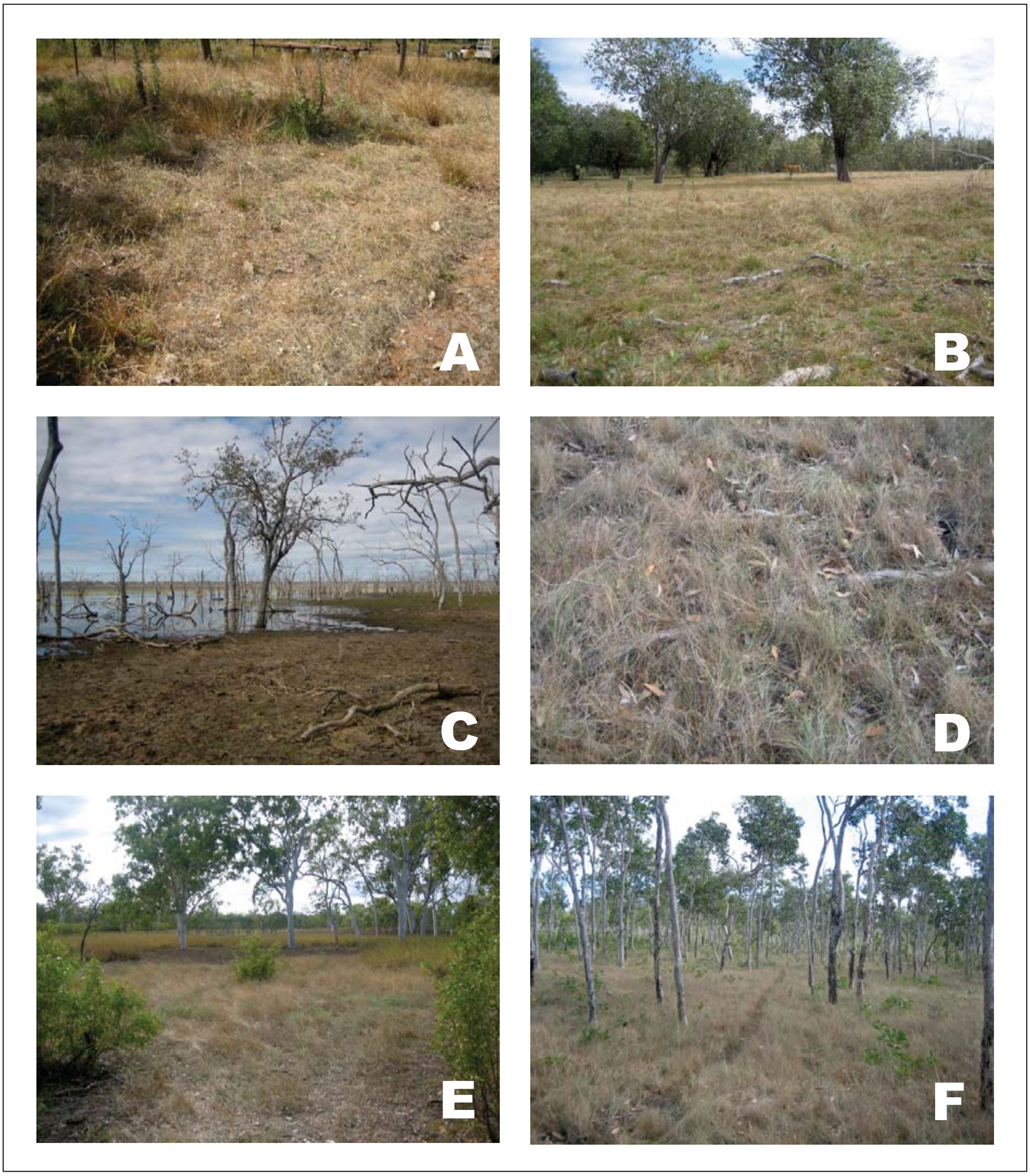


Plate 1. Swamp habitats sampled. A. Crocodilus swamp showing cattle present; B. vegetation adjacent to Crocodilus swamp; C,D. grass sampled adjacent to swamps; E,F. areas sampled around swamp.

Within each landscape unit or vegetation type to be sampled, small pitfalls and yellow pans were normally placed in a line across the site. Pitfalls consisting of McArtney bottles 1.3 cm in diameter, were three quarters filled with absolute alcohol with a few drops of glycerin to retard evaporation and yellow pans consisting of rectangular plastic take-away food containers, were three quarters filled with soapy water and left for two days. Pitfalls were exposed from two to five days and yellow pans from one to two and checked daily. Where leaf litter occurred, samples of from one to two litres of leaf litter and top soil from the ground were extracted in Tullgren extraction wherever practical. Sweeping with linen net and suction sampling using a custom built suction sampler was used on sites with grassy ground cover.

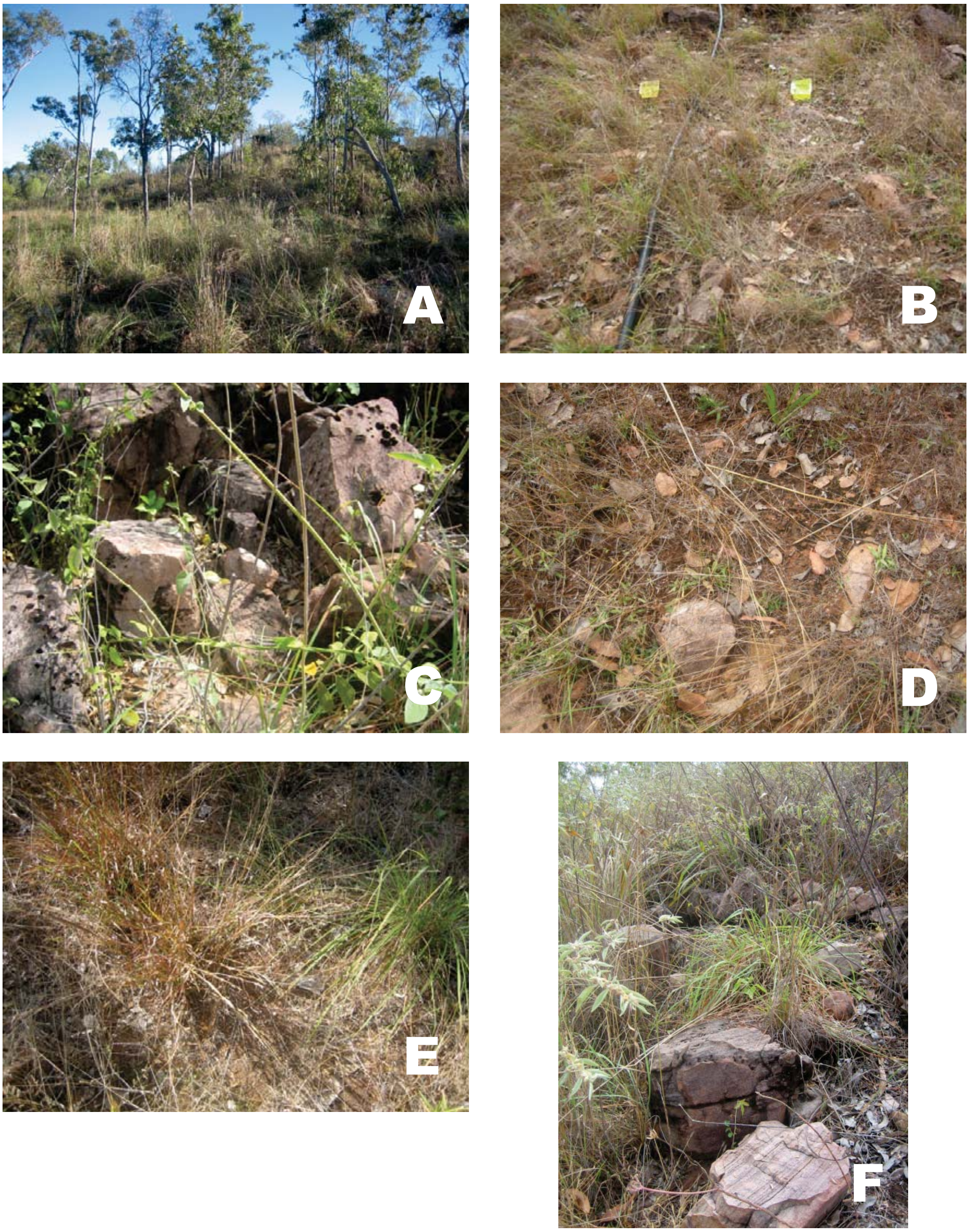


Plate 2. Sites on the Tank transect. A. view of Tank hill; B. yellow pans on site 4 bottom of transect; C. ground cover on site 4; D. ground cover on site 2; E. site 3; F. site 3.

Sampling with a fine net from the surface of water bodies and hand collections from the ground surface were undertaken in caves. Guano was collected from two caves. Fauna was extracted from this material both by flotation in salt water and by using Tullgren funnels. Baits of rotten cheese and sardines were also placed in two caves. Four sites up a rocky outcrop about 15 m high on the summit of which a water storage tank was situated, were sampled with pitfalls

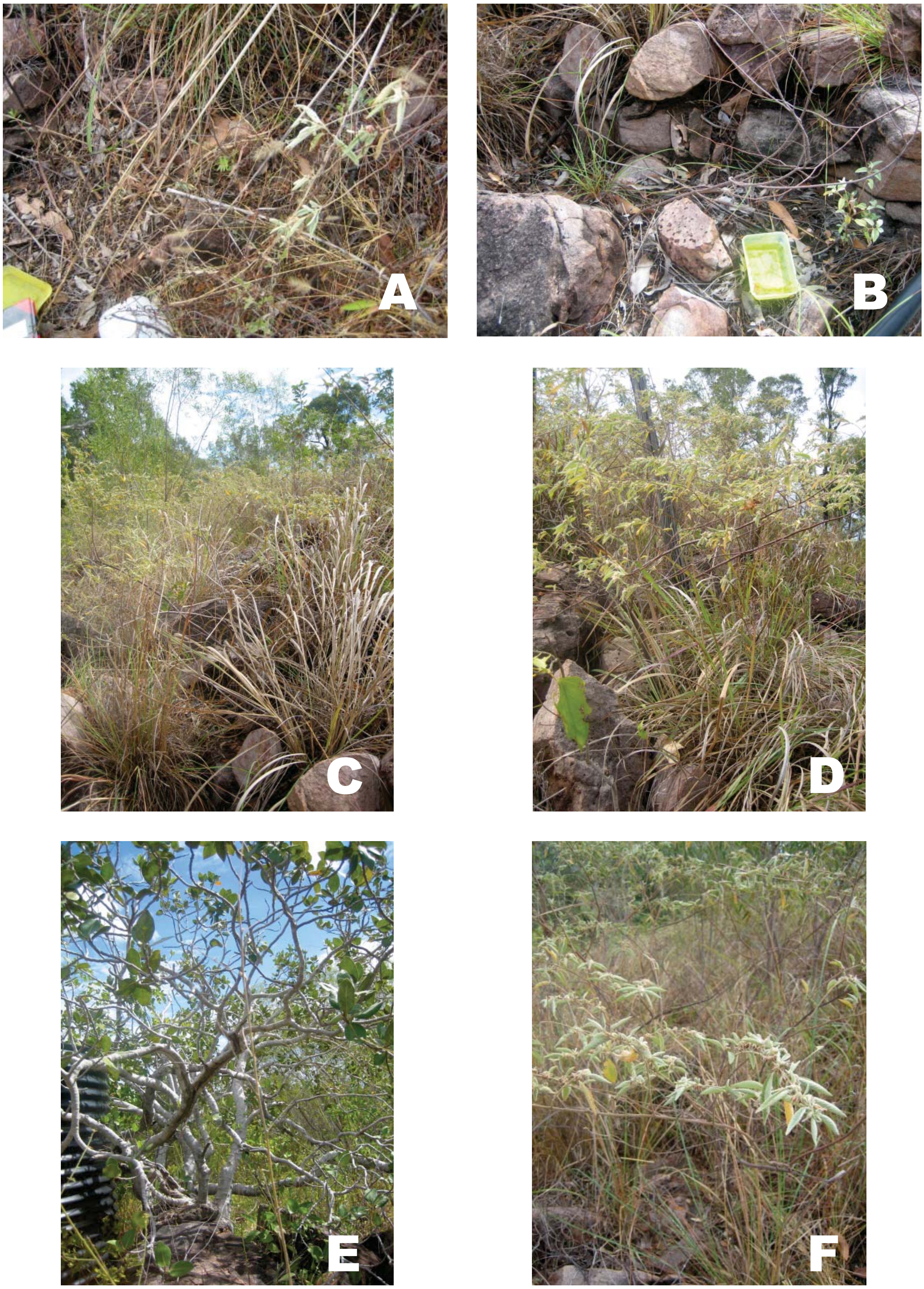


Plate 3. More sites along the Tank transect. A. site 3; B. site 4; C. site 3; D. site 4; E. site 4; F. site 3.

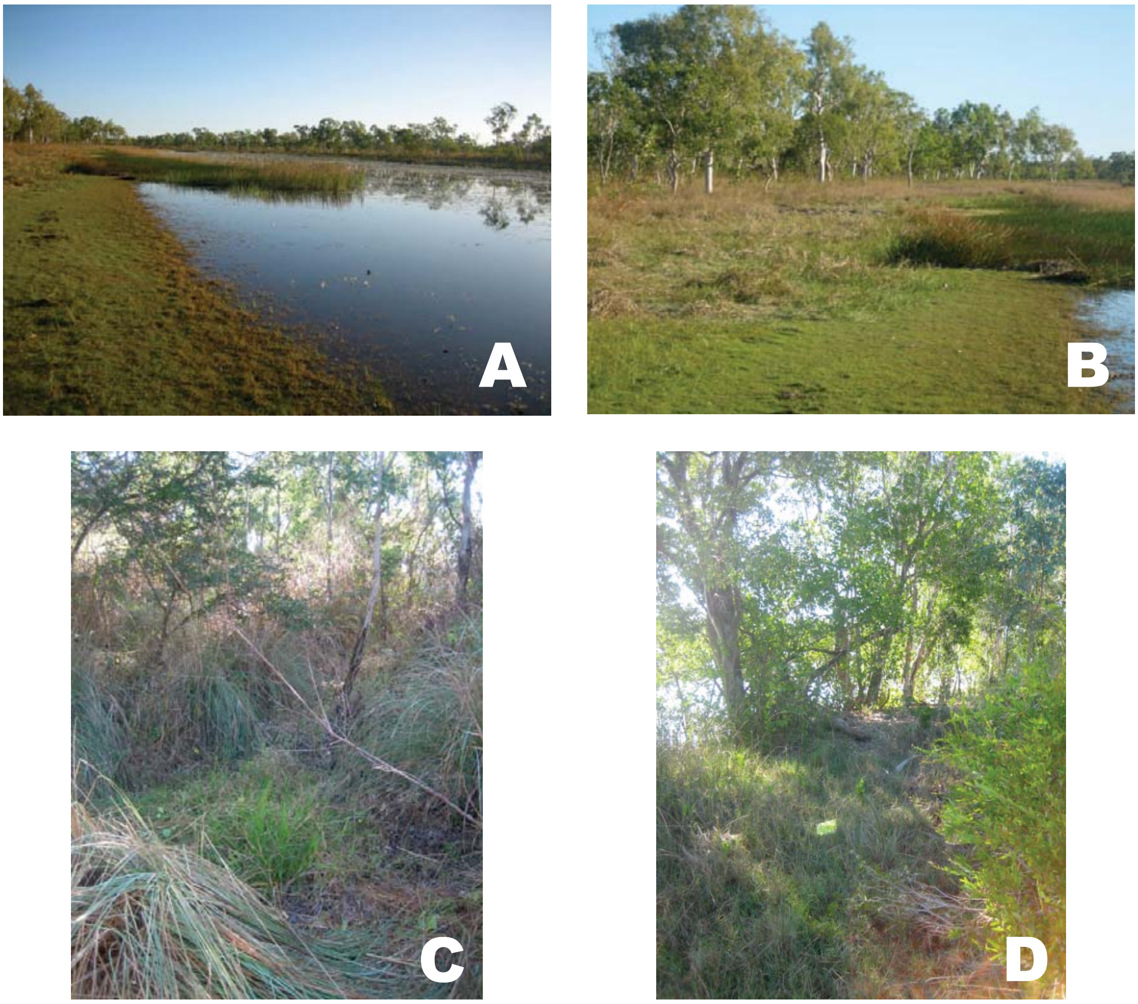


Plate 4. Big Stinky Swamp and Pungalina creek sites. A. bank sampled on bank of Big Stinky Swamp; B. general view of Big Stinky Swamp; C. forest sampled near Calvert River mouth; D. bank sampled near Calvert River mouth.

and yellow pans. The sites and collections made are documented in Table 1 (page 12) and Table 2 (page 13) and shown in Figure 1 (page 13).

Each sampling site was photographed and coordinates recorded. Ground temperatures were taken on some sites (Plates 1 to 5, starting on page 14).

Collections were sorted to taxa partly in the field but mainly on return to the laboratory. Collembola were identified to species and other individuals to higher taxa. Species richness of each site sampled using each collecting method was recorded. Possible factors influencing faunal composition and abundance are discussed.

All material collected has been deposited in the South Australian Museum except for the non-Collembola invertebrates collected from the caves which have been sent to Dr T. Moulds who has other collections from the same caves.

Results

The fauna collected from the different sites are recorded in Tables 3 to 9 (starting page 19) under the different methods and the Collembola listed in Table 10, page 28.

Sweep samples

Sweep samples were taken on an opportunistic basis; altogether eight sweeps were made from grasses and one from samphire vegetation. A few Collembola were collected from samples taken near water but samples from swamps contained no Collembola. No Symphypleona were collected, either from fine native grass or from samphire vegetation; both vegetation types

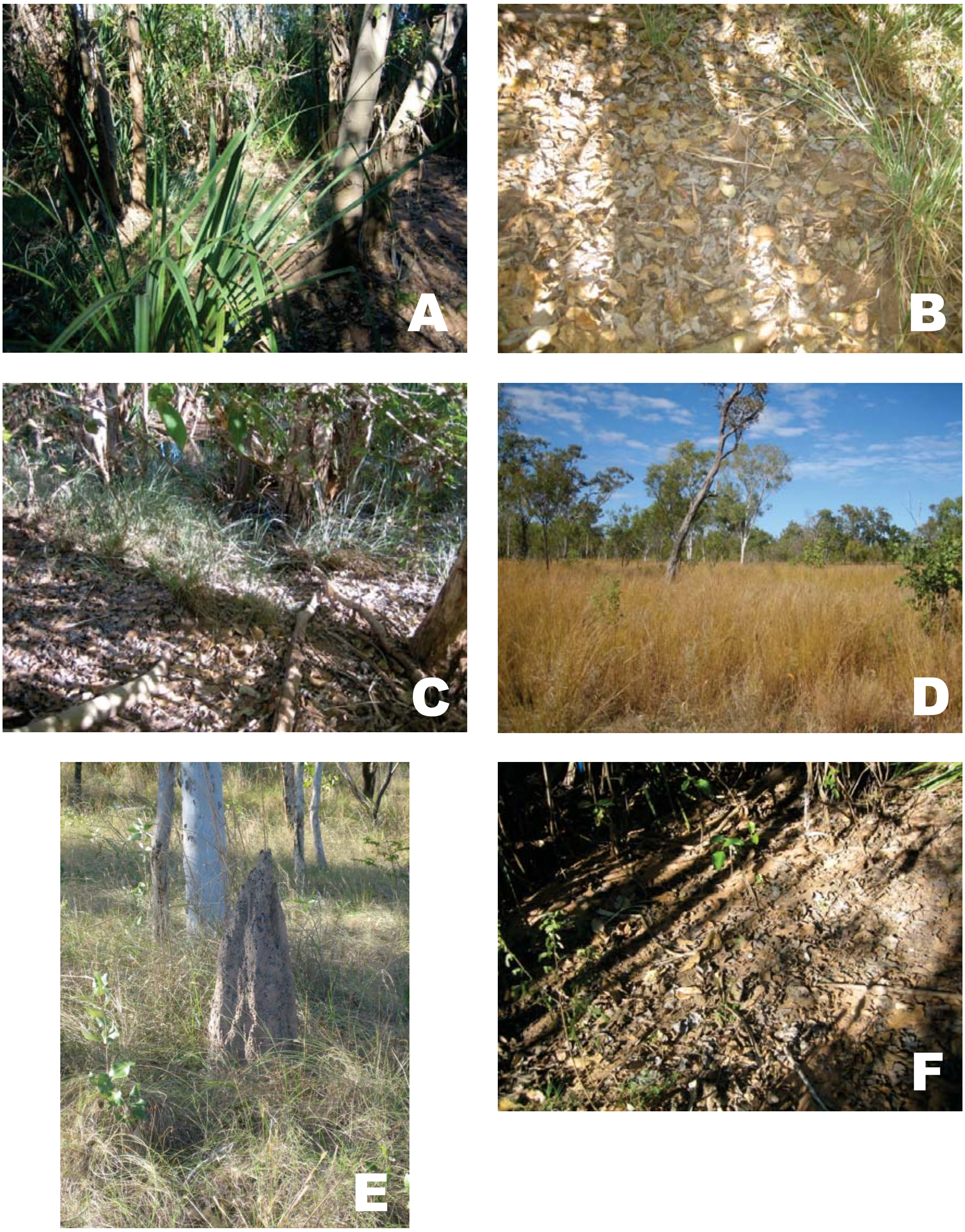


Plate 5. A. forest near Pungalina camp; B. ground surface of forest site; C. *Pandanus* near Pungalina camp; D. ground surface of *Pandanus* site; E. termite mound; F. grassland adjacent to Pungalina camp.

throughout arid and semi-arid regions of Australia normally yield numerous individuals of this Order (Table 3, page 19).

Suction samples

Five suction samples were taken (each comprising ten samples 15 cm diameter of ten second duration) from lawns of exotic grass, either

Table 3. Invertebrates collected in sweep samples from Pungalina–Seven Emu sites, p denotes presence

	Taxa	Bottom Tank hill, grass 8.vii	Samphire 14.vii	Jabiru swamp 10.vii	Fern Spring 10.vii	Mystery Shovel Creek 10.vii	Lake Croco-dilus 10.vii	Green Swamp 10.vii.	Big Stinking Lagoon grass 13.vii
Collembola	*Drepanura cinquilineata*	p	p						
	Lepidocyrtus (*Carocyrtus*) *ralumensis*								p
	Metacoelura articulata		p						
	Collembola imm Entomobryidae	p							
Insecta	Battodea						p		
	Coleoptera	p	p	p		p	p	p	
	Diptera	p	p				p		
	Hemiptera (Cicadellidae)								
	Hemiptera (other)	p	p	p	p	p			p
	Hymenoptera (Formicidae)	p	p	p			p		
	Hymenoptera (wasp)	p	p	p				p	
	Isoptera								
	Lepidoptera larvae					p			
	Mantoidea	p							
	Odonata								p
	Orthoptera		p						
	Psocoptera								
	Thysanoptera	p		p					
	Indet larvae	p					p		
Arachnida	Acarina	p	p	p	p	p			
	Araneae	p	p	p	p	p	p	p	p
Mollusca	Gastropoda					p			

mown, slashed or neither, around the camp site at Pungalina. Very few Collembola were caught but other small, light, winged species of insects were caught. *Drepanura cinquilineata* was the only entomobryid caught. It is a widespread species throughout Australia and found associated with native grasses. The only specimen of interest was an *Isotoma* sp., a possible exotic, from the lawn at the Pungalina camp site, which was not further identified as there was only a single specimen caught (Table 4, page 20).

Yellow pans

Again few Collembola were caught except from pans exposed for two days on the edge of Big Stinking Lagoon and on Tank transect. Large numbers of *Lepidocyrtus (Carocyrtus) ralumensis* were caught at Big Stinking Lagoon showing that this species was dispersed on air currents. Numerous flying insects were caught in these traps. A small number of *Paronellidae* and *Entomobryidae* were caught in yellow pans set along the Tank transect and beside the Calvert River and creek beside camp. In all 11 of the 12 species of the total number of *Entomobryidae* and *Paronellidae* found in the survey were caught in the yellow pans indicating that all of them were capable of being dispersed on wind currents (Table 5, page 21).

Leaf litter samples

Funnel extraction of leaf litter and soil samples were able to be carried out from only two main sites, the Tank transect and creek bank near the camp, apart from cave guano because of equipment and time limitations. Collembola

Table 4. Invertebrates collected in suction samples, all from near Pungalina camp site, p denotes presence.

Pungalina camp site						
	Taxa	**Lawn around camp site 10.vii**	**Clover near drain 10.vii**	**Green grass over septic 15.vii**	**Slashed grass 15.vii**	**Native grass, 15.vii**
Collembola	*Isotoma* sp. (bluish)	p				
	Drepanura cinquilineata			p	p	p
	Lepidocyrtus sp. 1 (pale grey)			p		p
	Collembola imm Entomobryidae			p		
Arachnida	Acarina					p
Insecta	Diptera		p	p	p	
	Hemiptera (Cicadellidae)				p	
	Hemiptera (other)	p		p	p	
	Hymenoptera (not Formicidae)		p	p	p	p
	Lepidoptera larvae		p		p	
	Psocoptera	p		p	p	p
	Thysanoptera		p	p		p

were abundant in these samples, mainly species of Isotomidae. Insects, especially larvae, were also numerous (Table 6, page 22). Several species of poduroid Collembola were found only in the soil around a fig tree under rocks at the top of Tank hill (site 1).

Pitfall catches

Thirty pitfalls were set at three main localities, on four sites on Tank hill, at two sites of different vegetation beside the creek at Pungalina and at two sites adjacent to Big Stinking Lagoon. The same number of species of Collembola (23) was collected in the pitfalls as from the litter samples. These two collecting methods were the most successful of the five used in the survey. Numerous other invertebrates, except for insect larvae, were also collected (Table 7, page 24). Most of the species of Collembola belonged to the *Arthropleona* and few poduroid species were trapped except on site 1 (Tank transect).

Hand collections

Hand collections were made by skimming water surfaces with a fine net, by flotation of beach sand and in caves. No Collembola were collected in any of the samples taken but large numbers of insects were collected from still-water pools adjacent to creek below Pungalina camp (Table 8, page 26).

Differences between localities

Big Stinking Lagoon

Yellow pans and pitfalls were inserted close to and at the edge of the swamp in two sites. The second site was under a tree and some moss was present. The vegetation in the immediate vicinity of the camp site comprised tall coarse grass and was swept thoroughly to collect any fauna present. Eucalypt woodland was present. Fauna were poor in both species richness and abundance. The most abundant Collembola was a species of *Acrocyrtus* (Entomobryidae) possibly *Lepidocyrtus (Carocyrtus) ralumensis* Schäffer, collected in large numbers in yellow pans set beside the swamp. This is a common and widespread species further north and has been recorded from Indonesia, Irian Jaya, and Solomon Islands and was described from the Bismark Archipelago (Yoshi and Suhardjono 1992). A few specimens of *Brachystomella dianae*, *Isotoma tridentifera*, *Salina* sp., *Sminthurides* sp., were also collected. Other fauna was even rarer, with only *Diptera*, *Araneae*, *Hymenoptera*, *Thysanoptera* found.

Table 5. Collections from yellow pans collected from Pungalina–Seven Emu, p denotes presence.

	Taxa	Creek bank nr camp *Pan-danus* 19.vii	Creek bank nr camp Wood-land 19.vii	Big Stinking Lagoon 1 12-13.vii	Big Stinking Lagoon 2 12-13.vii	Tank transect site 1 9.vii	Tank transect site 2 1 9.vii	Tank transect site 3 1 9.vii	Tank transect site 4 1 9.vii	Nr Calvert River mouth wood-land
Collembola	*Acanthocyrtus* sp. 1 (pale)	p	p				p			
	Acanthocyrtus sp. 2 (dark blotches)									
	Drepanura albocoelura						p			
	Drepanura coeruleopicta						p			
	Isotoma sp.				p					
	Lepidocyrtus (Carocyrtus) ralumensis				p					
	Lepidocyrtus sp. 1 (grey)	p	p							
	Lepidocyrtus sp. 2 (black th)						p			
	Metacoelura articulata		p		p	p	p	p	p	p
	Plumachaetas sp.		p							
	Immature Entomobryidae	p	p	p		p	p		p	
Arachnida	Araneae	p?	p	p	p	p		p	p	
	Pseudoscorpionida								p	
Crustacea	Copepoda			p						
Insecta	Coleoptera	p		p	p	p			p	
	Coleoptera larvae	p?								
	Diptera	p	p	p	p	p			p	
	Embioptera			p						
	Hemiptera (Cicadellidae)				p	p				
	Hemiptera (not Formicidae)	p	p	p	p	p		p	p	
	Hymenoptera(Formicidae)	p	p			p			p	
	Isoptera								p	
	Lepidoptera	p?	p					p		
	Lepidoptera larvae	p?				p				
	Odonata				p					
	Orthoptera					p				
	Orthoptera	p	p	p	n	p				
	Thysanoptera				p			p		
Mollusca	Gastropoda		p						p	

Tank transect

Four sites which were approximately equally spaced from the base of the Tank hill to the top were sampled (Table 2, page 13). The vegetation varied along the transect, and site 1 (top) was most different to the other three, due to the fact that a fig tree was growing among the rocks beside the water tank and the soil was moist. Sites 2, 3 and 4 were subject at times to inundation and, more rarely, fire (pers. comm. AWC staff). This difference was reflected in the collembolan species collected. Although the total species collected in pitfalls did not differ significantly between sites being 11, 9, 8, and 9 respectively from sites 1, 2, 3 and 4, the composition of the fauna differed markedly. *Poduroid* and *Isotomid* species were the taxa that showed a clear difference between site 1 (six species) which was not subject to fire or flood and the other three sites (one species from each site). In contrast, entomobryid species readily dispersed on wind, showed the opposite distribution being in number 3,6,7,6 respectively from sites 1, 2, 3 and 4.

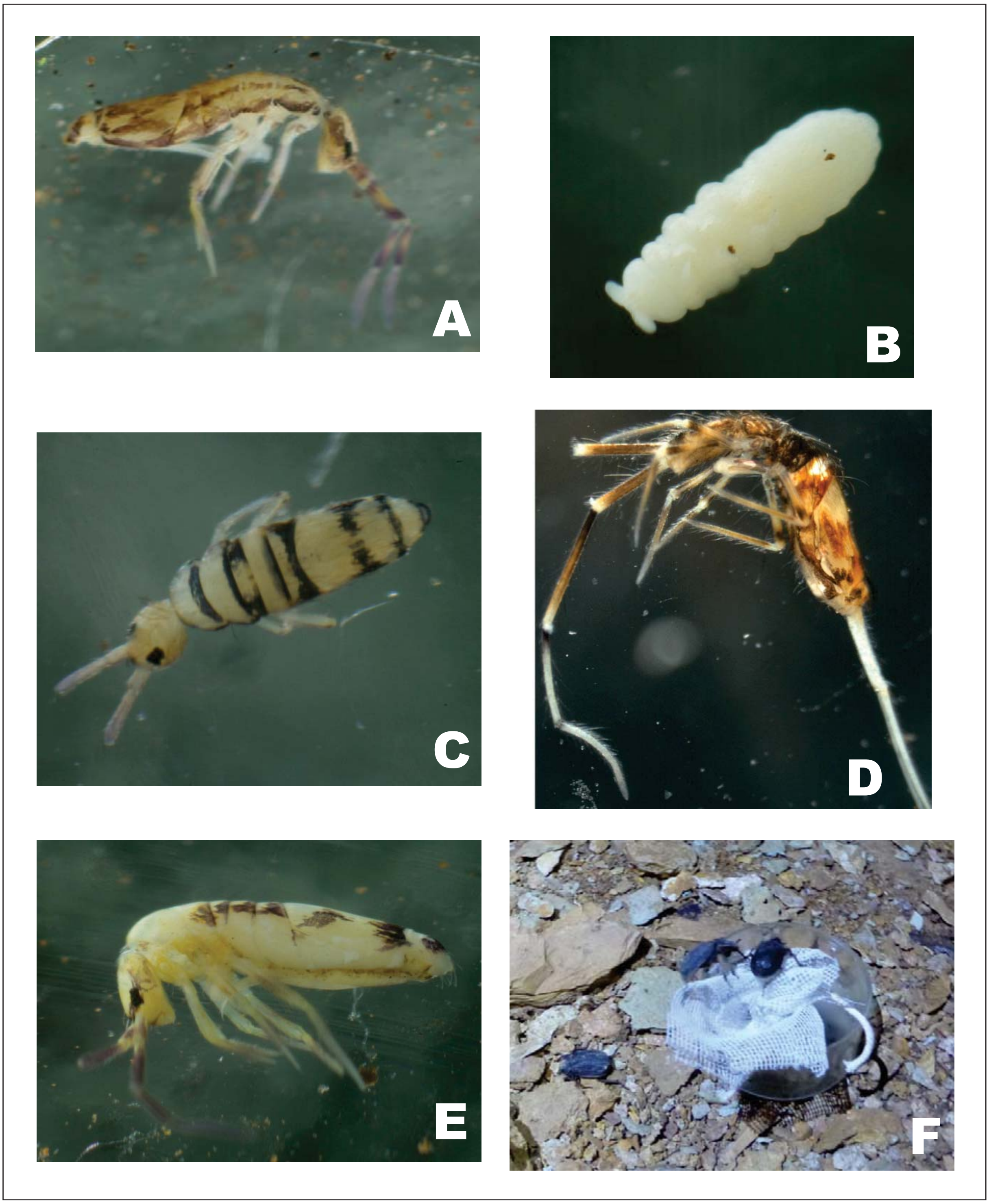
Table 6. Invertebrates collected from leaf litter and soil samples at Pungalina–Seven Emu, p denotes presence.

	Taxa	Karns Creek 18.vii, Fig	Tank hill 8, 10.vii. Top site 1	Creek *Pandanus* nr camp 15.vii	Creek woodland nr camp 15.vii
Collembola: Entomobryidae	*Acanthocyrtus* sp. pale slight bands		p		p
Collembola: Brachystomellidae	*Brachystomella dianae*		p		
Collembola: Entomobryidae	*Acanthocyrtus* sp. (lat dk patches)			p	
	Drepanura cinquilineata		p		
	Drepanura coeruleopicta		p		
	Indet. Entomobryidae		p	p	
	Lepidocyrtus sp. (pale grey)		p	p	p
Collembola: Hypogastruridae	*Xenylla* sp.		p		
Collembola: Isotomidae	*Folsomides exiguus*	p	p	p	p
	Folsomides sp. 1 (grey lobe mucro)		p		
	Folsomides sp.2 (grey no lobe mucro)			p	p
	Hemisotoma thermophila gp		p		
	Isotomiella spp.		p	p	p
	Isotomodes sp.			p	p
Collembola: Katiannidae	*Stenognathellus*			p	p
Collembola: Neanuridae	*Kenyura* sp.		p		
	Lobellini indet. sp.		p		
	Neanurinae indet. sp.		p		
	Pseudachorutes sp.		p		
Collembola: Neelipleona	*Megalothorax* sp.			p	p
Collembola: Paronellidae	*Metacoelura articulata*				p
	Plumachaetas sp.		p		
Collembola: Sminthurididae	*Sphaeridia* sp.		p		
Entognathous Hexapoda	*Protura*		p		
	? Projapygidae		p		
Arachnida	Acarina		p		p
	Araneae		p		
Crustacea	Isopoda		p		p
Insecta	Psocoptera			p	
	Isoptera		p		
	Blattodea		p		
	Orthoptera				p
	Hemiptera		p	p	p
	Lepidoptera larva		p	p	
	Coleoptera		p	p	p
	Coleoptera larvae		p		
	Diptera larva			p	
	Diptera	p			p
	Hymenoptera	fig wasp			
	Hymenoptera Formicidae		p	p	p
	Indet larvae				
Mollusca	Gastropoda		p		
Myriapoda	Diplopoda		p		
Nematoda		p			
Oligochaeta	Enchytraeidae		p		

Specialised habitats

Caves

Three collection methods were used in the two caves entered which were Totem Pole Cave and Ballroom Cave. Because of the high temperature and humidity in both caves, collecting time was limited to one hour on each of four visits. Three methods of collection were used, hand collections, extraction of fauna from guano by funnel extraction and flotation and bait stations. The baits used were over-ripe cheese and sardines. Both were successful in attracting fauna.



Animals Plate 1. Colour photographs of preserved Collembola species from Pungalina. A. *Drepanura cinquilineata*; B. Neanuridae, new genus; C. *Drepanura coeruleopicta*; D. *Metacoelura*; E. *Acanthocyrtus* sp.; F. Trogidae beetles at bait in cave.

Table 7. Invertebrates collected from pitfalls at Pungalina–Seven Emu, p denotes presence.

	Collembola	**Tank hill 1**	**Tank hill 2**	**Tank hill 3**	**Tank hill 4**	**Big Stinking Lagoon water's edge site 1**	**Big Stinking Lagoon water's edge site 2**	**Calvert R nr mouth. woodland 13.vii**	**Calvert R nr mouth bank**	**Creek woodland nr camp**	**Creek *Pandanus* nr camp**
Brachystomellidae	*Brachystomella dianae*	p	p		p	p					
Entomobryidae	*Acanthocyrtus* sp. pale			p	p						
	Lepidocyrtus (Carocyrtus) ralumensis		p	p		p	p			p	p
	Drepanura albocoelura	p	p	p	p						
	Drepanura cinquilineata		p								
	Drepanura sp. *coeruleopicta*	p	p	p	p						
	Indet Ent		p							p	p
	Lepidocyrtus sp. pale grey	p	p	p	p	p				p	p
	Lepidocyrtus sp. th black							p		p	
Isotomidae	*Folsomides* sp. grey	p		p							
	Isotoma sp. dk grey						p				
	Isotoma sp. Cf. *tridentifera*						p				
	Isotomiella	p									
Katiannidae	*Stenognathellus* sp.	p	p		p						
Neanuridae	*cf Kenyura* sp.	p									
Odontellidae	*Odontella sp.*	p									
Paronellidae	Indet.			p				p	p		
	Pseudoparonella sp. banded, blotchy		p	p	p						
	Salina sp. dk th to abd III			p	p	p					
	Salina sp. orangy blotches							p		p	
Sminthurididae	*Sminthurides* sp. male					p					
	Sphaeridia sp.	p	p	p	p						

Continued on following page

Continued from previous page

	Collembola	Tank hill 1	Tank hill 2	Tank hill 3	Tank hill 4	Big Stinking Lagoon water's edge site 1	Big Stinking Lagoon water's edge site 2	Calvert R nr mouth. woodland 13.vii	Calvert R nr mouth bank	Creek woodland nr camp	Creek *Pandanus* nr camp
Insecta	Coleoptera					p	p		p	p	p
	Coleoptera larvae	p		p							
	Diptera	p	p		p	p	p		p	p	p
	Diptera larva			p							
	Hemiptera		p			p	p	p		p	p
	Hymenoptera other	p					p			p	
	Hymenoptera Formicidae	p	p	p	p	p	p	p	p	p	p
	Isoptera	p									
	Orthoptera					p	p		p	p	p
Arachnida	Acarina	p	p				p	p		p	
	Araneae			p	p	p	p		p		
Mollusca	Gastropoda			p							
Amphibia	Anura						p				
	Indet segmented Vermes					p					

Twenty-one taxa were collected altogether, the samples being dominated by Coleoptera and Diptera particularly at baits (Table 9, page 27). The most abundant fly species belonged to the family Phoridae and individuals were particularly abundant in bait samples in both caves as adults, larvae and eggs. They belonged to a new species of *Megaselia* (Phoridae) (H. Disney pers. com.). However all individuals were females and collected at baits. This is normal for this group as the females are searching for a high energy source before laying eggs while the males rest on the walls of the cave. Identification and descriptions cannot be made without males in this family.

A number of large beetles belonging to the genus Trogidae, of which only one genus *Omorgus*, is known from Australia, was collected. Adults and larvae feed on dry animal remains (Lawrence and Britton 1991). The group is common in arid Australia and in Ballroom Cave a number of specimens was found as well as larvae clustered on sardine baits. Elytra were found in flotation samples of guano.

Some of the other species (marked with an asterisk in Table 9, page 27) may have flown into the funnel sample during extraction of the guano. However one adult moth was found together with two caterpillars, both of which may have belonged to the family Tineidae, which is commonly found in caves throughout the world.

Two specimens of a highly cave adapted Blattodea (Cockroach) were collected which were white, lacked eyes and had very long antennae. Mesostigmatid mites were numerous in guano samples in both caves. This species also appeared to be cave adapted being pale in colour. Small Mollusca were numerous both at baits and in guano. At least three species were present. Other taxa, Araneae, Isopoda, Nematoda, and Enchytraeidae were collected only in low numbers (Table 9, page 27).

Collembola fauna

Thirty-three species were collected. The fauna was typical of the wet-dry topics, a fauna that has been intensively surveyed on Barrow Island and consists there of 77 species of which ten were confined to the marine littoral zone.

Table 8. Collections made by hand on Pungalina–Seven Emu, p denotes presence.

	Taxon	Creek nr camp water surface 21.7	Cycad camp, surface water, 14.7,	Fisherman's Camp, sand flotation 14.vii	Pungalina Camp at light	Totem Pole Cave	Ballroom Cave
Entognathus Hexapoda	Campodeidae	p					
Insecta	Blattodea					p	
	Coleoptera					p	p
	Diptera	p					
	Formicidae			p			
	Hemiptera	p	p				
	Odonata	p					
	Odonata	p					
	Orthoptera				p		
	Trichoptera	p					
Acarina	Prostigmata						p
Oligochaeta	Enchytraeidae	p					
				Arthropod debris i.e. carapace beetles, skins			

Sweers Island has a similar climate to the survey area and is also subject to flooding but it is subject to maritime influences. The island is small, and has been impacted by human disturbance both currently and in the past. Twenty species were found including five marine littoral species after a survey of similar intensity to the current one.

Differences between Barrow Island and the Pungalina–Seven Emu region are that there is no standing fresh water on the former, fire is rare and is suppressed and the land is not subject to flooding. However some comparisons can be made. Two common and diverse genera in northern Australia, *Corynephoria* and *Prorastriopes* (Symphypleona: Bourletiellidae) of which six and three species respectively are known from Barrow Island, were completely absent from the present survey region. This is the first time that collections have been made anywhere in Australia in summer from native grasses where no *Corynephoria* have been found. Other Symphypleona genera normally present are *Temeritas* and *Rastriopes*. Even on the small Sweers Island species of *Corynephoria* and *Temeritas* were collected. The only exceptions are collections from cold montane sites and sub Antarctic islands.

The reason for this absence is obscure but may be related to the frequent, widespread and intense fires at Pungalina–Seven Emu earlier and currently. *Corynephoria* and *Prorastriopes* species have desiccation resistant eggs which are tolerant of hot, dry conditions and hatch only after rain, but this is the period described as 'late dry season' when prescribed burning is currently carried out in the survey area. It appears possible that a frequent and extensive fire regime, which promotes spread of exotic grass species (Tooth and Leishman 2014), has locally extirpated these genera from the survey area. These native Collembola genera cannot live on exotic grasses but only on native grasses. It is less likely that the season of sampling was the reason as immediately after the Pungalina–Seven Emu survey, a less extensive survey of only three days was carried out 200 km approximately further west at McArthur River in similar vegetation. Here *Corynephoria* species were fairly abundant and four species were collected (P. Greenslade 2012 unpublished report).

Poduromorph genera and species were generally restricted to sites protected from both fire and flood; the only example of such a site found and sampled being the Tank transect site 1 (top). However, as the transect covered both sites

Table 9. Invertebrates collected from two caves at Karns Creek, Totem and Ballroom, p denote presence. Species marked * may be contaminants in funnel samples.

		Ballroom Cave			Totem Pole Cave	
		On roots	**In guano**	**At baits**	**At baits**	**In guano**
Collembola	*Folsomina onychiurina*		p			
	Blattodea	p	p			
Diptera	*Megaselia* sp. nov. Phoridae sp.		p	p	p	p
	Diptera sp. 2*		p			p
	Diptera sp. 3*		p			
Coleoptera	Trogididae		p (elytra only)	p		
	Coleoptera sp. 2*		p			p
	Coleoptera sp. 3		p	p		
	Coleoptera sp. 4*		p			
Hemiptera			p			
Lepidoptera	Tineidae?		p			p
	Hymenoptera		p	p		
Araneae	sp. 1	p	p			p
Acarina	Mesostigmata		p			p
	Mollusca sp. 1		p			
	Mollusca sp. 2		p			
	Mollusca sp. 3		p			
	Nematoda		p	p		
	Isopoda		p			
	Enchytraeidae		p			
	Chiroptera (bones)		p			

which were subjected to flood, some fire and only the top (site 1) was not subject to these two impacts, the data can be supported. Moreover, leaf litter samples from sites on the edge of the creek below the camp and only 100 m or so from the Tank transect which were subject to flood and not fire, contained no poduromorph forms but Isotomidae of several species were fairly numerous. Table 10, page 28, lists Collembola species identified and infers they were tolerant or not of fire and/or flood. The classification has been based on information on the ecology and distribution of the species/genus gleaned from collections made outside the current survey area. Five of the seven poduromorph genera are known to be intolerant of fire and extended floods. All five genera were found only on the top of the Tank transect in damp soil around a fig beside the tank which occasionally overflowed. By contrast only four of the ten *Isotomidae* were found only on this site, while another was found only in a cave. This latter species/genus is known to have a requirement for constant high humidity and warm temperatures. Five other species of *Isotomidae* seem to be able to tolerate extended flooding based on the data here. Only single specimens of the other two species (*Isotoma* spp) were collected so no comments can be made on their ecological requirements. All the Entomobryidae and Paronellidae species appear to be easily transported in wind currents based on presence in yellow pans. The only Symphypleona and Neelipleona species collected were either rare (2 spp), have an absolute requirement for standing water (1 spp) or are common also on Barrow Island so may have a desiccation resistant egg stage.

Discussion

The aims and objectives as proposed have all been met although logistic and time restrictions

Table 10. List of Collembola species collected from Pungalina–Seven Emu stations from 07 July to 23 July 2012. NF=intolerant of fire; NFL=intolerant of flood; DW=dispersed on air currents; RS=resting stage; ?=unknown. Brackets in column 3 denote distinguishing features of a species.

	Family	Genus and species	Status	Collection	Classification
1	**Brachystomellidae**	*Brachystomella* sp. cf. *dianae*		Several collections and locations	RS
2	**Neanuridae**	*Pseudachorutes* sp.	rare	Tank transect only around fig	IF, IFL
3		*Kenyura* sp.	rare	Tank transect only around fig	IF, IFL
4		cf *Lobellini* sp.	rare	Tank transect only around fig	IF, IFL
5		cf *Australonura* sp.	rare	Tank transect only around fig	IF, IFL
6	**Odontellidae**	*Odontella* sp.	rare	Tank transect site 4 (bottom)	IF, IFL
7	**Hypogasturidae**	*Hypogastrura manubrialis*	exotic	Only one specimen found	DW
8		*Xenylla* sp. cf *stachi*	rare	Tank transect only around fig	?IF, IFL
9	**Isotomidae**	*Isotoma* sp. cf *tridentifera*	rare	Big Stinky swamp only adjacent fresh water	IF
10		*Isotoma* sp. 2		Exotic? Only on lawn at Pungalina camp	?
11		*Hemisotoma thermophila* grp.		Tank transect only around fig	?IF, IFL
12		*Folsomina onychiurina*	rare	cave guano only	IF,
13		*Isotomodes* sp.	rare	soil and humus *Pandanus* and forest creek leaf litter	IF
14		*Folsomides* sp. 1 (grey mucro ridge)	rare	leaf litter *Pandanus*	RS
15		*Folsomides* sp. 2 (grey mucro lobe)		Tank transect and creek forest and *Pandanus* leaf litter	?
16		*Folsomides* sp. cf *parvulus*	rare	Tank transect and *Pandanus* and forest creek	?
17		*Folsomides* cf *arnoldi*	rare	Tank transect only	RS
18		*Isotomiella* sp. 2 spp?		soil and humus creek forest and *Pandanus* leaf litter	IF, IFL
19	**Entomobryidae**	*Drepanura cinquilineata*	common	widespread on native grasses	DW
20		*Drepanura albocoelura*		Only on Tank Hill all sites below summit, on grasses	DW
21		*Drepanura* sp. *coeruleopicta*	common	widespread, leaf litter	Dw
22		*Lepidocyrtus* sp. 1 (pale greyish)	common	widespread on in leaf litter	DW
23		*Lepidocyrtus* sp. 2 (Th I-abd I black)		Calvert River mouth only	?
24		*Lepidocyrtus (Carocyrtus) ralumensis*		widespread	DW
25		*Acanthocyrtus* sp. 1 (white)		epigaeic species, not widespread	DW
26		*Acanthocyrtus* sp. 2 (lat dk patches)		epigaeic species, fairly widespread	DW
27	**Paronellidae**	*Plumachaetas* sp. cf *queenslandica*		epigaeic species, highly dispersive	DW
28		*Salina* sp. 1 (dk thorax)		epigaeic species, highly dispersive	DW
29		*Salina* sp. 2 (orangey streaks)		epigaeic species, highly dispersive	DW
30		*Metacoelura articulata*	common	leaf litter of *Pandanus* and forest trees	DW
31	**Neelidae**	*Megalothorax* sp.	rare	soil and humus	?
32	**Katiannidae**	*Stenognathellus* sp.		Tank transect all sites	RS?
33	**Sminthurididae**	*Sphaeridia* sp.		Tank transect all sites	RS
34		*Sminthurides* sp.	rare	Big Stinky Swamp adjacent fresh water	IF

limited the range of vegetation types that were sampled. The two hypotheses proposed that could be tested were also supported by the data to some extent (see Table 10, page 28) although locally endemic species were not detected because of few other collections in the region.

It was found that the collembolan and other fauna of the Pungalina–Seven Emu region are subject to three major environmental impacts. Firstly the climate which is wet/dry and tropical so that species must be able to tolerate hot dry conditions for much of the year and then annually extremely wet conditions leading to inundation. Flood being of regular annual occurrence on low lying land and that adjacent to water bodies, means that the land can be inundated for several weeks, if not several months a year. Secondly, the other impact is fire which, before European settlement was of smaller areas and well controlled. Since then fires have been more frequent, intense and widespread possibly partly because of more flammable exotic grass spread. Although since the AWC has been managing the land a planned fire management plan has been in operation. However its aim is to reduce flammable vegetation and not to protect native invertebrates and it does not mimic aboriginal burning. It is the second impact to which the fauna would not necessarily be evolutionarily adapted. There is a third impact and that is of a comparatively recent invasion by exotic grasses and other exotic plants but few exotic Collembola species were found in the survey region except around station buildings.

In the arid zone further south, extreme events such as floods and fires, although they may be extensive, are infrequent with a periodic occurrence perhaps of 20 up to 100 years. Here the fauna has been shown to respond only indirectly to these two impacts being directly related to vegetation condition and type, the latter being determined more by soil type and topography than by fire itself (Greenslade et al. 2012).

The collections of invertebrates made during the survey illustrate well these impacts on the fauna. Only species able to disperse rapidly on wind currents or those that have a resistant stage to fire and/or flood are widespread. A proportion of the fauna may be species of conservation significance as they appear to be restricted in distribution and are intolerant of both fire and flood so can only persist on sites which are not subject to these impacts. Another group of species appears tolerant of floods but possibly not fire. The sites on which these species occur in leaf litter adjacent to creeks and rivers are probably never burnt. Species intolerant of fire and flood yet which do not have a requirement for continuous moist conditions were absent from the survey area. These are genera such as those of *Corynephoria*, *Prorastriopes*, *Temeritas* and *Rastriopes*, which are common and in some cases, species rich in native grasses shrubs and herbs in the Northern Territory which respond to short effective rainfalls.

Conclusions

The invertebrate fauna of the Pungalina–Seven Emu survey area was abundant but a high proportion of species collected were highly vagile.

Thirty-three species of Collembola were collected. About a quarter of these species were rare and restricted to permanently moist habitats not subject to fire.

No species belonging to the normally common and species rich genera in northern Australia, *Corynephoria* and *Prorastriopes* were collected. All species of these genera, except one found on samphire vegetation, are associated with native grasses or leaf litter. It is possible that frequent fires were causing these genera to become locally extinct.

Collections indicate that sites subject to flood, plus or minus fire, carry species with strong dispersal abilities.

Sites protected from fire and/or flood can harbor what could include locally endemic species. Examples of these sites are rocky outcrops and caves.

The different effects of fire and flood cannot be separated but it appears that species adapted to surviving short term floods are not adapted to fire.

Based on the results reported here, future management of the survey area should reduce the extent and frequency of deliberately lit fire and exotic plants should be controlled in order to maintain the integrity of native ecosystems.

Acknowledgements

Thanks are due to the Royal Geographical Society of Queensland Inc for providing logistic support and organizing the field survey and also to the Australian Wildlife Conservancy for permission to conduct field work on their land. I would like to acknowledge, in particular, the University of Queensland geomorphology team for transport, Graham Rees for being an excellent host at Karns Creek, Sharyn Yelverton and Herman Mouthaan for transport and information, Patti Spearritt for assistance at Big Stinking Lagoon and the Victorian cavers, Nick and Susan White, for transporting equipment, field assistance and for facilitating a memorable experience for me.

References

Greenslade, Penelope. 1991. Chapter 11 Collembola In The Insects of Australia. A textbook for students and research workers. 2nd Edition. Division of Entomology, CSIRO, Australia: 252–264.

Greenslade, Penelope. 2005. Collembola (springtails) of Sweers' Island and Pennefather River with notes on some other invertebrates. The Royal Geographic Society of Queensland, Geography Monograph Series 10. Gulf of Carpentaria Scientific Study Report. 227–238.

Greenslade, Penelope . 2012. Collembola and other invertebrates in the McArthur River region. Unpublished report to Conzinc RioTinto.

Greenslade, Penelope. 2013. Barrow Island Collembola. *Records of the Western Australian Museum*. Supplement 83: 221–228.

Greenslade, Penelope . 2014. Australian springtails: tiny titans of the earth. Wildife Australia. 51:9–13.. *e*

Greenslade, Penelope, Florentine, S., Horrocks, G. 2012 Invertebrates and extreme events: responses of ants and springtails to a flood and fire in arid Australia. *Soil Organisms* 84(3): 569–587.

Moulds, T., Bannink, P. 2012. Preliminary notes on the Cavernicolous Arthropod Fauna of Judbarra/Gregory Karst Area, Northern Australia. *Helictite* 41: 75–85.

Tooth IM, Lewishman MR (2014) Elevated carbon dioxide and fire reduce biomass of native grass species when grown in competition with invasive exotic grasses in a savanna experimental system. Biological Invasions 16L 257–268.

Yoshii R, Suhardjono YR (1992a) Notes on the Collembolan fauna of Indonesia and its vicinities II: Collembola of Irian Jaya and Maluku Islands. Acta Zoologica Asiae Orientalis 2: 1–52.

Baseline studies of the dung beetles of the Pungalina Seven-Emu Sanctuary, Gulf Coastal region, Northern Territory

Nicole L. Gunter and Thomas A. Weir

Australian National Insect Collection, CSIRO Ecosystem Sciences, GPO Box 1700, Canberra, ACT, 2601, Australia.

Abstract Dung beetles from the Gulf Coastal bioregion are poorly documented yet they are an important indicator of an ecosystem's health. The first survey of the dung beetle fauna of Pungalina Seven-Emu Sanctuary was conducted as part of joint Australian Wildlife Conservancy - Royal Geographical Society of Queensland Inc expedition. Dung beetles were collected in pitfall traps and flight intercept traps from 26th June to 8th July 2012. Five species representing two genera were collected on the reserve, all representing the first records for the Gulf Coastal IBRA region. An undescribed species of *Lepanus* was collected in riparian forest in the reserve; this species will be described in the near future. All described species collected belong to the northern savannah woodland and northern grassland biomes developed by Matthews (1971) and provide evidence that other species within these groups may be present if further sampling was undertaken.

Introduction

The Gulf Coastal IBRA bioregion is a 26,150km² area located in the Gulf of Carpentaria on the northeastern coast of the Northern Territory (SEWPaC, 2013). The dominant vegetation types include stringy bark woodland, samphire shrub land and mangrove forests. The region is subject to a tropical monsoonal climate (SEWPaC, 2013). During the 1990s over 80% of the bioregion was grazed (SEWPaC, 2013) including Pungalina Seven-Emu Sanctuary, a 3,060km² nature reserve recently acquired by Australian Wildlife Conservancy. Biological surveys of vertebrate fauna of Pungalina Seven-Emu Sanctuary have recorded almost 200 species of birds, 95 frog and reptile species and 40 species of mammals (AWC, 2013) however the invertebrate fauna has yet to be surveyed.

Dung beetles (Coleoptera: Scarabaeidae) have been considered as biological indicators of ecosystem health as they play a critical role in the ecosystem process, by nutrient cycling, aeration of soil seed and spore dispersal; furthermore, their diversity can be related to other organisms that provide dung sources on which they feed (McGeoch *et al.* 2002). Despite this, little is known about diversity and distribution of dung beetles in many of the IBRA regions in Australia, including Gulf Coastal bioregion and also the surrounding regions of Gulf Fall and Uplands and Gulf Plains. Records of dung beetles on the "Atlas of Living Australia" indicate only 11 species of *Onthophagus* as well as the genus *Lepanus* having been recorded from the Gulf Coastal region (ALA, 2013) with no records from Pungalina Seven-Emu Sanctuary. However, the apparent lack of diversity is likely to reflect a lack of sampling effort, due to the remote location as well as incomplete data-basing of existing museum collections.

Here we conduct the first survey of dung beetles of Pungalina Seven-Emu Sanctuary. Based on the habitat type and the known distributional patterns recorded for dung beetles, it is expected that species that occur in the northern savannah woodland and northern grassland biomes of Matthews (1971) will occur in the reserve. Although the checklists of Matthews (1971, 1974) are over 40 years old, they provide a comprehensive revision of the dung beetle fauna that may be expected in the area. In total, 40 species belonging to the genera *Onthophagus* (32 spp.), *Monoplistes* (3 spp.), *Temnoplectron* (2 spp.), *Tesserodon* (2 spp.) and *Lepanus* (1 sp.) occur in the biomes to which Pungalina Seven-Emu Sanctuary belongs.

To collect dung beetles, baited pitfall traps were placed at nine localities in Pungalina

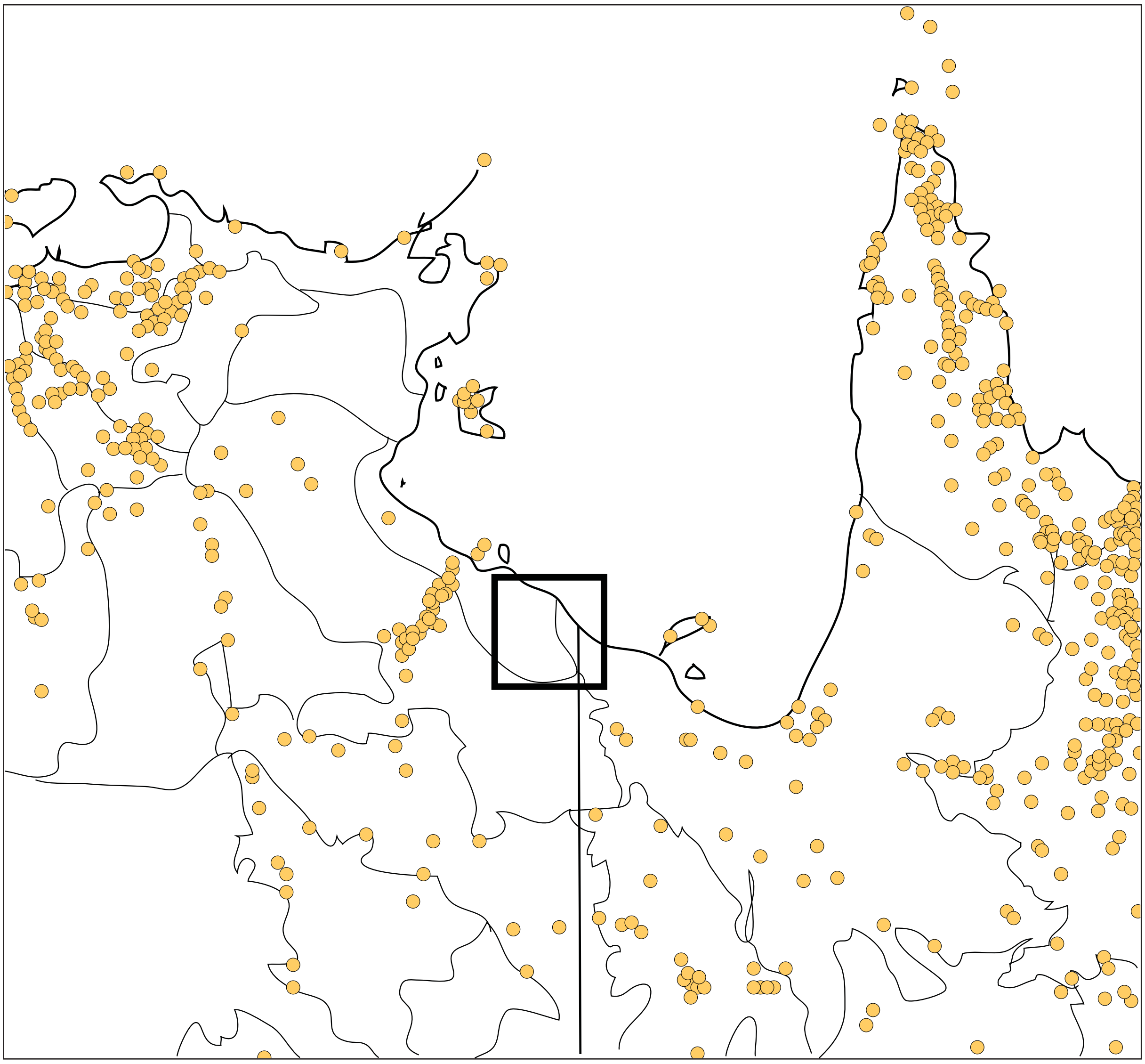


Figure 1: Collection localities of dung beetles *Scarabaeinae* recorded in the Atlas of Living Australia as of July 2013. Black rectangle indicates approximate area of Pungalina Seven-Emu Sanctuary.

Seven-Emu Sanctuary with flight intercept traps also set at four of the sites (see Figure 2, page 33) These traps were collected over a period of a fortnight (26 June to 8 July 2012). The pitfall traps consisted of a round plastic container measuring 12 cm in diameter and 9 cm deep, buried flush in the soil. The traps were baited with a combination of macropod, human faeces and decomposing mushrooms. This bait was wrapped in gauze and suspended under a 3 cm plastic mesh grid used to limit by-catch. The containers were filled with a hyper-saline solution approximately 1 cm deep and a drop of detergent was added to break the surface tension. Traps were checked at two to three day intervals and specimens were transferred to 96% ethanol for preservation. Dung beetles were identified using the keys in Matthews (1971, 1974) and by reference to the holdings at the Australian National Insect Collection.

Results

During this short survey of the dung beetle community of Pungalina Seven-Emu Sanctuary, three species of *Onthophagus* and two species of *Lepanus* were collected. Table 1, page 34, lists the nine collection sites, the collection method and the dung beetle species collected. Although sampling was limited, dung beetles were collected at four sites and in both pitfall traps and flight intercept traps, however baited pitfall traps recovered more specimens than flight intercept traps. Abundance data at each

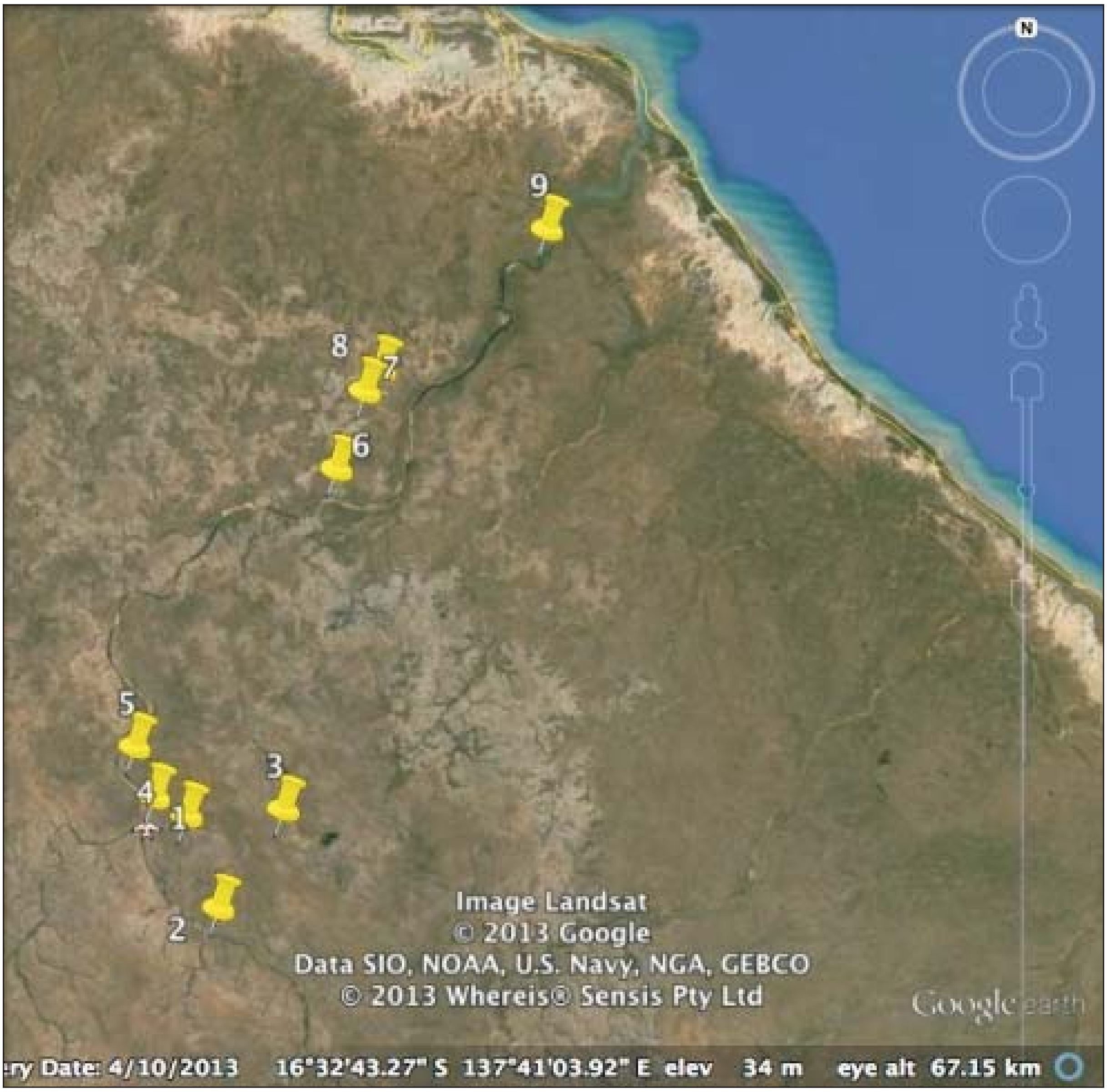


Figure 2: Collection sites within Pungalina Seven-Emu Sanctuary. Site numbers correspond to those listed in Table 1, page 34. Map generated from http://biocache.ala.org.au

site should be interpreted cautiously due to the very short trapping period.

Discussion and Conclusion

The species list provided here results from a very short term trapping schedule and in no way represents a complete species inventory of the area. Very limited data are available for the dung beetles known in the Gulf Coastal IBRA region. In the past only two genera representing 11 identified *Onthophagus* species and an unidentified *Lepanus* species are known from this IBRA region (ALA, 2013). All previously recorded dung beetles were grouped within the northern savannah woodland biome pattern of Matthews (1971) which are characterised as species occurring in open and semi-open areas in northern Australia with predominately savannah woodland and a tropical monsoonal climate. On the basis of Matthews' (1971 and 1974) dung beetle biome groups, a further 23 species in the northern savannah woodland group are projected to occur but have not yet been recorded in the Gulf Coastal bioregion. Additionally, six species belonging to the northern grassland biome group should also occur in the Gulf Coastal bioregion, yet no species have been recorded on the ALA database. During our short survey we collected

Table 1: Collection site and dung beetles identified during the two week survey of Pungalina-Seven Emu Sanctuary.

Site	Longitude and latitude	Site description	Collection method	Dung beetles
1	16° 43' 16" 137° 24' 55"	Back of AWC homestead, riparian forest along side of creek	a) Baited pitfall traps b) Flight intercept trap	a) *Onthophagus fabricii* Waterhouse (n=1), *Onthophagus propinquus* Macleay (n=1), *Onthophagus consentaneus* Harold (n=1) and *Lepanus pygmaeus* Macleay (n=1)
2	16° 47' 30" 137° 27' 27"	Karns creek, shaded forest along side of creek bordered by open savannah grassland	a) Baited pitfall traps b) Flight intercept trap	a) *Onthophagus fabricii* Waterhouse (n=1), *Onthophagus propinquus* Macleay (n=11), *Lepanus pygmaeus* Macleay (n=2) and *Lepanus* n. sp. (n=2) b) *Onthophagus propinquus* Macleay (n=1) and *Lepanus pygmaeus* Macleay (n=1)
3	16° 43' 45" 137° 30' 02"	Open forest, savannah woodland	Flight intercept trap only	
4	16° 43' 59" 137° 26' 12"	Safari camp, pandanus and creek side vegetation	Baited pitfall traps	
5	16° 41' 22" 137° 24' 09"	Figtree camp, open savannah woodland bordering creek	Baited pitfall traps	
6	16° 30' 50" 137° 32' 09"	Calvert River, open savannah woodland bordering creek	Baited pitfall traps	*Onthophagus fabricii* Waterhouse (n=1)
7	16° 27' 53" 137° 33' 17"	AWC camp site, riparian forest along side of creek	Baited pitfall traps	*Onthophagus fabricii* Waterhouse (n=25), *O. propinquus* Macleay (n=5) and *Lepanus pygmaeus* Macleay (n=9)
8	16° 27' 04" 137° 33' 54"	nr Cycad creek, open savannah woodland	a) Baited pitfall traps b) Flight intercept trap	-
9	16° 21' 44" 137° 40' 29"	Riparian forest and mangroves along side of Calvert River	Baited pitfall traps	-

four described species and an undescribed species, all of which were not yet recorded on the ALA database within this region. Of the described species collected from Pungalina Seven-Emu Sanctuary *Onthophagus fabricii*, *Onthophagus propinquus* and *Lepanus pygmaeus* all are grouped within the northern savannah woodland biome pattern while *Onthophagus consentaneus* belongs to the savannah grasslands group (Matthews, 1971 and 1974). These results provide support for the biome groups developed by Matthews (1971) and it is predicted that other species within the northern savannah woodland and savannah grasslands group are likely to occur within the reserve. No introduced dung beetles such as *Onitis alexis*, *Onthopagus gazella* or *Onthophagus sagittarius* which are known to be established in the Northern Territory (Edwards, 2007), were collected during this survey.

This is the first survey of the dung beetles at Pungalina Seven-Emu Sanctuary and it provides additional insights into the dung beetle fauna of the Gulf Coastal bioregion. Overall, very few dung beetles were collected during the preliminary survey of Pungalina Seven-Emu Sanctuary. There could be many reasons for this including seasonality as collection occurred in midwinter when dung beetles may be less active. Noticeably there were very few macropods observed during the collection period so sourcing fresh, and therefore volatile, macropod dung to bait the pitfall traps with was not possible. Regardless of this three species of *Onthophagus* and two *Lepanus* were recorded from the survey. *Onthophagus fabricii* were collected from all sites at which dung beetles were recorded while *Onthophagus propinquus* and *Lepanus pygmaeus* were also recorded from multiple collection sites. Species richness was highest in riparian forest edging water sources and no dung beetles were collected in any traps in savannah woodland away from creek lines however sampling was very limited so results should be interpreted cautiously. Sampling under better conditions, over extended periods representing multiple seasons is likely to recover other species with wide spread distributions grouped within the northern savannah woodland and savannah grasslands developed by Matthews (1971).

In general, most of dung beetle biomass is derived from nutrients obtained from mammal dung (Halffter and Matthews 1966). Increases in abundance of dung beetles may correlate with recovery of the ecosystem and may also indicate increases in the abundance of other vertebrates on whose dung they feed. Studies between the correspondence of mammal and dung beetle communities have shown that declines in mammal abundances and richness are followed by decreases in dung beetle biomass and richness (Carpaneto et al. 2005; Hanski and Cambefort, 1991). However no comprehensive studies have examined this model for recovery of environments. Monitoring dung beetle communities at Pungalina Seven-Emu Sanctuary could provide an interesting case study of dung beetles as bio-indicators as the nature reserve was formerly a grazing property and was only acquired by the Australian Wildlife Conservancy in 2009. However, the remoteness of the locality constrains the feasibility of intensive monitoring surveys.

References

Atlas of Living Australia (ALA) website at http://biocache.ala.org.au/occurrences/search?q=lsid%3Aurn%3Alsid%3Abiodiversity.org.au%3Aafd.taxon%3Aaa650142-a6f3-47ac-a21ae94e01788501&fq=ibra:%22Gulf%20Coastal%22#tab_chartsView Accessed 23 July 2013.

Australian Wildlife Conservancy (AWC) website at http://www.awc.org.au/Pungalina/Property-Profile.aspx Accessed 23 July 2013.

Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) website at http://www.environment.gov.au/land/publications/acris/pubs/bioregion-gulf-coastal.pdf Accessed 23 July 2013.

Carpaneto, G. M., Mazziotta, A., Piattella, E. (2005). Changes in food resources and conservation of scarab beetles: from sheep to dog dung in a green urban area of Rome (*Coleoptera*, *Scarabaeoidea*).

Biological Conservation 123: 547–556

Edwards P. (2007) Introduced Dung Beetles in Australia 1967- 2007: Current status and future directions. *Landcare Australia*. http://www.landcareonline.com.au/?page_id=2790

Halffter, G., Matthews, E. G. (1966). The natural history of dung beetles of the subfamily *Scarabaeinae*.

Folia Entomologica Mexicana 12–14: 1–312

Hanski, I., Cambefort, Y. (eds.). 1991. Dung Beetle Ecology. Princeton University Press, Princeton.

Matthews E.G. (1971) A revision of the *Scarabaeine* dung beetles of Australia. I. Tribe Onthopagini. *Australian Journal of Zoology Supplementary Series* 19 (9): 1–330.

Matthews E.G. (1974) A revision of the *Scarabaeine* dung beetles of Australia. II. Tribe Scarabaeini* *Australian Journal of Zoology Supplementary Series* 22(24) 1 – 211.

McGeoch, M.A., van Rensburg, B.J., Botes, A. (2002) The verification and application of bio-indicators: a case study of dung beetles in a savanna ecosystem. *Journal of Applied Ecology.* 39:661-672

Baseline study of the weevils (Coleoptera: Curculionoidea) of the Pungalina Seven Emu area, with particular emphasis on the *Melanterius* (Erichson) weevils associated with *Acacia* species

Sara V. Pinzón-Navarro and Rolf G. Oberprieler

CSIRO Australian National Insect Collection, GPO Box 1700, Canberra, ACT 2601

Abstract A total of 308 weevils were collected from 13 *Acacia* species. The acacias sampled were representatives of the Sections Phyllodineae, Juliflorae and Plurinerves. The weevils represented three families and 11 genera. The seed-feeding genus *Melanterius* was well represented on six species of *Acacia*. DNA has been extracted from a subsample of the *Melanterius* weevils from all *Acacia* hosts and sequenced for the mitochondrial gene *cytochrome oxidase 1*. Plant specimens were identified and lodged in the Australian National Herbarium (CANB) and insects will be kept, after molecular analysis, in the Australian National Insect Collection (ANIC).

Introduction

Weevils (Coleoptera: Curculionoidea) constitute one of the most diverse groups of beetles, with more than 60 000 described species, feeding on almost all plant tissues and species. Seed-feeding weevils play a major role in forest dynamics (e.g. by reducing seed production) and many species are used as biocontrol agents (economic importance). However, given the difficulty of morphological identification, they are often excluded from major biodiversity studies (Novotny et al. 2010) and many species remain to be described (Oberprieler et al. 2007; Pinzon-Navarro et al. 2010). The Australian weevil genus *Melanterius* (Erichson, 1842) is a large group of weevils exclusively associated with Australian acacias, and several of its species function as important biocontrol agent of acacias that are invasive in other countries. The weevils lay their eggs on young seed pods, and the larvae feed on the developing seeds and destroy most of the seed tissue (New 1983, Donnelly 1992). Species of *Melanterius* are crucial elements in the control of weedy acacias given that:

- their seed parasitism is very high (up to 100% in South Africa, Dennill et al. 1999),
- the species generally have restricted host ranges (van den Berg 1980, 1982, Auld 1983), and
- their impact on the plants is restricted to seeds as they do not damage other parts of the plant.

The genus *Acacia* comprises approximately 1 020 species in Australia and represents a dominant component of the Australian vegetation (Murphy et al. 2010). Its highest species diversity is in Western Australia and along the Great Dividing Range in eastern Australia (Maslin 2001). Within *Acacia* the Section Botrycephalae, consisting of approximately 46 species, is of great importance due to the weediness of several of its species in southern Africa.

Since 1985, five species of *Melanterius* have been employed as biocontrol agents of these acacias (van den Berg 1980), and additional species have been considered to control other invasive *Acacia* species (Dennill et al. 1999). Identification of the *Melanterius* species was difficult from the beginning, and the inability to distinguish weevils collected from some *Acacia* species in Australia roused the need for a comprehensive taxonomic study of this entire species assemblage. It appeared that one species in particular, *M. maculatus* (Lea), may constitute a complex of species attacking *Acacia mearnsii*

(De Wild), *A. dealbata* (Link), *A. decurrens* (Wild) (section Botrycephalae) and possibly others, not only making their identification problematic but also potentially wasting biocontrol efforts (Dennill et al. 1999). Further sampling of *Acacia* species in Australia registered *A. baileyana* (Mueller), *A. elata* (Benth.) and *A. terminalis* (Salisb.) (section Botrycephalae) as well as *A. linifolia* (Vent), *A. pycnantha* (Benth.) and *A. rubida* (A.Cunn.) (Phyllodineae) as additional hosts for species in the *M. maculatus* complex. The species reared from these various hosts showed no significant morphological differences, suggesting that all of them belong to the same species (Oberprieler & Zimmermann, 2001). In contrast, *Melanterius* species attacking other invasive *Acacia* species are morphologically more distinct, e.g. *M. servulus* (Pascoe) slightly but *M. ventralis* (Lea) significantly so (Oberprieler & Zimmerman 2001). In previous molecular analysis Clarke sequenced a fragment of COI, COII and the D2 region of 28S showing no sequence divergence. Previous molecular analysis using two mitochondrial and one nuclear gene fragments showed small sequence divergence (0–0.9%), even between individuals developing on different hosts and in different areas (Clarke 2002).

These inconclusive results emphasise the need for sampling weevils from a wider range of *Acacia* species and from different areas of their distributions. A more comprehensive molecular analysis of more individuals from more hosts and localities throughout Australia will assist in the delineation of natural, genetically different species of *Melanterius* species, in the determination of their host specificity and in the recognition of further species of potential importance in *Acacia* biocontrol. This project constitutes the Northern Territory component of a wider study sampling *Melanterius* species in all Australian states. The aim of this project is to determine which species occur in the region and how specific they are to their *Acacia* hosts.

Methods

Field Collection

Collection took place between 26 June and 8 July 2012 at 32 locations in the Pungalina Seven Emu Wildlife Sanctuary. The collecting method used was to beat *Acacia* trees and shrubs with flowers and/or fruits over a beating sheet. A sample of each plant was collected for identification and lodged as a voucher in the Australian National Herbarium (Table 1, starting page 39). The weevils collected were preserved in 100% ethanol until DNA analysis. After DNA extraction, specimens were mounted and deposited in the Australian National Insect Collection (CSIRO). Specimens not used for molecular study are stored in ethanol.

Molecular Analysis

Representatives of *Melanterius* from each host plant and locality were selected for DNA sequencing (Table 2, page 41). Tissues were extracted from the prothorax and head and DNA was extracted from them using the Qiagen DNeasy 96-well plate Blood and Tissue Extraction Kit. The mitochondrial fragment of the 3' end of the cytochrome oxidase 1 (*cox1*) was amplified using standard oligonucleotide primers C1-J-2183 (Simon et al. 1994) and SPat (Timmermans et al. 2010). Amplification was made in a 25µl reaction using MyTaq Mix (Bioline). Amplification products were sequenced in both directions, using Big Dye Terminator technology and cleaning with an ethanol precipitation method. This template was sent to the Biomolecular Resource Facility at the John Curtin School of Medical Research of the Australian National University for sequencing. Sequences were edited with Sequencher 4.8 (Gene Codes, Ann Arbor, MI).

Results

A total of 314 beetles were collected at 32 localities during the two weeks at the Pungalina Seven Emu Wildlife Sanctuary. Of these 287 were weevils, collected from 14 species of Fabaceae (Table 1, starting page 39). These weevils represent three families (Attelabidae, Brentidae and Curculionidae) and 11 genera, and 169 (58%) belong to the genus *Melanterius*, the target of our study. All host associations of the weevils collected in this study were recorded (Appendix, starting page 43).

DNA has been extracted from 27 specimens and the mitochondrial *cox1* gene has been amplified from all of these. The species will be identified in the course of the delimitation analysis including all *Melanterius* specimens collected in all Australian states on all possible *Acacia* species.

Discussion and Conclusions

Hitherto only two species of *Melanterius* are recorded in the literature to occur in the Northern Territory, *M. leptorrhynchus* Lea and *M. tropicus* Lea, from Port Darwin and Groote

Table 1. Plant species inspected for weevils (vouchers lodged in the Australian National Herbarium; CANB, CSIRO).

Taxon name	Field no.	Accession no.	Determined by	Locality	Latitude	Longitude
Fabaceae						
Sesbania cannabina (Retz.) Pers.	67	810198	Lally, T.R.	Pungalina property, near Karnes Creek	16° 47' 05" S	137° 27' 38" E
Acacia alleniana Maiden	73	810204	Cowley, K.J.	Pungalina property: Mystery Shovel	16° 39' 35" S	137° 24' 58" E
Acacia alleniana Maiden	98	810226	Cowley, K.J.	Seven Emu property: Site Stop	16° 30' 37" S	137° 31' 55" E
Acacia alleniana Maiden	103	810231	Cowley, K.J.	Seven Emu property	16° 29' 22" S	137° 33' 14" E
Acacia dimidiata Benth.	86	810214	Cowley, K.J.	Seven Emu property: Left turn 45 m. Near Cycad Creek Camp	16° 26' 59" S	137° 33' 42" E
Acacia difficilis Maiden	82	810210	Cowley, K.J.	Pungalina property: Safari Road	16° 43' 59" S	137° 25' 22" E
Acacia drepanocarpa F.Muell. subsp. *drepanocarpa*	69	810200	Cowley, K.J.	Pungalina property: Wattle Heaven	16° 43' 46" S	137° 31' 06" E
Acacia hammondii Maiden	76	810206	Cowley, K.J.	Pungalina property: ca 4 km SW of Calvert River crossing	16° 32' 39" S	137° 30' 39" E
Acacia hammondii Maiden	87	810215	Cowley, K.J.	Seven Emu property: AWC Camp near Cycad Creek	16° 27' 52" S	137° 33' 17" E
Acacia hammondii Maiden	92	810219	Cowley, K.J.	Seven Emu property: eastern border / Calvert River area	16° 26' 15" S	137° 36' 52" E
Acacia hammondii Maiden	95	810223	Cowley, K.J.	Seven Emu property: AWC Camp	16° 27' 52" S	137° 33' 17" E
Acacia holosericea A.Cunn. ex G.Don	70	810201	Cowley, K.J.	Pungalina property: Mystery Shovel	16° 34' 38" S	137° 29' 19" E
Acacia holosericea A.Cunn. ex G.Don	72	810203	Cowley, K.J.	Pungalina property: Mystery Shovel	16° 39' 35" S	137° 24' 58" E
Acacia holosericea A.Cunn. ex G.Don	102	810230	Cowley, K.J.	Seven Emu property	16° 29' 22" S	137° 33' 14" E
Acacia holosericea A.Cunn. ex G.Don	84	810212	Cowley, K.J.	Pungalina property: near Calvert River, Fig Tree	16° 41' 22" S	137° 24' 09" E
Acacia lamprocarpa O.Schwarz	94	810222	Cowley, K.J.	Seven Emu property: AWC Camp	16° 27' 52" S	137° 33' 17" E
Acacia leptocarpa A.Cunn. ex Benth.	97	810225	Pinzon-Navarro, S.	Seven Emu property: AWC Camp	16° 27' 52" S	137° 33' 17" E
Acacia leptocarpa A.Cunn. ex Benth.	74	810205	Cowley, K.J.	Seven Emu property: Cycad Creek	16° 27' 04" S	137° 33' 54" E
Acacia leptocarpa A.Cunn. ex Benth.	85	810213	Cowley, K.J.	Seven Emu property: c. 4 km SSW of Calvert River mouth. Near Fisherman's Camp	16° 17' 55" S	137° 43' 52" E
Acacia leptocarpa A.Cunn. ex Benth.	88	810216	Cowley, K.J.	Seven Emu property: AWC Camp near Cycad Creek	16° 27' 52" S	137° 33' 17" E
Acacia leptocarpa A.Cunn. ex Benth.	80	810208	Cowley, K.J.	Pungalina property: Lake Jabiru	16° 45' 26" S	137° 32' 24" E
Acacia leptocarpa A.Cunn. ex Benth.	92b	810220	Cowley, K.J.	Seven Emu property	16° 30' 00" S	137° 32' 44" E

Taxon name	Field no.	Accession no.	Determined by	Locality	Latitude	Longitude
Acacia nuperrima Baker f.	91	810218	Cowley, K.J.	Seven Emu property: eastern border / Calvert River area	16° 26' 15" S	137° 36' 52" E
Acacia nuperrima Baker f.	100	810228	Cowley, K.J.	Seven Emu property	16° 29' 22" S	137° 33' 14" E
Acacia nuperrima Baker f.	104	810232	Cowley, K.J.	Seven Emu property	16° 29' 22" S	137° 33' 14" E
Acacia platycarpa F.Muell.	101	810229	Cowley, K.J.	Seven Emu property	16° 29' 22" S	137° 33' 14" E
Acacia platycarpa F.Muell.	93	810221	Cowley, K.J.	Seven Emu property	16° 30' 00" S	137° 32' 44" E
Acacia plectocarpa A.Cunn. ex Benth. subsp. plectocarpa	68	810199	Cowley, K.J.	Pungalina property: Wattle Heaven	16° 43' 46" S	137° 31' 06" E
Acacia producta Tindale	77	810207	Cowley, K.J.	Pungalina property: ca 4 km SW of Calvert River crossing	16° 32' 39" S	137° 30' 39" E
Acacia producta Tindale	96	810224	Cowley, K.J.	Seven Emu property: AWC Camp	16° 27' 52" S	137° 33' 17" E
Acacia producta Tindale	99	810227	Cowley, K.J.	Pungalina property	16° 32' 04" S	137° 31' 41" E
Acacia torulosa Benth.	81	810209	Cowley, K.J.	Pungalina property: ca 28 km S of Calvert River crossing	16° 46' 16" S	137° 31' 51" E
Acacia torulosa Benth.	89	810217	Cowley, K.J.	Seven Emu property: road to Stinky Lagoon	16° 21' 44" S	137° 40' 29" E
Acacia torulosa Benth.	83	810211	Cowley, K.J.	Pungalina property: Wattle Patch	16° 40' 12" S	137° 25' 05" E
Myrtaceae						
Lophostemon grandiflorus subsp. *riparius* (Domin) Peter G.Wilson & J.T.Waterh.	71	810202	Craven, L.A.; Nightingale, M.E.	Pungalina property: Mystery Shovel	16° 34' 38" S	137° 29' 19" E

Eylandt, respectively. Study of the material of all described species of *Melanterius* available in the Australian National Insect Collection (ANIC) in Canberra, the Australian Museum in Sydney, the Museum Victoria in Melbourne, the South Australian Museum in Adelaide, the Western Australia Museum in Perth and the Queensland Museum in Brisbane did not reveal any other records of described species from the Northern Territory. In the ANIC there are, however, 25 specimens from the Northern Territory not identified to species level. Therefore the material we collected during this project represents a significant increase in the known fauna of this important genus in the Northern Territory. Subsequent study of this material revealed that it represents three new species of *Melanterius*, which are in the process of being described.

More than 135 species of *Acacia* are recorded from the Northern Territory, and 12 of these from the study area (Rigel Jensen, personal comm.) at the time of our sampling. We collected weevils from 13 *Acacia* species (Table 1, starting page 39), of which five species (*A. difficilis, A. drepanocarpa sub. drepanocarpa, A. holosericea, A. plectocarpa* and *A. producta*) were not previously known from the study site. Moreover, four of the species recorded from the area were not encountered (*A. galioides* Benth., *A. hyaloneura* Pedley*, A. latifolia* Benth. and *A. retivenea* F. Muell.). The reason for not encountering these is likely due to the fact that *Melanterius* weevils are generally encountered on flowering or fruiting trees and we therefore only targeted plants with flowers and fruits (Table 2, page 41).

Acknowledgements

We thank our colleagues Nicole Gunter, Tom Weir and Barry Richardson for their company and help in collecting specimens, Joe Miller for his support of the project, Maggie Nightingale for her hard work of entering the data of the plant vouchers and Kirsten Cowley for their identification, and the volunteers of the Royal Geographical Society of Queensland and Australian Wildlife Conservancy for facilitating the expedition and assisting in our research.

Table 2. Seed-feeding *Melanterius* specimens used for DNA extraction, including host plant parts collected and flowering seasons.

Host Plant	Section	Extracted Melanterius (Specimen No.)	Flower	Fruits	Leaves	Flowering times
Acacia dimidiata Specimen 1	Juliflorae	3 (2623-2625)			Y	July - October
Acacia dimidiata Specimen 2	Juliflorae	3 (2626-2628)			Y	July - October
Acacia holosericea Specimen 1	Juliflorae	2 (2605-2606)	Y	Y	Y	June - August or April-October
Acacia holosericea Specimen 2	Juliflorae	4 (2613-2616)			Y	June - August or April-October
Acacia holosericea Specimen 3	Juliflorae	2 (2602-2603)	Y		Y	June - August or April-October
Acacia leptocarpa Specimen 1	Juliflorae	2 (2608-2609)	Y		Y	May - December
Acacia leptocarpa Specimen 2	Juliflorae	3 (2617-2619)	Y		Y	May - December
Acacia plectocarpa subsp. *plectocarpa* Specimen 1	Juliflorae	1 (2604)	Y		Y	March - July
Acacia producta Specimen 1	Plurinerves	1 (2607)	Y	Y	Y	all months
Acacia torulosa Specimen 1	Juliflorae	2 (2610-2611)	Y		Y	March - July
Acacia torulosa Specimen 2	Juliflorae	1 (2612)			Y	March - July
Acacia torulosa Specimen 3	Juliflorae	3 (2620-2622)	Y		Y	March - July

References

Auld, T. D. 1983. Seed predation in native legumes of south-eastern Australia. *Australian Journal of Ecology* 8: 367–376.

Clarke, G. M. 2002. Molecular phylogenetics and host ranges of the *Melanterius* weevils used as biocontrol agents of invasive Australian acacias in South Africa. A report prepared for ARC – Plant Protection Research Institute South Africa. CSIRO, 19 pp.

Dennill, G. B., Donnelly, D., Stewart, K. & Impson, F. A. C. 1999. Insect agents used for the biological control of Australian *Acacia* species and *Paraserianthes lophanta* (Willd). Nielsen (Fabaceae) in South Africa. *African Entomology Memoir* 1: 45–54.

Donnelly, D. 1992. The potential host range of three seed-feeding *Melanterius* spp. (Curculionidae), candidates for the biological control of Australian *Acacia* spp. and *Paraserianthes* (*Albizia*) *lophanta* in South Africa. *Phytophylactica* 24: 163–167.

Maslin, B. R. 2001. Introduction to Acacia. Pp. 3–13 in: Orchard, A. E. & Wilson, A. J. G. (eds.), *Flora of Australia*, *Vol. 11A, Mimosaceae, Acacia, part 1*. Melbourne: ABRS/CSIRO.

Murphy, D. J, Brown, G. K., Miller, J. T. & Ladiges, P. Y. 2010. Molecular phylogeny of *Acacia* Mill. (Mimosoideae: Leguminosae): Evidence for major clades and informal classification. *Taxon* 59 (1) 7–19.

New, T. R. 1983. Seed predation of some Australian acacias by weevils (Coleoptera: Curculionidae). *Australian Journal of Zoology* 31: 345–352.

Novotny, V, Miller, S., Baje, L., Balagawi, S., Basset, Y., Cizek, L., Craft, K., Dem, F., Drew, R., Hulcr, J., Leps, J., Lewis, O. T., Pokon, R., Stewart, A., Samuelson, G. and Weiblen, G. 2010. Guild-specific patterns of species richness and host specialization in plant–herbivore food webs from a tropical forest. *Journal of Animal Ecology* 79: 1193–1203.

Oberprieler, R. G., Marvaldi, A. E. & Anderson, R. S., 2007. Weevils, weevils, weevils everywhere. *Zootaxa* 491-520.

Oberprieler, R. G. & Zimmerman, E. C. 2001. Identification and host ranges of the Melanterius weevils used as biocontrol agents of invasive Australian acacias in South Africa. A study and report for ARC - Plant Protection Research Institute, South Africa. CSIRO, 25 pp.

Pinzón-Navarro, S., Barrios, H., Múrria, C., Lyal, C. H. C & Vogler, A. P. 2010. DNA-based taxonomy of larval stages reveals huge unknown species diversity in neotropical seed weevils (genus *Conotrachelus*): relevance to evolutionary ecology. *Molecular Phylogenetics and Evolution* 56: 281–293.

Simon, C., Frati, F., Beckenbach, A., Crespi, B., Liu, H. & Flook, P. 1994. Evolution, weighting, and phylogenetic utility of mitochondrial gene sequences and a compilation of conserved polymerase chain reaction primers. *Annals of the Entomological Society of America* 87: 651–701.

Timmermans, M. J. T. N., Dodsworth, S., Culverwell, C. L., Bocak, L., Ahrens, D., Pons, J. & Vogler, A. P. 2010. Why barcode? High-throughput multiplex sequencing of 688 mitochondrial genomes for molecular systematics. *Nucleic Acids Research* 38: 1–14.

Van den Berg, M. A. 1980. Natural enemies of *Acacia cyclops* A. Gunn. ex G. Don. and *Acacia saligna* (Labill.). Endl. in Western Australia. II. Coleoptera. *Phytophylactica* 12: 169–171.

Van den Berg, M. A. 1982. Coleoptera attacking *Acacia dealbata* Link., *Acacia decurrens* Willd., *Acacia longifolia* (Andr.) Willd., *Acacia mearnsii* De Wild. and *Acacia melanoxylon* R. Br. in Australia. *Phytophylactica* 14: 51–55.

Appendix. Weevils collected at the study site in June-July 2012, including host plants and localities

Subfamily	Tribe	Genus	Individuals	Host Plant	Locality	Latitude	Longitude
ATTELABIDAE							
Rhynchitinae	Auletobiini	*Metopum*	1	N/A	Pungalina Station, Safari Camp	16° 43' 59" S	137° 26' 12" E
Rhynchitinae	Auletobiini	*Metopum*	1	*Acacia drepanocarpa* subsp. *drepanocarpa*	Wattle heaven	16° 43' 45" S	137° 31' 06" E
Attelabinae	Euopini	*Euops*	2	beating	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Attelabinae	Euopini	*Euops*	1	*Acacia torulosa*	Wattle Patch	16° 40' 12" S	137° 25' 06" E
BRENTIDAE							
Apioninae	Apionini	*Apion*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Apioninae	Apionini	*Apion*	3	*Acacia nuperrima*	Pungalina Station, Road to big Stinky Lagoon	16° 26' 15" S	137° 36' 52" E
Apioninae	Apionini	*Apion*	1	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Apioninae	Apionini	*Apion*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Apioninae	Apionini	*Apion*	1	*Acacia hammondii*	Seven Emu Station, Road to big Stinky Lagoon	16° 26' 15" S	137° 36' 52" E
Apioninae	Apionini	*Apion*	2	sweeping	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Apioninae	Apionini	*Apion*	1	*Acacia hammondii*	Seven Emu Station, Road to big Stinky Lagoon	16° 26' 15" S	137° 36' 52" E
Apioninae	Apionini	*Apion*	1	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Apioninae	Apionini	*Apion*	1	*Acacia nuperrima*	Seven Emu Station, Road to big Stinky Lagoon	16° 26' 15" S	137° 36' 52" E
Apioninae	Apionini	*Apion*	2	*Acacia dimidiata*	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Apioninae	Apionini	*Apion sp.1*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Apioninae	Apionini	*Apion sp.2*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Apioninae	Apionini	*Apion*	4	*Acacia dimidiata*	Pungalina Station, nr Karnes Creek Camp	16° 47 30" S	137° 27' 27" E
Apioninae	Apionini	*Apion*	1	*Acacia torulosa*	Road to Fishermans Camp	16° 21' 44" S	137° 40' 29" E

Subfamily	Tribe	Genus	Individuals	Host Plant	Locality	Latitude	Longitude
Apioninae	Apionini	*Apion*	1	*Lophostemon grandiflorus* subsp. *riparius*	Mystery Shovel	16° 34' 38" S	137° 29' 19" E
Apioninae	Apionini	*Apion*	1	beating	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Apioninae	Apionini	*Pseudopiezotrachelus*	1	*Acacia holosericea*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Apioninae	Apionini	*Pseudopiezotrachelus*	7	*Acacia dimidiata*	Pungalina Station, nr Karnes Creek Camp	16° 47 30" S	137° 27' 27" E
Apioninae	Apionini	*Pseudopiezotrachelus*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Apioninae	Apionini	*Pseudopiezotrachelus*	4	beating	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Apioninae	Myrmacicelini	*Rhynolaccus*	1	*Acacia torulosa*	Wattle Patch	16° 40' 12" S	137° 25' 06" E
CURCULIONIDAE							
Entiminae	Cyphicerini	*Myllocerus*	1	*Acacia alleniana*	Mystery Shovel 7km	16° 39' 35" S	137° 24' 52" E
Entiminae	Cyphicerini	*Myllocerus*	1	*Acacia drepanocarpa* subsp. *drepanocarpa*	Open Space	16° 43' 45" S	137° 30' 02" E
Entiminae	Cyphicerini	*Myllocerus*	1	*Acacia plectocarpa* subsp. *plectocarpa*	Wattle heaven	16° 43' 45" S	137° 31' 06" E
Entiminae	Cyphicerini	*Myllocerus*	1	*Acacia holosericea*	Pungalina Station, Karnes Creek	16° 43' 45" S	137° 31' 06" E
Entiminae	Leptopiini	*Polyphrades*	5	Sweeping	Seven Emu Station, Rd to big Stinky Lagoon	16° 26' 15" S	137° 36' 52" E
Entiminae	Leptopiini	*Polyphrades*	1	*Acacia alleniana*	Mystery Shovel 7km	16° 39' 35" S	137° 24' 52" E
Curculioninae	Storeini	*Epamoebus*	1	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Curculioninae	Storeini	*Epamoebus*	1	*Acacia plectocarpa* subsp. *plectocarpa*	Pungalina Station, Lake Crocodylus	16° 43' 54" S	137° 30' 02" E
Curculioninae	Storeini	*Epamoebus*	2	*Acacia plectocarpa* subsp. *plectocarpa*	Pungalina Station, Open space	16° 43' 54" S	137° 30' 02" E
Curculioninae	Storeini	*Epamoebus*	1	*Acacia torulosa*	Pungalina Station, Wattle patch	16° 40' 12" S	137° 25' 06" E
Curculioninae		*Eristinus*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Curculioninae		*Eristinus*	1	*Lophostemon grandiflorus* subsp. *riparius*	Mystery Shovel	16° 34' 38" S	137° 29' 19" E
Molytinae	Cryptorhynchini	*Tentegia*	1	N/A	Pungalina Station, Cave Entrance	16° 46' 39.4" S	137° 28' 14.2" E

Subfamily	Tribe	Genus	Individuals	Host Plant	Locality	Latitude	Longitude
Scolytinae			2	*Ficus sp.*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 27" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia torulosa*	Wattle Patch	16° 40' 12" S	137° 25' 06" E
Molytinae	Cleogonini	*Melanterius*	2	*Acacia holosericea*	Gully	16° 29' 22" S	137° 33' 14" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Molytinae	Cleogonini	*Melanterius*	17	*Acacia leptocarpa*	Cycad Creek AWC Camp	16° 27' 53" S	137° 33' 17" E
Molytinae	Cleogonini	*Melanterius*	2	*Acacia dimidiata*	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Molytinae	Cleogonini	*Melanterius*	8	*Acacia dimidiata*	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Molytinae	Cleogonini	*Melanterius*	11	*Acacia holosericea*	Pungalina Station, Mystery Shovel	16° 34' 38" S	137° 29' 19" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Molytinae	Cleogonini	*Melanterius*	11	*Acacia leptocarpa*	Pungalina Station, Road to Jaribu	16° 45' 26" S	137° 32' 24" E
Molytinae	Cleogonini	*Melanterius*	6	*Acacia holosericea*	Pungalina Station, Mystery Shovel	16° 34' 38" S	137° 29' 19" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia holosericea*	Pungalina Station, Karnes Creek Campsite	16° 44' 05" S	137° 29' 23" E
Molytinae	Cleogonini	*Melanterius*	2	*Acacia holosericea*	Pungalina Station, Karnes Creek entrance	16° 47' 30" S	137° 27' 37.1" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia holosericea*	Pungalina Station, Karnes Creek entrance	16° 47' 30" S	137° 27' 37.1" E
Molytinae	Cleogonini	*Melanterius*	8	*Acacia leptocarpa*	Pungalina Station, Road to Jaribu	16° 45' 26" S	137° 32' 24" E
Molytinae	Cleogonini	*Melanterius*	13	*Acacia leptocarpa*	AWC Camp	16° 27' 53" S	137° 33' 17" E
Molytinae	Cleogonini	*Melanterius*	2	*Acacia holosericea*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Molytinae	Cleogonini	*Melanterius*	4	*Acacia dimidiata*	Seven Emu Station, Calvert River	16° 30' 50" S	137° 32' 09" E
Molytinae	Cleogonini	*Melanterius*	11	*Acacia holosericea*	Pungalina Station, Mystery Shovel	16° 34' 38" S	137° 29' 19" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia holosericea*	Pungalina Station, Karnes Creek	16° 30' 50" S	137° 32' 09" E
Molytinae	Cleogonini	*Melanterius*	5	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
Molytinae	Cleogonini	*Melanterius*	5	*Acacia leptocarpa*	AWC Camp	16° 27' 53" S	137° 33' 17" E
Molytinae	Cleogonini	*Melanterius*	19	*Acacia holosericea*	Mystery Shovel 7km	16° 39' 35" S	137° 24' 52" E

Subfamily	Tribe	Genus	Individuals	Host Plant	Locality	Latitude	Longitude
Molytinae	Cleogonini	*Melanterius*	1	*Acacia holosericea*	Pungalina Station, Karnes Creek	16° 30' 50" S	137° 32' 09" E
Molytinae	Cleogonini	*Melanterius*	7	*Acacia leptocarpa*	AWC Camp	16° 27' 53" S	137° 33' 17" E
Molytinae	Cleogonini	*Melanterius*	1	*Acacia dimidiata*	Pungalina Station, Karnes Creek	16° 30' 50" S	137° 32' 09" E
Conoderinae	Baridini	*Baris*	1	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Conoderinae	Baridini	*Baris*	7	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Conoderinae	Baridini	*Baris*	1	*Acacia drepanocarpa* subsp. *drepanocarpa*		16° 43' 45" S	137° 31' 06" E
Conoderinae	Baridini	*Baris*	8	*Acacia drepanocarpa* subsp. *drepanocarpa*		16° 43' 45" S	137° 30' 02" E
Conoderinae	Baridini	*Baris*	1	*Acacia plectocarpa* subsp. *plectocarpa*	Wattle heaven	16° 43' 45" S	137° 31' 06" E
Conoderinae	Baridini	*Baris*	4	*Acacia alleniana*	Mystery Shovel 7km	16° 39' 35" S	137° 24' 52" E
Conoderinae	Baridini	*Baris*	5	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Conoderinae	Baridini	*Baris*	3	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Conoderinae	Baridini	*Baris*	22	*Acacia torulosa*	Seven Emu Station, Nr Big Stinking lagoon	16° 22' 04" S	137° 40' 18" E
Conoderinae	Baridini	*Baris*	1	*Acacia plectocarpa* subsp. *plectocarpa*	Pungalina Station, Lake Crocodylus	16° 43' 54" S	137° 30' 02" E
Conoderinae	Baridini	*Baris*	4	*Acacia torulosa*	Pungalina Station, Road to Jaribu	16° 46' 16" S	137° 31' 51" E
Conoderinae	Baridini	*Baris*	5	*Acacia plectocarpa* subsp. *plectocarpa*	Wattle heaven	16° 43' 45" S	137° 31' 06" E
Conoderinae	Baridini	*Baris*	1	*Acacia drepanocarpa* subsp. *drepanocarpa*	Wattle heaven	16° 43' 45" S	137° 31' 06" E
Conoderinae	Baridini	*Baris*	8	*Acacia plectocarpa* subsp. *plectocarpa*	Pungalina Station, Lake Crocodylus	16° 43' 54" S	137° 30' 02" E
BUPRESTIDAE							
		Trachys	6	*Acacia dimidiata*	Pungalina Station, Karnes Creek Campsite	16° 47' 30" S	137° 27' 37" E
		Trachys	6	*Lophostemon grandiflorus* subsp. *riparius*	Mystery Shovel	16° 34' 38" S	137° 29' 19" E

The nature and distribution of jumping spider (Araneae: Salticidae) diversity on Pungalina and Seven Emu Stations

Barry J. Richardson

Australian National Insect Collection, National Research Collections, Australia CSIRO, Canberra, ACT

Abstract Totals of 73 lots, 22 genera, 28 species and 132 specimens were collected. Twenty-two genera were predicted to be present using BIOCLIM and 20 of these were collected. Two genera that were not predicted were also found. As well, specimens of two new genera were collected. One of these has now been described as *Pungalina weiri* Richardson 2013. Biogeographically, the fauna has closer links to the tropical, Torresian, fauna than to the inland, Eremaean, fauna. The area maintains the highest predicted diversity of any area around the coast of the Gulf of Carpentaria. In the study area, the highest diversity is predicted to be present on the northern faces of the scarps. This may be related to the direction from which the wind and rain come, especially during the drier times when what little moisture is present will be driven upslope by the prevailing wind to fall as rain in the cooler conditions.

Introduction

Jumping spiders, or salticids, of the spider family Salticidae, are a diverse and common component of the Australian fauna, with over 350 species described and possibly a further 1,000 species present (Richardson and Zabka, 2015). The fauna is highly endemic, especially in central and western parts of the continent. The salticid faunas of the tropical and coastal habitats of eastern and northern Australia show a strong New Guinean and Oriental influence (e.g. *Cosmophasis*). Some species are cosmotropical in distribution (e.g. *Plexippus*) and ranges of a few extend to New Caledonia and New Zealand (Zabka 1990, 2002). Salticids are skillful jumpers that use their excellent vision to hunt in daylight. Some Australian salticid genera (e.g. *Myrmarachne, Damoetas, Rhombonotus*) mimic ants. Others are beetle or fly mimics. Some species supplement their diet with nectar (Jackson *et al*. 2001). The behaviour of some Australian species has been studied extensively by Jackson and his co-workers. A multigene, molecular-based phylogeny of the family is being developed, particularly by Dr W. Maddison and his co-workers. This shows several distinctive Australian-based radiations at the subfamilial level (Maddison et al. 2008). A good summary of the general ecology and behavior of jumping spiders can be found in Forster and Forster (1999). Photographs and drawings of many Australian species can be found in Proszynski (2011).

The salticid fauna of the Gulf country is poorly known, with the nearest records prior to the present study represented by six specimens collected 400 km further south and inland at Musselbrook Camp on a previous RGSQ expedition (Figure 1, page 48). Nearer the coast only a single specimen from Normanton and eight from Nhulunbuy are present in the collections studied. The first aim of the present work was to survey the area to obtain preliminary estimates of the composition and nature of the fauna in the region. Of interest are the biogeographical links (Bridgewater, 1987) of the fauna: are they to the tropical faunas of Cape York or Arnhem Land (i.e Torresian) or to the dry land (i.e. Eremaean) faunas further south?

Of further interest is the distribution of diversity at Pungalina and Seven Emu Stations, given the high scarps and plains, distance from the coast and distinct riverine and savannah woodland habitats.

A further matter that is of interest is the developing capacity to use modelling to estimate the faunas of areas that have not been the subject of any survey work. In this case, the program BIOCLIM (Shattuck & Fitzsimmons 2002) has been used to predict the suite of genera likely to be found at Pungalina and to compare this with actual suite of genera found. Further, the predicted distribution of each genus (made

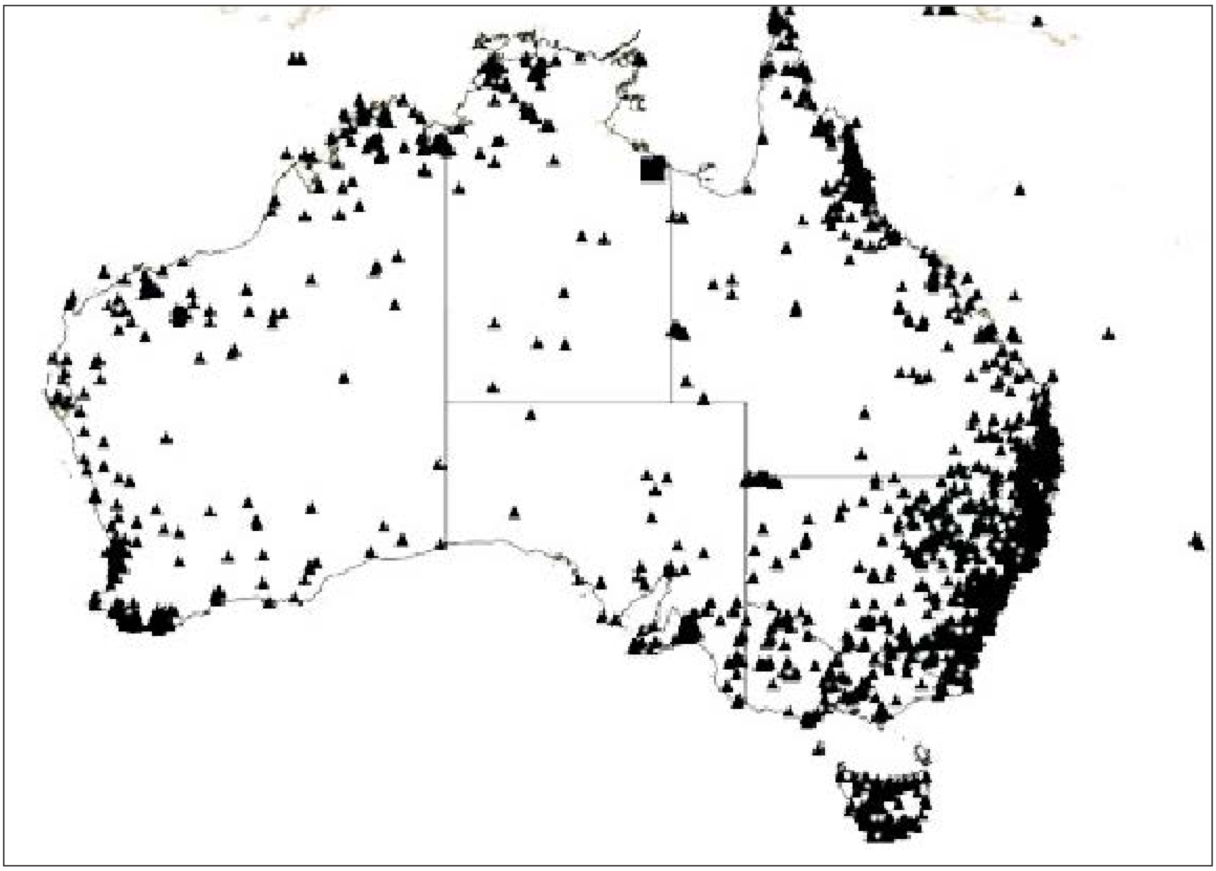


Figure 1. The distribution of salticid specimens (▲) held by the ANIC, AM, QM, NTM and in published records. The location of Pungalina Station homestead is shown (■).

including the new Pungalina data) allows the likely geographical distribution of diversity in the study area to be examined. Genera (given that a genus, in this context, often reflects a way of living that is common to all included species (Wood & Collard, 1999)) rather than species were used in this analysis as the amount of available data is restricted because only a third of species have so far been described and many specimens are either unplaced or misidentified. The distributions predicted from such larger sets of records are likely to give a better insight into the probable distribution of each genus (including both known and unknown species), than the sum of the distributions of the few species with extensive locality data and accurate identifications. Such an approach allows specimen records identified only to genus, or from undescribed species within the genus to be also used.

Methods

Field Collecting

Collections were made between 26 June and 8 July 2012 at 19 locations on Pungalina Station (16° 43'S, 137° 25'E) and Seven Emu Station (16° 27'S, 137° 34'E), both properties owned by the Australian Wildlife Conservancy. The collecting methods used were beating trees and shrubs, sweeping ground cover, searching through litter, malaise traps, pitfall traps and extracting specimens from litter using Berlese funnels. The specimens collected were returned to the Australian National Insect Collection where they were identified to at least genus and added to the collection. In several cases specimens were too immature to allow identification even to this level.

Predicting the distribution of each genus

A set of 6,206 locality records for specimens of salticid species from the Australian Museum, the Queensland Museum, the Northern Territory Museum and Art Gallery and the Australian National Insect Collection and published records (Figure 1, page 48) was used to predict the distributions of genera predicted to be found in the general area where locality records were well distributed and for which at least six well distributed collecting localities were available.

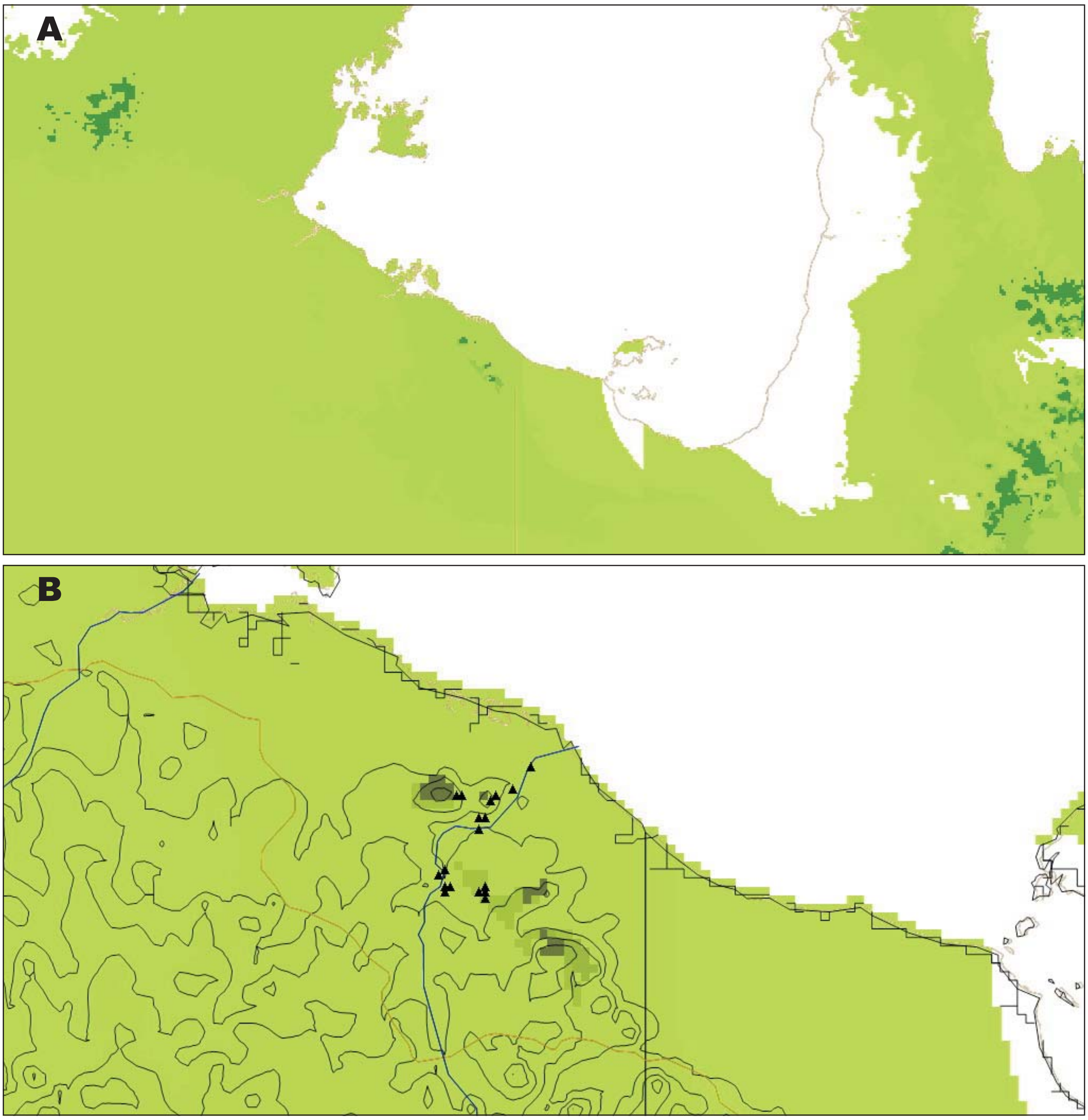


Figure 2. A. The distribution of predicted generic diversity around the Gulf of Carpentaria. The shading shows the predicted distribution of diversity with the darker the colour the higher the diversity (darkest 75% of genera predicted to be present; lightest 25% of genera predicted). B. The detailed distribution of predicted generic diversity on Pungalina and Seven Emu Stations. Also shown are the locations of collecting sites (▲), altitude contours, the position of the Calvert River and the State border.

The data from Pungalina and Seven Emu Stations were not used in making these predictions.

The locality records were stored in BioLink (version 3.0; Shattuck & Fitzsimmon, 2002). The predicted distribution map for each genus was generated on the basis of its bioclimatic envelope, using the boxcar version of BIOCLIM available in BioLink. The logic of using BIOCLIM to examine the distribution of continental faunas can be found in Nix (1986), Lindenmayer *et al*. (1991), Richardson *et al* (2006) and Richardson (2009).

As used here, BIOCLIM estimates ten bioclimatic indices for the location of each specimen and thence the range found for each variable for the taxon.

The indices estimated are:

1. Annual Mean Temperature (°C)

Table 1. Summary of the material collected during the Pungalina Scientific Study.

Genus	No. samples	No. species	Predicted	Observed	Biogeographical Range			Mussel-brook	Cravens Peak
					Torresian	Eremaean	Bassian		
Afraflacilla	0		Yes	No	+	+	+		
Bavia	0		Yes	No	+	+	+	+	
Bianor	1	1 species	Yes	Yes	+	+	+		+
Clynotus	2	1 species	Yes	Yes	+	+	+		
Cosmophasis	4	2 species	Yes	Yes	+	-–	+		
Cytaea	10	2 species	Yes	Yes	+	+	+	+	+
Damoetus	1	1 species	Yes	Yes	+	+	+	+	+
Evarcha	0		Yes	No	+	-–	-–		
Holoplatys	1	1 species	Yes	Yes	+	+	+		+
Lycidas	9	2 species	Yes	Yes	+	+	+	+	+
Margaromma	1	1 species	No	Yes	+	+	+		
Mopsolodes	1	1 species	Yes	Yes	-–	+	+		
Mopsus	0		Yes	No	+	-–	+		
Myrmarachne	3	3 species	Yes	Yes	+	+	+		
‘Neon’	2	2 species	Yes	Yes	+	+	+		
Opisthoncus	3	3 species	Yes	Yes	+	+	+		
Pellenes	1	1 species	Yes	Yes	+	+	-–		
Plexipus	1	1 species	Yes	Yes	+	-–	+		
Rhombonotus	1	1 species	No	Yes	-–	-–	+		
Simaetha	12	1 species	Yes	Yes	+	+	+		+
Tara	1	1 species	Yes	Yes	+	-–	+	+	
Thyene	4	1 species	Yes	Yes	+	-–	+	+	
Trite	5	1 species	Yes	Yes	+	-–	-–		
Zenodorus	3	1 species	Yes	Yes	+	+	+		
Unknown 1 (Pungalina)	3	1 species							
Unknown 2	1	1 species							

2. Annual Rainfall (mm)
3. Maximum temperature in the warmest period (°C)
4. Mean Rainfall in the driest quarter (mm)
5. Mean Rainfall in the wettest quarter (mm)
6. Mean temperature in the coldest quarter (°C)
7. Mean temperature in the warmest quarter (°C)
8. Minimum temperature in the coolest period (°C)
9. Rain seasonality (mm)
10. Temperature seasonality (°C)

These variables provide estimates of total energy and water inputs, seasonal extremes and a measure of conditions prevailing during potential active and dormant seasons. The range of values obtained for the taxon is then compared with the values for each point on a 20 second grid covering the continent. The points meeting the criteria for the taxon are identified and mapped. The darker the colour used for each point in the final map, the more likely the taxon is to be present (cut-offs are 25 and 75 percentiles, 10 and 90 percentiles, 5 and 95 percentile, 0 and 100 percentiles for all variables). The final maps were examined to see if the genera were likely to be present on Pungalina or Seven Emu Stations.

Predicted distribution of generic diversity

The generic diversity map was calculated using BIOCLIM by summing the number of genera predicted at each point on the continental grid, ie a diversity measure for each locality with the colour cut-off levels being 75%, 50%, 25% and 0% of the difference between the highest and lowest levels of diversity. The total set, including the data for Pungalina Station and Seven Emu Station was used in the analysis.

Figure 3. A new species and genus of jumping spider found at Pungalina Station and described as *Pungalina weiri* Richardson 2013.

Results

The distribution of collecting sites on Pungalina and Seven Emu Stations is shown in Figure 2, page 49. Totals of 73 lots, 22 genera, 28 species and 132 specimens were collected. A further six lots, consisting of unidentifiable juveniles were also collected. The genera and other information collected are summarised in Table 1 (page 50) and a detailed inventory of the genera collected in Appendix 1 (starting page 54). One of the two undescribed genera has now been described elsewhere (Richardson, 2013) and given the name *Pungalina weiri* Richardson 2013 (Figure 3, page 51).

The genera likely to be present were predicted in advance using BIOCLIM. Four typical patterns of the predicted distributions of genera, subsequently found on the study area, are shown in Figure 4, page 52. Of interest is the extension of the predicted distributions of suitable habitat to the study area in each case, unlike the areas to the east and west of Pungalina. Twenty-two genera were predicted to be present in the study area of which 20 were collected. However two genera that were not predicted were found. As well, specimens of two new, undescribed, genera were collected.

In comparing the biogeographical relationships of the genera found in the study area (Table 1, page 50), 13 of the collected genera are found in both the Torresian (tropical) and Eremaean (inland) faunas; five are Torresian but not Eremaean while none are Eremaean but not Torresian. The fauna is clearly part of the Torresian biogeographical zone.

Examination of Figure 2A, page 49, shows that the generic diversity is higher in the western gulf than in the eastern Gulf while parts of Pungalina and Seven Emu Stations are predicted to support the highest category of diversity anywhere around the Gulf. Further, more detailed examination of the distribution of this diversity across Pungalina and Seven Emu Stations (Figure 2B, page 49) shows that the highest diversity is predicted to be present on the northern and north-western faces of the higher areas of the scarps. This is also the usual direction of the wind (55% of days; Bureau of Meteorology, 2012, Central Island) and, presumably, rain. Figure 2A, page 49, also shows that diversity is higher on the north-western side of Wellesley Island.

The genera found on two previous trips organised by the RGSQ are also shown in Table 1 (page 50). Five of the genera collected at Musselbrook were also found at Pungalina,

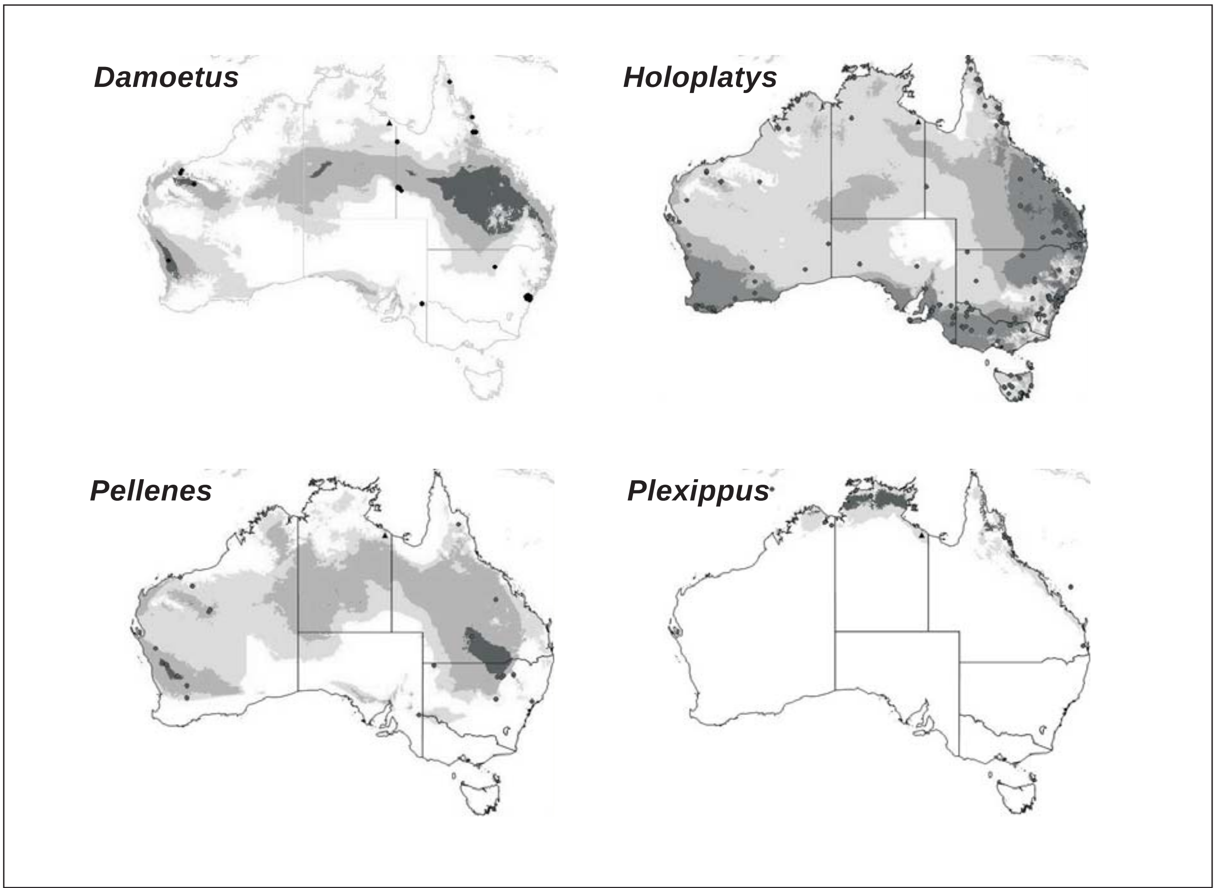


Figure 4. The predicted distribution of each of four genera. The darker the colour the more likely the genus is to occur. The specimen data sets used to make the prediction (●) and the location of Pungalina Station (▲) are also shown. The Pungalina data were not used in making the predictions.

while one was not. Six of the genera collected at Cravens Peak were also collected at Pungalina while one was not. The shared genera are all widely distributed across Australia.

Discussion

The addition of material from Pungalina and Seven Emu Stations to the national collection has significantly improved the quality of the collections as no material from this biogeographically distinctive area has been databased in Australian museum collections (Figure 1, page 48). Nevertheless, modelling using BIOCLIM and the data from present collections to predict the genera likely to be present shows the value of the technique in supporting conservation and management decisions as all but two of the predicted genera were collected. These genera will probably be found eventually as their absence from the field collection can be explained on the basis of the limited collecting time and localities, and likely seasonal changes in the adult fauna. Only two unpredicted genera were collected, and these had not been included in the original analysis due to lack of specimens in museum collections.

Richardson *et al* (2006) suggest that, in jumping spiders, predicting the distribution of genera, rather than known species is the best approach in poorly known groups. This is supported by the present study which shows that many of the species found are undescribed and so their presence would not be predicted using species level analyses. As members of known genera, however they were predicted to be present in the study area.

Examination of the pattern of predicted generic diversity (Figure 2A, page 49) shows that the area is likely to be the most diverse of any area along the Gulf of Carpentaria coast and therefore an excellent choice for conservation management. Within the area (Figure 2B, page 49) the modelling showed that the north and north-western faces of the scarps are likely to maintain the highest diversity. These areas were not sampled during the present study, highlighting the value of carrying out such analyses before deciding on the locations of collecting effort. Why these areas were preferred is unknown. It might be surmised that this is the direction from which wind and rain come and that the rainfall is higher especially perhaps at drier times of the year as moisture is driven upwards to higher altitudes. The lack of high diversity on the southern and eastern sides of the scarps, which would be in a rain shadow, would support such a view.

Acknowledgements

I would like to especially thank my colleagues Nicole Gunter, Sara Pinzón-Navarro and Tom Weir for their company and the hard work they put in helping collect specimens and the Australian Wildlife Conservancy for allowing us to work on their properties. To the volunteers and the Royal Geographical Society of Queensland who made the trip not only possible but enjoyable, my grateful thanks.

References

Bureau of Meteorology (2012) Wind speed and direction rose, Centre Island http://www.bom.gov.au/cgi-bin/climate/cgi_bin_scripts/windrose_selector.cgi

Bridgewater, P.B. (1987) The present Australian environment – Terrestrial and freshwater. *Fauna of Australia*, vol 1A. General Articles (eds G.R. Dyne and D.W. Walton), pp. 69-100. AGSP, Canberra.

Forster, R. & Forster, L. 1999. *Spiders of New Zealand and their Worldwide Kin*. Otago: University of Otago Press

Jackson, R.R., Pollard, S.D., Nelson, X.J., Edwards, G.B. & Barrion, A.T. 2001. Jumping spiders (Araneae : Salticidae) that feed on nectar. *Journal of Zoology*, London 255, 25-29

Lindenmayer, D.B., Nix, H.A., McMahon, J.P., Hutchinson, M.F & Tanton, M.T. (1991) The conservation of Leadbeater's possum, *Gymnobelideus leadbeateri*: a case study of the use of bioclimatic modelling. *Journal of Biogeography*, 18, 371-383.

Maddison, W. P., Bodner, M.R. & Needham, K.M. 2008. Salticid spider phylogeny revisited, with the discovery of a large Australian clade (Araneae: Salticidae). *Zootaxa* 1893, 49-64

Nix, H. (1986) A biogeographical analysis of Australian elapid snakes. *Atlas of elapid snakes of Australia* (ed. by R. Longmore), pp. 4-15. AGPS, Canberra.

Proszynski, J. 2011. *Monograph of Salticidae (Araneae) of the World*: 1995-2011. http://www.miiz.waw.pl/salticid/main.htm [Revised version April 27th, 2011]

Richardson, B.J. (2009) The jumping spiders (Salticidae: Araneae) found or predicted to be found on Cravens Peak Station. *Cravens Peak Scientific Study Report*. (H Freeman ed.), The Royal Geographical Society of Queensland. pp. 295-299.

Richardson, B.J. (2013) New unidentate jumping spider genera (Araneae: Salticidae) from Australia. Zootaxa 3716, 460-474.

Richardson, B.J., Zabka, M., Gray, M.R. and Milledge, G. (2006) *The distributional patterns of jumping spiders (Araneae: Salticidae) in Australia*. J. Biogeogr. 33, 701-719.

Richardson, B.J. & Zabka, M. (2015) *Salticidae*. *Australian Biological Resources Study*. Australian Faunal Directory home page: http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/home

Shattuck, S. & Fitzsimmons, N. (2002) *BioLink, The Biodiversity Information Management System (software and documentation)*. CSIRO Publishing, Collingwood, Australia.

Wood, B, & Collard, M. (1999) The human genus. *Science* 284, 65-71.

Zabka, M. 1990. Remarks on Salticidae (Araneae) of Australia. *Acta Zoologica Fennica* 190, 415-418

Zabka, M. 2002. Zoogeography of Salticidae (Arachnida : Araneae) of New Zealand. *Annales Zoologici, Warszawa* 52: 459-464.

Appendix 1. Detailed inventory of material collected

Genus	Number	Material	Location	Latitude	Longitude
Bianor	42 001637	1M	Pungalina Stn, Lake Crocodylus Rd	16° 44'S	137° 31'E
Clynotis	42 001559	1F	Pungalina Stn, 6.8km N on rd	16° 40'S	137° 25'E
Clynotis	42 001655	1F	Pungalina Stn, Karns Creek Camp Rd	16° 27'S	137° 27'E
Clynotis	42 001653	1M	Pungalina Stn, Karns Creek Camp, NT	16° 27'S	137° 27'E
Cosmophasis	42 001595	1F	Pungalina Stn, HS	16° 43'S	137° 25'E
Cosmophasis	42 001590	1M	Pungalina Stn, HS	16° 43'S	137° 25'E
Cosmophasis	42 001617	2 imm	Pungalina Stn, Safari Camp	16° 43'S	137° 26'E
Cosmophasis	42 001602	1F	Seven Emu Stn, Calvert R crossing	16° 31'S	137° 32'E
Cytaea	42 001614	2 imm	Pungalina Stn, Figtree Camp	16° 41'S	137° 24'E
Cytaea	42 001648	1 imm	Pungalina Stn, Karns Creek Camp	16° 27'S	137° 27'E
Cytaea	42 001629	2 imm	Pungalina Stn, Karns Creek Camp Rd	16° 27'S	137° 27'E
Cytaea	42 001642	3 imm	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Cytaea	42 001598	2 imm	Pungalina Stn, rd to Cycad Camp	16° 31'S	137° 32'E
Cytaea	42 001605	3M, 1 imm	Seven Emu Stn, Big Stinking Lagoon Rd	16° 26'S	137° 37'E
Cytaea	42 001601	1 imm	Seven Emu Stn, Calvert R crossing	16° 31'S	137° 32'E
Cytaea	42 001607	1M, 3 imm	Seven Emu Stn, Fishing Camp Rd	16° 22'S	137° 40'E
Cytaea	42 001651	1 imm	Seven Emu Stn, scarp near Cycad Camp	16° 27'S	137° 34'E
Damoetus	42 001634	1M	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Holoplatys	42 001616	3 imm	Pungalina Stn, Safari Camp	16° 43'S	137° 26'E
Lycidas	42 001631	1 imm	Pungalina Stn, 7 mile track	16° 43'S	137° 26'E
Lycidas	42 001649	2 imm	Pungalina Stn, Karne Creek Camp	16° 27'S	137° 27'E
Lycidas	42 001664	1 imm	Pungalina Stn, Karne Creek Rd	16° 27'S	137° 27'E
Lycidas	42 001643	5M 3F 1 imm	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Lycidas	42 001663	2 imm	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Lycidas	42 001638	1M, 2 imm	Pungalina Stn, Lake Crocodylus Rd	16° 44'S	137° 31'E
Lycidas	42 001626	2 imm	Pungalina Stn, Lake Jabiru	16° 45'S	137° 32'E
Lycidas	42 001611	1 imm	Pungalina Stn, Seven Emu Rd	16° 44'S	137° 25'E
Lycidas	42 001662	2 imm	Seven Emu Stn, Big Stinking Lagoon Rd	16° 26'S	137° 37'E
Margaromma	42 001657	1F	Pungalina Stn, rd to Cycad Camp	16° 27'S	137° 32'E
Myrmarachne	42 001661	1F	Pungalina Stn, 7 mile track	16° 43'S	137° 26'E
Myrmarachne	42 001633	1F	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Myrmarchne	42 001658	1F	Seven Emu Stn, AWC Camp	16° 28'S	137° 33'E
Neon	42 001592	1 F	Pungalina Stn, Figtree Camp	16° 41'S	137° 24'E
Neon	42 001604	1F	Seven Emu Stn, Calvert R crossing	16° 31'S	137° 32'E
Opisthoncus	42 001641	1M	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Opisthoncus	42 001608	2 imm	Seven Emu Stn, AWC Camp	16° 28'S	137° 33'E

Genus	Number	Material	Location	Latitude	Longitude
Opisthoncus	42 001596	1 imm	Seven Emu Stn, near Cycad Camp	16° 27'S	137° 34'E
Pellenes	42 001650	1 imm	Seven Emu Stn, scarp near Cycad Camp	16° 27'S	137° 34'E
Plexippus	42 001591	1F	Pungalina Stn, HS	16° 43'S	137° 25'E
Pungalina	42 001660	1M, 1F	Pungalina Stn, 6.8km N on rd	16° 40'S	137° 25'E
Pungalina	42 001666	1 imm	Pungalina Stn, Lake Jabiru	16° 45'S	137° 32'E
Pungalina	42 001656	1m, 1F	Pungalina Stn, Rd to Cycad Camp	16° 27'S	137° 32'E
Rhombonotus	42 001636	1M	Pungalina Stn, Lake Crocodylus Rd	16° 44'S	137° 31'E
Simaetha	42 001623	2 imm	Pungalina Stn, 7 mile track	16° 43'S	137° 26'E
Simaetha	42 001615	3 imm	Pungalina Stn, Figtree Camp	16° 41'S	137° 24'E
Simaetha	42 001647	1F 1 imm	Pungalina Stn, Karne Creek Camp	16° 27'S	137° 27'E
Simaetha	42 001645	1 imm	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Simaetha	42 001640	1F	Pungalina Stn, Lake Crocodylus Rd	16° 44'S	137° 31'E
Simaetha	42 001618	2 imm	Pungalina Stn, Safari Camp	16° 43'S	137° 26'E
Simaetha	42 001622	2 imm	Pungalina Stn, Safari Camp Rd	16° 44'S	137° 25'E
Simaetha	42 001630	2 imm	Pungalina Stn, Seven Emu Rd	16° 44'S	137° 25'E
Simaetha	42 001627	1M, 1F, 1 imm	Pungalina Stn, Karne Creek Camp Rd	16° 27'S	137° 27'E
Simaetha	42 001606	1M, 3 imm	Seven Emu Stn, Big Stinking Lagoon Rd	16° 26'S	137° 37'E
Simaetha	42 001603	1 imm	Seven Emu Stn, Calvert R crossing	16° 31'S	137° 32'E
Simaetha	42 001597	2 imm	Seven Emu Stn, rd to Cycad Camp	16° 31'S	137° 31'E
Tara	42 001599	2M, 2F	Seven Emu Stn, AWC Camp	16° 28'S	137° 33'E
Thyene	42 001632	3 imm	Pungalina Stn, 7 mile track	16° 43'S	137° 26'E
Thyene	42 001628	1 imm	Pungalina Stn, Karne Creek Camp Rd	16° 27'S	137° 27'E
Thyene	42 001625	1F	Pungalina Stn, Lake Jabiru	16° 45'S	137° 32'E
Thyene	42 001620	2 imm	Pungalina Stn, Safari Camp	16° 43'S	137° 26'E
Thyene	42 001621	1 imm	Pungalina Stn, Safari Camp Rd	16° 44'S	137° 25'E
Thyene	42 001612	3 imm	Pungalina Stn, Seven Emu Rd	16° 44'S	137° 25'E
Trite	42 001610	1 imm	Pungalina Stn, HS	16° 43'S	137° 25'E
Trite	42 001624	2 imm	Pungalina Stn, Lake Jabiru	16° 45'S	137° 32'E
Unknown	42 001609	1 imm	Pungalina Stn, Karne Creek Camp	16° 27'S	137° 27'E
Unknown	42 001644	1 imm	Pungalina Stn, Lake Crocodylus	16° 43'S	137° 32'E
Unknown	42 001619	1 imm	Pungalina Stn, Safari Camp	16° 43'S	137° 26'E
Unknown	42 001613	1 Imm	Pungalina Stn, Seven Emu Rd	16° 44'S	137° 25'E
Unknown	42 001600	9 imm	Seven Emu Stn, AWC Camp	16° 28'S	137° 33'E
Unknown 2	42 001593	1 M	Pungalina Stn, Karne Creek Camp	16° 27'S	137° 27'E
Zenodorus	42 001665	1mm	Seven Emu Stn, Cycad Camp	16° 27'S	137° 34'E
Zenodorus	42 001639	1F	Pungalina Stn, Lake Crocodylus Rd	16° 44'S	137° 31'E
Zenodorus	42 001646	1 imm	Pungalina Stn, Karne Creek Camp Rd	16° 27'S	137° 27'E

A survey of the tidal and non-tidal wetland plants of the Pungalina Seven Emu conservation area on the Calvert River, Northern Territory

Peter Saenger

School of Environment, Science and Engineering, Southern Cross University, Lismore, NSW 2480.

Abstract The Pungalina Seven Emu conservation area, managed since October 2008 by the Australian Wildlife Conservancy, contains a range of tidal and non-tidal wetlands, including mangroves, freshwater swamps and spring-fed creeks. Eleven sites were sampled for wetland plants during the 2012 dry season and a diversity of wetland plants was recorded. A full taxonomic listing is provided, together with relevant biogeographic observations. Threats to this wetland plant diversity are briefly discussed.

Introduction

The Pungalina Seven Emu conservation area, managed since October 2008 by the Australian Wildlife Conservancy, is largely contained within the approximately 8,255 km² (Bucher and Saenger, 1989) catchment area of the Calvert River. With a regional summer rainfall of around 800 mm and surface discharge of groundwater from the Barkly Tableland via springs, it is not surprising that an array of extensive wetlands, both tidal and non-tidal, can be found throughout the Calvert River catchment.

Using the classification of wetland types for the Northern Territory provided by Finlayson et al. (1988) and Lukacs and Finlayson (2010), the following wetland types were recognised: 1. Tidal wetlands – 1.1 mangroves, 1.2 saltmarsh and 1.3 saltflats; 2. Non-tidal wetlands – 2.1 swamps, 2.2 lagoons, 2.3 rivers and creeks, and 2.4 springs. Each of these types is briefly described below.

Wetlands of the Study Area

1.1 Mangroves: Approximately 1.1 km² of mangroves have been recorded from the estuarine reaches of the Calvert River and tributaries up to the upstream limit of mangroves (Bucher and Saenger, 1989). In line with other regions of the wet-dry tropics, with seasonal water deficits and high salinities, the local mangrove vegetation is not luxuriant, but rather depauperate, generally less than 4-6 m high, and relatively open (Figure 1, page 58). Saltmarsh, or saltflats devoid of vegetation is often observed on their landward margins (Fosberg, 1961; Saenger and Hopkins, 1975).

1.2 Saltmarsh: Extensive saltmarsh areas occur around the peripheries of the saltflats in the estuarine reaches of the Calvert River and tributaries (Figure 2, page 58). A combined total of 8.0 km² has been recorded (Bucher and Saenger, 1989), of which the largest proportion are saltflats. Saltmarshes in the wet-dry tropics contain fewer species compared to more temperate saltmarshes and are generally characterised by comparative low above-ground biomass compared to their more temperate counterparts.

1.3 Saltflats: As mentioned above, extensive saltflats occur on the landward margins of the mangroves of the estuarine reaches of the Calvert River and tributaries. Saltflats are common in areas where total annual rainfall is less than 1000 mm, and where rainfall is highly seasonal. Saltflats are unvegetated, as during the site visit, but may support algal mats during the wet season. Together with intertidal sandflats (2.4 km²) and estuarine openwater (6.7 km²), these areas form important habitat for waders and other shorebirds.

2.1 Swamps: These are vegetated wetlands without any free-water surface. Despite its name, Jabiru Lagoon (Figure 3, page 59) consisted of a uniform cover of *Eleocharis sanguinolenta*. In contrast, Green Swamp consisted of a shallow depression supporting dense stands of *Melaleuca nervosa* and *M. viridiflora,*

Figure 1: Mangroves, consisting predominantly of 3-6 m high *Rhizophora stylosa,* formed extensive stands around the mouth of the Calvert River.

Figure 2: Saltmarshes formed extensive thickets between the landward mangrove fringe (on the left) and dune ridges (on the right).

extensive patches of *Eleocharis sanguinolenta,* with a dense ground cover of *Marsilea drummondii*. Visited during the dry season, most of the ground vegetation was dried out and largely flattened by the activities of feral pigs.

2.2 Lagoons: Most of the lagoons sampled during the survey were more or less permanent waterholes in drainage channels, with extensive free-water surfaces. Thus, Big Stinking Lagoon (Figure 4, page 60) and Lily Lagoon are examples of this type, characterised by a linear morphology. On the other hand, Lake Crocodylus was a large depression (Figure 5, page 60). Lagoons were characterised by a diversity of floating and shallow-rooted aquatics such as *Nymphaea violacea,* several species of *Nymphoides, Marsilea mutica* and fringing clumps of the sedge *Eleocharis sanguinolenta*.

2.3 Rivers and Creeks: These riparian wetlands consist of the fringing vegetation of flowing rivers and streams, of which the Calvert River, Cycad Creek (Figure 6, page 61) and Karns Creek were the only examples briefly surveyed. Common and widespread species of these riparian wetlands include *Lophostemon grandiflorus, Melaleuca* spp. and *Pandanus* spp. In the spring-fed Karns Creek, the large charophyte *Chara lucida* was common.

2.4 Springs: More or less permanent springs are common around the basal foothills of the Barkly Tableland from the headwaters of the Calvert River to the vicinity of the Pungalina homestead. Accessible examples sampled included Bubbling Sands (Figure 7, page 62), springs at the Safari Camp, and an unnamed ephemeral spring near Site 7. These springs supported a dense vegetation of ferns (such as *Ceratopteris thalictroides* and *Ampelopteris prolifera*) as well as submerged (such as *Najas ?tenuifolia* and *Hygrophila angustifolia*) and floating (such as *Lobelia arnhemiaca*) aquatic macrophytes.

As the wetlands of northern Australia are inadequately known (Lukacs and Finlayson, 2010), the opportunity offered by the Royal Geographical Society of Queensland's expedition to the area allowed detailed observations and collections of wetland plants to be made at various sites throughout the study area, spread between the tidal and non-tidal wetlands of the Calvert River catchment.

Figure 3: During this survey, Jabiru Lagoon was a vegetated wetland with a limited free-water surface. Sparse stands of *Melaleuca nervosa* formed fringing vegetation, and extensive stands of *Eleocharis sanguinolenta* occupied the central portion of the depression.

Figure 4: The linear feature known as Big Stinking Lagoon consists of the deeper parts of the watercourse, dominated by an extensive cover of the waterlily *Nymphaea violacea,* and the shallow margins, which showed a range of aquatic species, here dominated by the sedge *Eleocharis sanguinolenta.*

Figure 5: Dead specimens of *Corymbia polycarpa* in and around Lake Crocodylus, killed by extended waterlogging during the wet season of 2010. The green clumps around their bases consist of the sedge *Eleocharis sanguinolenta.*

Figure 6: Cycad Creek with clump of *Pandanus aquaticus* on the far bank. Floating plants of *Nymphoides aurantiaca* can be seen along both banks.

Sampling Methods

A total of eleven sites, covering this entire range of wetland types, were visited (Table 1, page 62 and Figure 8, page 63) and wetlands plants were surveyed and photographed. Species that could not be fully identified in the field were collected as herbarium specimens (and lodged in the Northern Territory Herbarium, Darwin) and, in selected cases, as preserved specimens in 90% ethanol for later determination.

Results

A listing of all plants observed in the various wetland types is given in Table 2, page 64, and a detailed taxonomic list of the wetland species is provided in Appendix 1, starting on page 68.

Discussion

Although Matthew Flinders' 'botanical gentlemen', Robert Brown, Peter Good and Ferdinand Bauer, had made extensive plant collections in the Wellesley and Sir Edward Pellew island groups in the southern Gulf of Carpentaria in November and December 1802 respectively, Flinders sailed past the coastline at the mouth of the Calvert River, noting that the low sandy shoreline was of 'tedious uniformity'.

The first scientific plant collections in the area were made by Ludwig Leichhardt, who not only named the Calvert River – after his fellow expeditioner, James Calvert – but also named Cycas (now Cycad) Creek on 16 September 1845, after the groves of cycads (*Cycas angulata* R. Br.) he found near his campsite. Moving from waterhole to waterhole, Leichhardt (1847) made numerous observations and collections of aquatic plants. Unfortunately the extensive plant collection of Leichhardt was regrettably burned after three horses drowned in the Roper River. This had greatly reduced the carrying capacity of the remaining animals, and Leichhardt, who 'for a moment ... turned almost giddy', burnt his and the deceased John Gilbert's nearly 5,000 plant specimens on 21 October 1845.

Between June to December 1856, the botanist Ferdinand von Mueller as a member of Augustus Charles Gregory's Northern Australia Expedition, crossed northern Australia from the mouth of the Victoria River in Western Australia, to Moreton Bay, Queensland. On that epic ride, he collected the type specimens of around

Figure 7: Bubbling Sands Spring with its dense surrounding stands of *Pandanus aquaticus* and *P. spiralis*.

nine species of Eucalyptus (*E. aspera, E. confertiflora, E. miniata, E. microtheca, E. polycarpa* – now transferred to *Corymbia, E. ptychocarpa, E. phoenicea, E. tectifica* and *E. tetradonta*) as well as numerous other notable records. Mueller traversed the present study area on 12-14 August 1856 and undoubtedly made opportunistic collections of wetland plants.

Despite these early botanical collecting efforts, and the more recent activities of the officers of the Australian Wildlife Conservancy, the flora of the Calvert River catchment is poorly documented – as are northern wetlands in general (Lukacs and Finlayson, 2010). The catchment of the Calvert River is geographically and logistically far from Darwin, and is over the border from Queensland. Thus, it is not surprising

Table 1: Complete listing of collection sites 1-11, together with dates and GPS co-ordinates (WGS84).

Site Number and Name	Collection Date	GPS Co-ordinates
1. Big Stinking Lagoon	11 July 2012	16° 24.940’ S 137° 38.415’ E
2. Calvert River	12 July 2012	16° 23.580’ S 137° 38.892’ E
3. Calvert River mouth	13 July 2012	16° 16.580’ S 137° 44.170’ E
4. Cycad Creek	14 July 2012	16° 27.430’ S 137° 34.410’ E
5. Jabiru Lagoon	16 July 2012	16° 45.419’ S 137° 32.400’ E
6. Lake Crocodylus	16-19 July 2012	16° 43.706’ S 137° 31.830’ E
7. Karns Creek	16-17 July 2012	16° 47.495’ S 137° 27.614’ E
8. Green Swamp	17 July 2012	16° 43.417’ S 137° 29.596’ E
9. Lily Lagoon	19 July 2012	16° 42.494’ S 137° 34.222’ E
10. Safari Camp	19 July 2012	16° 43. 994’ S 137° 26.193’ E
11. Bubbling Sands	19 July 2012	16° 46.854’ S 137° 27.224’ E

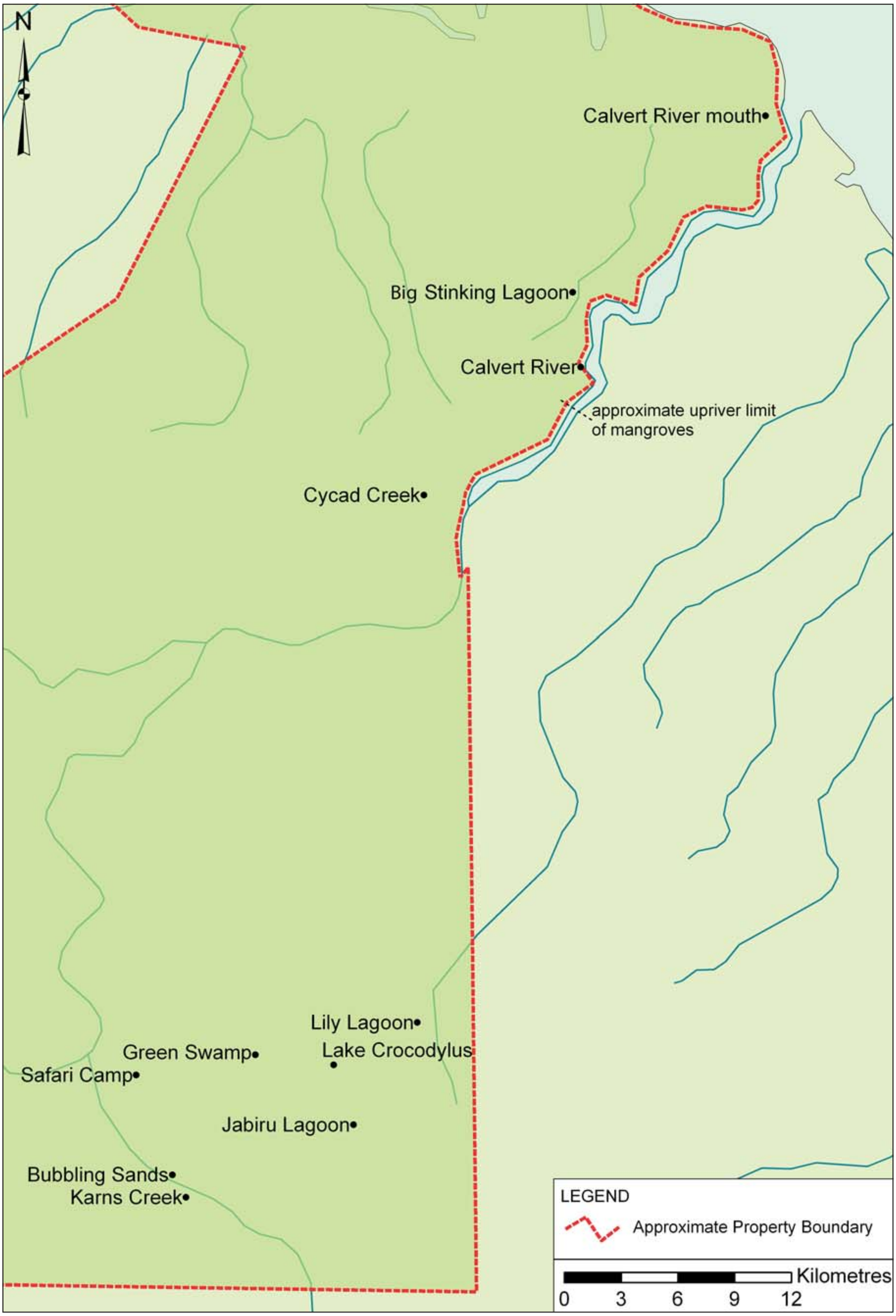


Figure 8: Sampling locations in and around the Calvert River catchment area, together with the approximate upstream limit of mangroves in the Calvert River.

Table 2: Listing of plant species in relation to wetland types and collecting sites 1-11.

Wetland Types(Site No.)	Mangrove (3)	Saltmarsh Saltflats (2)	Swamps (5,8)	Lagoons (1,6,9)	Rivers Creek (4,7)	Springs (10,11)
Aegialitis annulata	+					
Aegiceras corniculatum	+	+				
Ampelopteris prolifera						+
Aponogeton aff. vanbruggenii					+	
Avicennia marina	+	+				
Caldesia oligococca				+		
Cathormion umbellatum	+					
Ceratopteris thalictroides						+
Ceriops australis	+					
Chara lucida					+	
Commelina agrostophylla				+		
Corymbia polycarpa			+	+		
Cycas angulata					+	
Cyperus aquatilis			+		+	
Eleocharis sanguinolenta			+	+	+	
Eriocaulon spectabile			+	+		
Excoecaria ovalis	+	+				
Excoecaria parvifolia	+					
Ficus racemosa					+	+
Halosarcia indica	+	+				
Hibiscus tiliaceus	+					
Hygrophila angustifolia						+
Limnophila brownii				+		
Lobelia arnhemiaca						+
Lophostemon grandiflorus				+	+	
Ludwigia octovalvis				+		
Lumnitzera racemosa	+					
Marsilea aff. angustifolia				+		
Marsilea drummondii			+	+		
Marsilea mutica				+		
Melaleuca nervosa			+	+	+	
Melaleuca viridiflora			+	+	+	
Najas ?tenuifolia						+
Nelsonia campestris				+	+	
Nymphaea violacea				+	+	
Nymphoides aurantiaca				+	+	
Nymphoides indica				+		
Nymphoides minima				+		
Nymphoides parvifolia				+		
Nymphoides quadriloba				+		
Pandanus aquaticus				+	+	+
Pandanus spiralis				+	+	+
Parkinsonia aculeata	+					
Rhizophora stylosa	+	+				
Rhynchospora affinis				+		
Sphaeranthus africanus		+				
Sporobolus virginicus	+	+				
Thespesia populneoides	+					
Utricularia gibba				+		
Xylocarpus moluccensis	+					

that many of the present records extend species' ranges, purely by consolidating the records where only sporadic collecting has been carried out. Thus, the records for *Cycas angulata* in the Calvert River catchment consolidates the presently known disjunct distribution of this species from the lower reaches of the Wearyan, Foelsche and Robinson Rivers to the 'Bountiful Island group further east' (Hill, 1998, p. 614; Hill and Osborne, 2001, p. 37). Similarly, *Rhynchospora affinis* is known from the western part of the Northern Territory and occurs east of Burketown in tropical Queensland. Its occurrence in the Calvert River catchment bridges this distribution gap.

Other examples of the extension or consolidation of plant distributions include *Marsilea drummondii, Nymphoides minima, N. parvifolia, N. quadriloba, Lobelia arnhemiaca, Eriocaulon spectabile* and *Eleocharis sanguinolenta*. On the other hand, other species, such as *Lophostemon grandiflorus* and *Cathormion umbellatum* are within the known distribution range.

As the present field visit was during the dry season, many mangrove, aquatic and riverine plants were not flowering, making surveying and identification difficult, and there can be no doubt that as a result many species of wetland plants were overlooked. In addition, records of *Marsilea aff. angustifolia, Najas tenuifolia* and *Aponogeton aff. vanbruggenii* will require further confirmation when fertile material can be obtained. This limitation emphasises the difficulties of wetland studies in the wet-dry tropics generally: in the dry season, many wetland plants are not fertile which consequently limits their identification, but in the wet season, when these species may be fertile, access is virtually impossible.

Despite these difficulties and the limited collecting effort, a diversity of wetland plants was noted, particularly from the non-tidal wetlands. Thus, for example, of the 20 species of *Nymphoides* occurring in Australia (Tippery and Les, 2011), five occur together in Big Stinking Lagoon. Such floristic diversity suggests that the swamps, lagoons and springs of the area have considerable conservation value on a regional basis. Consequently, particular management efforts need to be expended on the major threats to these ecosystems, which include weed invasions (limited to *Parkinsonia aculeata* at present), cane toad infestation (massive juvenile infestation at Lake Crocodylus) and feral pig foraging (results of foraging in evidence at all non-tidal wetlands). Although it has been suggested that 'any effect of feral pigs on wetland biota may be dwarfed by seasonal climatic effects' (Doupé et al. 2010), all three threats need effective management to ensure the maintenance of the existing wetland diversity.

Conclusions

A reconnaissance survey of wetland plants from eleven sites in tidal and non-tidal systems recorded the presence of 49 species of native (and one exotic species – *Parkinsonia aculeata*) wetland plants, comprising one species of charophyte; five species of ferns; one species of cycads; 32 species of dicotyledons and 11 species of monocotyledons). The observed species generally showed strong biogeographic affinities to northern Australia, from the Kimberley region to the Gulf plains and to southern Cape York Peninsula. In many cases, the present records extend the known distributional ranges of the species involved, or at least consolidate the distribution range for an area still relatively under-investigated floristically.

Acknowledgements

It is a pleasure to thank my wife Helen, who acted as technical assistant throughout the period of field work, and the volunteers of the Royal Geographical Society of Queensland, without whose assistance, logistic support and general good cheer, the field work could not have been undertaken. I am grateful for the support in plant identifications I received from Michael Mathieson and Megan Thomas of the Queensland Herbarium, and from Michelle Casanova of the Royal Botanic Gardens, Melbourne. The map was kindly prepared by Greg Luker and the photomicrograph of *Chara lucida* was taken by Maxine Dawes, both of Southern Cross University. Collecting was undertaken under Permit Number 44014, granted by the NT Department of Natural Resources, Environment, The Arts and Sport and, as required by the permit, all herbarium specimens have been lodged in the Northern Territory Herbarium, Darwin. Finally, I thank the Australian Wildlife Conservancy and their officers on the ground, for giving me the opportunity to undertake this investigation in this most interesting region.

References

Aston, H.I., 1977. *Aquatic plants of Australia*. Melbourne University Press, Melbourne.

Aston, H.I., 1982. New Australian species of *Nymphoides* Séguir (Menyanthaceae). *Muelleria* 5: 35-51.

Bostock, P.D., 1998. Thelypteridaceae. *Flora of Australia* 48: 327-358.

Bucher, D. and P. Saenger, 1989. *An inventory of Australian estuaries and enclosed marine waters. Vol. VII – Northern Territory*. Report prepared for the Australian Recreational and Sport Fishing Confederation and the Australian National Parks and Wildlife Service by the Centre for Coastal Management. UNE Northern Rivers, Lismore.

Casanova, M.T., 2005. An overview of *Chara* L. in Australia (Characeae, Charophyta). *Australian Systematic Botany* 18: 25-39.

Chaffey, C., 2003. *A field guide to Australian ferns: including all 370 ferns and fern allies north of Capricorn*. Natureview Publications, Bangalow.

Cowan, R.S., 1998. Mimosaceae. *Flora of Australia* 12: 1-50.

Doupé, R.G., J. Mitchell, M.J. Knott, A.M. Davis and A.J. Lymbery, 2010. Efficacy of exclusion fencing to protect ephemeral floodplain lagoon habitats from feral pigs (*Sus scrofa*). *Wetlands Ecology and Management* 18: 69-78.

Finlayson, C.M., B.J. Bailey, W.J. Freeland and M.R. Flemming, 1988. Wetlands of the Northern Territory. In: McComb, A.J. and P.S. Lake (Eds.), *The conservation of Australian wetlands*. Surrey Beatty & Sons, Sydney, pp. 103-126.

Fosberg, F.R., 1961. Vegetation-free zone on dry mangrove coasts. *U.S. Geological Survey, Professional Papers* 424D: 216-218.

Hellquist, C.B. and S.W.L. Jacobs, 2011. Aponogetonaceae. *Flora of Australia* 39: 44-52.

Hill, K.D., 1998. Cycadophyta. *Flora of Australia* 48: 597-661.

Hill, K.D. and R. Osborne, 2001. *Cycads of Australia*. Kangaroo Press, Sydney.

Jacobs, S.W.L. and K.A. McColl, 2011. Najadaceae. *Flora of Australia* 39: 99-105.

Jones, D.L., 1998. Marsileaceae. *Flora of Australia* 48: 166-173.

Leichhardt, L., 1847. *Journal of an overland expedition in Australia from Moreton Bay to Port Essington, a distance of upwards of 3000 miles, during the years 1844-1845*. T. & W. Boone, London.

Lukacs, G.P. and C.M. Finlayson, 2010. An evaluation of ecological information on Australia's northern tropical rivers and wetlands. *Wetlands Ecology and Management* 18: 597-625.

Maguire, T.L. and P. Saenger, 2000. The taxonomic relationships within the genus *Excoecaria* L. (Euphorbiaceae) based on leaf morphology and rDNA sequence data. *Wetlands Ecology and Management* 8: 19-28.

Messel, H., G.C. Vorlicek, A.G. Wells, W.J. Green and A. Johnson, 1980. *Surveys of tidal river systems in the Northern Territory of Australia and their crocodile populations. Monograph 13: Tidal waterways on the southern coast of the Gulf of Carpentaria*. Pergamon Press, Sydney.

Saenger, P., 2002. *Mangrove ecology, silviculture and conservation*. Kluwer Academic Publishers, Dordrecht.

Saenger, P. and M.S. Hopkins, 1975. Observations on the mangroves of the south-eastern Gulf of Carpentaria, Australia. In: Walsh, G., S. Snedaker and H. Teas (Eds.), *Proceedings of the International Symposium on the Biology and Management of Mangroves, Hawaii*. University of Florida, Gainesville, Vol. 1: 126-136.

Sharp, B.R. and R.J. Whittaker, 2003. The irreversible cattle-driven transformation of a seasonally flooded Australian savanna. *Journal of Biogeography* 30: 783-802.

Sheue, C.-R, Y.-P. Yang, H.-Y. Liu, F.-S. Chou, S.-C. Chang, P. Saenger, C.P. Mangion, G. Wightman J. W.H. Yong and C.-C. Tsai, 2009. Reevaluating the taxonomic status of *Ceriops australis* (Rhizophoraceae) based on morphological and molecular evidence. *Botanical Studies* 50: 89-100.

Tippery, N.P. and D.H. Les, 2011. Phylogenetic relationships and morphological evolution in *Nymphoides* (Menyanthaceae). *Systematic Botany* 36: 1101-1113.

Tsai, C.-C., S.-J. Li, Y.-Y. Su, J.W.H. Yong, P. Saenger, P. Chesson, S. Das, G. Wightman, Y.-P. Yang, H.-Y. Liu, and C.-R. Sheue, 2012. Molecular phylogeny and evidence for natural hybridization and historical introgression between *Ceriops* species (Rhizophoraceae). *Biochemical Systematics and Ecology* 43: 178-191.

Wightman, G., 2006. *Mangroves of the Northern Territory, Australia: identification and traditional use. Northern Territory Botanical Bulletin No. 31*. Department of Natural Resources, Environment & the Arts and Greening Australia, Darwin.

Wilson, K.L., 2011. New species of *Eleocharis* (family Cyperaceae) in Australia. *Telopea* 13: 295-312.

Wilson, P.G., 1980. A revision of the Australian species of Salicornieae (Chenopodiaceae). *Nuytsia* 3: 3-154.

Appendix 1: Taxonomic Listing of Wetland Species

CHAROPHYTA

Fam. CHARACEAE

Chara lucida (A. Braun) R.D. Wood: Material of this robust charophyte was first collected by Ferdinand von Mueller in about 1856 from the headwaters of the Victoria River region in Western Australia and from the 'Gulf of Carpentaria' region in the Northern Territory and described as *C. australis* var. *lucida*. It was subsequently elevated to species status as *C. lucida,* before being again reduced to a variety of *Chara australis.* The Australian species of the algal genus *Chara* are in urgent need of revision (Casanova, 2005), and this taxon is currently being reinstated to full species status (Casanova, pers. comm.). *Chara lucida* is a totally ecorticate, dioecious charophyte that grows up to around 40 cm in tropical waters (Figure 9, page 68). It occurs in northern Australia from Western Australia, the Northern Territory and in northern Queensland. It has generally been recorded from slow-flowing sites, but antheridia-bearing plants were found in a still river pool with *Nymphaea violacea* in Karns Creek.

Figure 9: The apical portion of the frond of the charophyte *Chara lucida*, showing the simple, whorled lateral branches and lack of cortication on both the main axes and laterals.

POLYPODIOPHYTA

Fam. MARSILEACEAE

Marsilea aff. *angustifolia* R. Br.: This small-leaved nardoo has been referred to this species, although it is sterile and requires sporocarps for final determination. Nevertheless, vegetatively it cannot be distinguished from this species and it falls within this species' distribution range (Jones, 1998; Chaffey, 2003).

Marsilea drummondii A. Braun: The common nardoo occurred in the moist margins of most lagoons and swamps, but was particularly abundant in Green Swamp. This species occurs in all mainland states but seems more widespread in southern regions, with no apparent records from the Northern Territory coastal lowlands of the Gulf of Carpentaria (Jones, 1998; Chaffey, 2003).

Marsilea mutica Mett.: This relatively large-leaved, smooth nardoo, with its glossy green and brown-banded rounded leaflets, has a wide Australian distribution from across northern Australian south to Tasmania (Jones, 1998). It was particularly abundant around the shallow margins of Big Stinking Lagoon but occurred in most fresh waterbodies.

Fam. PARKERIACEAE

Ceratopteris thalictroides (L.) Brongn.: This semi-aquatic fern grows rooted in mud of streams and ponds. Near Site 7 (16° 47.907' S 137° 29.095 E), it occurred in a dried up spring (Figure 10, page 68); the vegetative fronds had died back but the fertile fronds, with their recurved margins enclosing 1-3 rows of sporangia, were still abundantly present. It occurs in the northern parts of Western Australia, the Northern Territory and along the humid coasts of eastern Queensland (Chaffey, 2003).

Figure 10: The aquatic fern *Ceratopteris thalictroides* in a dried up spring, with only fertile fronds with their recurved margins remaining.

Fam. THELYPTERIDCEAE

Ampelopteris prolifera (Retz.) Copel.: This proliferous fern with fronds up to 5-6 m long, is widespread in swamps and shallow streams across northern Australia and along the Queensland east coast southwards to around Brisbane (Bostock, 1998; Coffey, 2003). At Pungalina, it was particularly abundant on the banks of the small streams flowing from the Safari Camp springs.

CYCADOPHYTA

Fam. CYCADACEAE

Cycas angulata R. Br.: First collected by Robert Brown from the Bountiful Island group in 1803 during Flinders's circumnavigation of Australia, this robust cycad was commonly observed on the middle reaches of the Calvert River, where it occurs in open grassy woodlands flanking the Calvert River but, most abundantly, in drainage lines on the scree-slopes of the Barkly Tableland outliers near Cycad Creek. In the Northern Territory, it has not previously been recorded east of the Robinson River (Hill, 1998), where it has been recorded from the lower reaches Wearyan, Foelsche and Robinson Rivers.

MAGNOLIOPHYTA

Fam. NYMPHAEACEAE

Nymphaea violacea Lehm.: This floating perennial herb, which grows from a rhizome in the sediments of the still water body, was common in all non-flowing water bodies such as lakes, lagoons and creeks. Flower colour is most commonly blue but can vary from violet to pink or white. This species is widespread in northern Australia from the Kimberley region to Cape York Peninsula, extending down the Queensland east coast to Rockhampton.

Fam. MORACEAE

Ficus racemosa L.: This spreading buttressed tree, with cauliflorous yellow to reddish when ripe fig clusters, is widely distributed across northern Australia, extending as far north as New Guinea and southern Asia to India. It is a species of the riverine (riparian) community and was commonly observed around the springs associated with the upper reaches of the Calvert River.

Fam. CHENOPODIACEAE (now generally included in the AMARANTHACEAE)

Halosarcia indica (Willd.) P.G. Wilson: This perennial, decumbent shrub occurred landward of the mangroves around the estuarine reaches of the Calvert River, most abundantly around the margins of saltflats (Figure 11, page 69). It occurs in all mainland states and is widespread in the Northern Territory (Wightman, 2006). It occurs widely around the tropical shores of the Indian Ocean. Wilson (1980) recognised four subspecies as occurring in Australia, even though they intergrade with each other. The material from the Calvert River is referable to *H. indica* subsp. *indica*.

Figure 11: Low rambling thickets of the halophyte *Halosarcia indica* comprised the saltmarsh areas landward of the mangroves.

Fam. PLUMBAGINACEAE

Aegialitis annulata R. Br.: This shrub to 2 m high is widespread and common around the entire northern Australian coastline, growing on sand, mud and rock substrates. The fruit is an indehiscent nut in which the embryo enlarges within the fruit without rupturing the pericarp, termed cryptoviviparous. Air-filled tissue in the fruit wall is presumed to aid buoyancy, thereby enhancing water borne dispersal. Previously recorded from the Calvert River estuary by Messel et al. (1980), this species is widespread across northern Australia, extending down the west coast to Exmouth Gulf, Western Australia and to Hervey Bay, Queensland on the east coast.

Fam. MALVACEAE

Hibiscus tiliaceus L.: This spreading tree, with its large orbicular, discolorous leaves and large yellow flowers, was occasionally met with above high tide mark on sandy beach ridges behind the mangroves at the mouth of the Calvert

River. *Hibiscus tiliaceus* has a pantropical distribution, extending down the east coast to southern New South Wales.

Thespesia populneoides (Roxb.) Kostel.: This medium tree, with large deltoid concolorous leaves, was occasionally observed immediately above the high tide mark on sandy beach ridges behind the mangroves at the mouth of the Calvert River. According to Wightman (2006) the large, showy flowers of this species are bird pollinated. The woody capsule and buoyant seeds are well adapted to water dispersal (Figure 12, page 70). This species is widespread and common around the entire northern Australian coastline.

Figure 12: The heart-shaped leaves and flowers of *Thespesia populneoides* closely resemble those of *Hibiscus tiliaceus*, which commonly co-occurs with this species. However, the rounded fruit of *Thespesia* is not enclosed by the calyx, which as shown here, forms a disc-like structure at its base.

Fam. MYRSINACEAE

Aegiceras corniculatum (L.) Blanco: The river mangrove was common in and around the estuarine reaches of the Calvert River, and occurred sparsely along the length of the river to the upriver limits of mangroves near Site 2. Previously recorded from the Calvert River estuary by Messel et al. (1980), this species occurs in northern Australia, extending down the west coast to Cossack, Western Australia and to Merimbula, NSW on the east coast.

Fam. MIMOSACEAE

Cathormion umbellatum (Vahl) Kosterm. subsp. *moniliforme* (DC) Brummit: This sprawling tree, with its characteristic compressed, moniliform pods (Figure 13, page 70), grows on alluvial soil in drainage lines on the landward side of the saltflats in the estuarine reaches of the Calvert River. It is widespread in south-east Asia and extends to northern Australia, ranging from the Kimberley region of Western Australia to Cape York Peninsula (Cowan, 1989).

Figure 13: *Cathormion umbellatum* is a sprawling tree, with characteristic compressed, moniliform pods, which occurs around the saltflats and sand dunes and swales at the mouth of the Calvert River.

Fam. CAESALPINIACEAE

Parkinsonia aculeata L.: Despite recent efforts by the Australian Wildlife Conservancy to eradicate this introduced weed, several sizeable patches of this weed were noted in and around the saltflats and sand dunes and swales near the mouth of the Calvert River (Figure 14, page 71). *Parkinsonia aculeata* is a native of tropical America, and has become a weed of national significance in Australia, with infestations in coastal, central and western Queensland, central and northern Northern Territory, and the Kimberley and Pilbara regions of Western Australia. In Queensland, the Northern Territory, Western Australia, South Australia and New South Wales, landholders are required by law to contain *P. aculeata* within dense infestations and eradicate all smaller outbreaks.

Fam. ONAGRACEAE

Ludwigia octovalvis (Jacq.) P.H. Raven: Robust branching hirsute to more or less glabrous herb to 4 m high, sometimes woody at base. Leaves are alternate, narrow-linear to ± ovate, with short petiole. Flowers solitary in upper leaf axils; sepals 4 and petals usually 10–20 mm long, yellow (Figure 15, page 71). This robust herb is common and widespread in wet or seasonally wet places throughout northern Australia; at Pungalina it was particularly abundant around the margins of Big Stinking Lagoon.

Figure 14: This shrub or small tree, *Parkinsonia aculeata,* with its conspicuous yellow flowers, is an introduced weed on sand dunes around saltflats near the mouth of the Calvert River.

Fam. COMBRETACEAE

Lumnitzera racemosa Willd.: This mangrove shrub or small tree, with its relatively small, somewhat fleshy, erect, spatulate, alternate leaves, was common at the landward margins of mangroves at the estuarine reaches of the Calvert River. Although two species of *Lumnitzera (L. racemosa* and *L. littorea*) are known from the Northern Territory (Wightman 2006), only the white-flowered *L. racemosa* was found in the Calvert River estuary.

Fam. MYRTACEAE

Corymbia polycarpa (F. Muell.) K.D. Hill and L.A.S. Johnson: The long-fruited bloodwood, characteristic of seasonally inundated alluvial flats, had formed dense stands around Lake Crocodylus which were killed by the elevated lake levels due to the intense wet of 2010. Around other lagoons, such as Green Swamp (Site 8) and Jabiru Lagoon (Site 5), extant stands were observed. This species occurs widely across northern Australia from the Kimberley region to Cape York Peninsula.

Lophostemon grandiflorus (Benth.) Peter G. Wilson and J.T. Waterh.: Northern swamp box is a tall, large-crowned tree which is a common component of the riverine vegetation, both of the Calvert River, smaller creeks such as Karns Creek, and in drainage depressions. Its general association with a high groundwater table has led to it occasionally being referred to as a ‘freshwater mangrove’. This species is widespread across northern Australia from the Kimberley region through the Northern Territory to Queensland, extending down the east coast to around Gympie.

Figure 15: The annual or short-lived perennial, *Ludwigia octovalvis,* grows in soft muds along the margins of pools, creeks and lagoons, as here, around Big Stinking Lagoon.

Melaleuca nervosa (Lindl.) Cheel: This small-leaved, straggly paperbark tree was common in seasonal swamps, around springs and in drainage depressions. It is widespread in northern Australia from north-western Western Australia to subtropical Queensland.

Melaleuca viridiflora Soland. ex Gaertn.: The broad-leaved paperbark occurred widely on banks of streams (e.g. Karns Creek and Calvert River), in swamps (e.g. Green Swamps) and around the margins of lagoons (e.g. Big Stinking Lagoon). It is widespread in northern Australia from north-western Western Australia to subtropical Queensland, extending southwards on the east coast to around Brisbane.

Fam. RHIZOPHORACEAE

Ceriops australis (C.T. White) E.R. Ballment. T.J. Smith and J.A. Stoddart: The smooth-fruited spur mangrove was common in the lower estuarine reaches of the Calvert River where it formed dense thickets 4-5 m high. It occurs in the northern parts of Western Australia, the Northern Territory and along the humid coasts of north-eastern Queensland, extending to Papua New Guinea and Indonesia (Tsai et al., 2012). Although three species of *Ceriops (C. australis, C. decandra* and *C. tagal*) occur in the Northern Territory (Wightman, 2006; Sheue, 2009), only the smooth-fruited *Ceriops australis* was found in the Calvert River estuary.

Rhizophora stylosa Griff.: The stilt-rooted mangrove was common throughout the mangrove fringe of the Calvert River from the mouth of the river to the upriver limits of mangroves near Site 2. This species was previously recorded from the Calvert River estuary by Messel et al. (1980). Although three species of *Rhizophora (R. apiculata, R. lamarckii* and *R.*

stylosa) occur in the Northern Territory (Wightman, 2006), only the more widespread *Rhizophora stylosa* was found in the Calvert River estuary. This species is widespread along the northern Australian coastline, extending from Exmouth Gulf in Western Australia to the Clarence River, in northern New South Wales.

Fam. EUPHORBIACEAE

Excoecaria ovalis Endl.: This species is common on sand and mud from the mouth of the Calvert River to close to the upriver limits of mangroves near Site 2. This species, which has long been considered a variety of *Excoecaria agallocha* L., has recently been elevated to species rank on the basis of leaf morphology (ovate leaves with entire margins) and rDNA sequence data, which showed that *E. agallocha* and *E. ovalis* are genetically distinct (Maguire and Saenger, 2000). The type material had been collected by Bauer, who accompanied Matthew Flinders in HMS *Investigator* during the survey of the Gulf of Carpentaria in 1802-3. This species was previously recorded from the Calvert River estuary as *Excoecaria agallocha* by Messel et al. (1980). *Excoecaria agallocha* with serrated leaves occurs in the Northern Territory (Wightman, 2006), but only *Excoecaria ovalis* was found in the Calvert River estuary.

Excoecaria parvifolia Muell. Arg.: This species, commonly called the Gutta-Percha tree, occurred around the margins of saltflats near the mouth of the Calvert River, where it grew as shrubs or small trees, up to 4-5 m high. This species is common and widespread across northern Australia, from north-western Western Australia to Cape York. It has been suggested that over recent years, this species has increased significantly across the northern savannah lands as a result of overgrazing and reduced fire frequency (Sharp and Whittaker, 2003). However, it should be noted that Leichhardt (1847) under the diary entry for 9 July 1845 observed 'a small green looking tree, which we found growing densely along the creek, had wood of a brown colour, which smelt like raspberry jam; and, upon burning it, the ashes produced a very strong lye, which I used in dressing the wounds of my companions. This tree was found in great abundance on all rivers and creeks around the gulf, within the reach of salt water; and when crossing Arnheim Land, though less frequently.'

Fam. MELIACEAE

Xylocarpus moluccensis (Lam.) M. Roem.: This species, with stout, conical pneumatophores, was sporadically present at the landward edge of the mangroves near the mouth of the Calvert River. It is widespread around the entire northern Australian coastline. Although two species *of Xylocarpus (X. granatum* and *X. moluccensis*) occur in the Northern Territory (Wightman, 2006), only the more widespread *Xylocarpus moluccensis* was found in the Calvert River estuary.

Fam. MENYANTHACEAE

Nymphoides aurantiaca (Dalzell) Kuntze: This floating aquatic herb, with its small leaves with entire margins, and conspicuous fringed yellow petals, was common in all freshwater lagoons as well as the backwaters of creeks and streams. It commonly co-occurred with *Marsilea mutica* in Big Stinking Lagoon. Sometimes referred to by its synonym *Nymphoides hydrocharoides* (F. Muell.) Kuntze, this species is widely distributed from the Kimberley region of Western Australia through the Northern Territory to Queensland, extending southwards along the east coast to around Rockhampton.

Nymphoides indica (L.) Kuntze: This floating aquatic herb has the unique growth form in that 'the stem continues beyond the cluster of pedicels' and produces a second leaf and pedicel cluster at its extremity (Aston, 1977). This species was particularly abundant around the moist margins of Lake Crocodylus and Big Stinking Lagoon. This species is widespread across northern Australia and extends down the east coast to around Newcastle.

Nymphoides minima (F. Muell.) Kuntze: This diminutive floating herb, with its somewhat horseshoe-shaped leaves, was common around the moist margins of Big Stinking Lagoon (Figure 16, page 73). According to the Australian Virtual Herbarium (avh.ala.org.au), *N. minima* is a northern species, recorded from the Kimberley region, the western Northern Territory and Cape York Peninsula. This species has not previously been recorded from the southern shores of the Gulf of Carpentaria.

Nymphoides parvifolia (Griseb.) Kuntze: This diminutive floating herb, with its somewhat horseshoe-shaped leaves, was common around the moist margins of Big Stinking Lagoon. According to the Australian Virtual Herbarium (avh.ala.org.au), it occurs across northern Australia from the Kimberley region to subtropical Queensland. This record consolidates its distributional range.

Nymphoides quadriloba Aston: This diminutive floating herb, with its somewhat

Figure 16: *Nymphoides minima* was common on the damp margins and in the shallows of Big Stinking Lagoon.

horseshoe-shaped leaves, is superficially similar to *N. minima*, but is easily distinguished in that the corolla consists of four, rather than five, fringed petals (Aston, 1982). It was particularly abundant at Big Stinking Lagoon (Figure 17, page 73). According to the Australian Virtual Herbarium (avh.ala.org.au), it occurs across northern Australia from the Kimberley region to subtropical Queensland. This record consolidates its distributional range.

Fam. VERBENACEAE

Avicennia marina (Forsk.) Vierh.: The white mangrove, now often placed in the monophyletic AVICENNIACEAE or the ACANTHACEAE, was common in and around the estuarine reaches of the Calvert River, and together with *Rhizophora stylosa*, dominated the riverine mangrove fringe to the upriver limits of mangroves near Site 2. This species was previously recorded from the Calvert River estuary by Messel et al. (1980). Common around the Australian coastline, it occurs in all states with the exception of Tasmania.

Fam. SCROPHULARIACEAE

Limnophila brownii Wannan: This aquatic herb has submerged stems and erect emergent branches, which bear white to pinkish flowers. It occurs in the moist fringes of watercourses from north-western Western Australia and the Northern Territory to Queensland, extending along the east coast as far south as Bundaberg. First collected by F. Mueller from the Fitzmaurice River, Northern Territory, during the Northern Australia Expedition in 1855-56.

Fam. LENTIBULARIACEAE

Utricularia gibba L.: This diminutive leafless plant was abundant around the drying shoreline of Lake Crocodylus. First recorded in northern Australia by Robert Brown, who

Figure 17: A cluster of *Nymphoides quadriloba* that commonly occurred on the damp margins of Big Stinking Lagoon.

described it as *U. exoleta*, it is widespread across northern Australia and along the east coast, south to Sydney (Aston, 1977). It is widely distributed in tropical and subtropical areas around the world.

Fam. ACANTHACEAE

Hygrophila angustifolia R. Br.: This erect herb, up to 1 m high, has axillary clusters of 4-12 pale mauve flowers. Widely used as an aquarium plant, the species occurs from north-western Western Australia and the Northern Territory to Queensland, extending southwards on the east coast to around the north coast of New South Wales. It was collected by F. Mueller in what is now the Gregory National Park, Northern Territory, during the Northern Australia Expedition in 1855-56.

Nelsonia campestris R.Br.: This densely pubescent, decumbent annual herb with tiny white flowers (Figure 18, page 74) is common on the banks of rivers, creek and lagoons from north-western Western Australia and the Northern Territory to Queensland, extending southwards on the east coast to around Rockhampton. It was collected by F. Mueller near the Fitzmaurice River, Northern Territory, during the Northern Australia Expedition in 1855-56.

Fam. CAMPANULACEAE

Lobelia arnhemiaca E. Wimm.: A prostrate, mat-forming herb, which roots at the nodes (Figure 19, page 74). The leaves are oblong to elliptical, minutely pubescent with toothed margins. Flowers solitary, calyx lobes 0.5–1.5 mm long, densely and minutely pubescent with a corolla tinged with mauve; found in slow-moving streams resulting from groundwater springs e.g. at Bubbling Sands. According to the Australian Virtual Herbarium (avh.ala.org.au), this species

Figure 18: The densely pubescent herb with delicate white flowers, *Nelsonia campestris,* commonly occurred around the damp margins of creeks and lagoons, as here, at Big Stinking Lagoon.

Figure 19: The mat-forming *Lobelia arnhemiaca*, with its dentate leaves and mauve-tinged corolla, was abundant in the spring-fed streams at Bubbling Sands spring.

was first collected by F. Mueller in the headwaters of the Victoria River in the Northern Territory during the Northern Australia Expedition in 1855-6. This species occurs in shallow waters of slow-flowing rivers in northern Western Australia, the Northern Territory, with a limited number of records from northern Queensland. This species has not previously been recorded from the southern shores of the Gulf of Carpentaria.

Fam. ASTERACEAE

Sphaeranthus africanus L.: This wing-stemmed annual herb is found in wet places, swamps and brackish water (Figure 20, page 75). It is widespread throughout tropical Africa, Asia – where it is considered a weed of rice fields – and northern Australia. Occurs in all mainland States but is predominant in tropical northern Western Australia through the Northern Territory to north-eastern Queensland, as far south as Belyando and Townsville (avh.ala.org.au).

Fam. ALISMATACEAE

Caldesia oligococca (F. Muell.) Buchenau: This rhizomatous aquatic herb, with floating leaves and emergent inflorescences, occurs from north-western Western Australia and the Northern Territory to Queensland, extending southwards along the east coast to around Gladstone. It was first collected by F. Mueller from the headwaters of the Victoria River, Northern Territory, during the Northern Australia Expedition in 1855-56.

Fam. APONOGETONACEAE

Aponogeton aff. *vanbruggenii* Hellq. & S.W.L. Jacobs: This long-leaved aquatic herb has been referred to this species although it is sterile, and requires flowering material for final determination. Nevertheless, vegetatively it cannot be distinguished from this species and it falls within this species' distribution range, which includes a record from the Calvert River (Hellquist and Jacobs, 2011). It occurs in rivers and billabongs of tropical Northern Territory and Cape York.

Fam. NAJADACEAE

Najas aff. *tenuifolia* R.Br.: This slender, flexuose submerged perennial has been referred to this species although it is sterile, and requires flowering material for final determination. Nevertheless, vegetatively it cannot be distinguished from this species and it falls within this species' distribution range (Jacobs and McColl, 2011), occurring in all mainland States but is predominant in northern tropical Australia from the Kimberley regions to tropical Queensland. The type material of this species was collected on the islands of the Gulf of Carpentaria by Robert Brown in 1803 during Flinders's circumnavigation of Australia.

Fam. PANDANACEAE

Pandanus aquaticus F. Muell.: This clump-forming species, with its crowded fruiting heads and prominent prop roots, occurs in the Kimberley region and in coastal Northern Territory, extending as far east as Riversleigh just across the border into Queensland. This record consolidates its distributional range in the Northern Territory.

Pandanus spiralis R. Br.: This rarely clump-forming species, with its clustered fruiting heads and prominent spiralled leaf scars, occurs widely across northern Australia from the

Figure 20: The wing-stemmed *Sphaeranthus africanus,* with its globular flowerheads, was common on the banks of the Calvert River where it is regularly inundated with brackish water.

Kimberley region to the western coast of Cape York Peninsula. The type material of this species was collected by Robert Brown on Allen Island in the Gulf of Carpentaria in 1803 during Flinders' circumnavigation of Australia.

Fam. COMMELINACEAE

Commelina agrostophylla F. Muell.: This procumbent glabrous herb, with large (c. 2-2.5 cm diameter) blue flowers (Figure 21, page 75), was conspicuously abundant around the damp margins of Big Stinking Lagoon. According to the Australian Virtual Herbarium (avh.ala.org.au), this species is widespread in the Northern Territory and Queensland, but only one record exists – that of F. Mueller, collected on the Northern Australia Expedition in March 1856 – from Western Australia.

Fam. ERIOCAULACEAE

Eriocaulon spectabile F. Muell.: This small tufted herb was first collected by Ludwig Leichhardt in June 1845 from a small lagoon near the Mitchell River, Queensland [MEL 0710138A].

Figure 21: The procumbent *Commelina agrostophylla* formed extensive, vivid blue clusters around the damp margins of Big Stinking Lagoon.

It was subsequently described by F. Mueller, and is now known to occur widely from north-western Western Australia, Northern Territory and Queensland, extending southwards on the east coast to the north coast of New South Wales. This record consolidates the distributional range of this species on the Gulf plains, where it is locally common in damp places.

Fam. CYPERACEAE

Cyperus aquatilis R. Br.: This slender tufted annual sedge with triquetrous culms was locally common in damp places e.g. in and around the damp margins of Jabiru Lagoon. Material of this species was collected by F. Mueller near the Fitzmaurice River, Northern Territory, during the Northern Australia Expedition in 1855-56. According to the Australian Virtual Herbarium (avh.ala.org.au), it occurs across north-western Western Australia, Northern Territory and Queensland, extending southwards on the east coast to around Brisbane.

Eleocharis sanguinolenta K.L. Wilson: This robust perennial, with conspicuously reddish glumes on tufted, erect culms, was common in all freshwater bodies throughout the Calvert River catchment. It is recorded from north-western Western Australia, Northern Territory and tropical Queensland (Wilson, 2011). This record consolidates the distributional range of this species on the Gulf plains.

Rhynchospora affinis W. Fitzg.: This small tufted annual sedge occurs from north-western Western Australia and the Northern Territory to Queensland. It was common on the damp soil amongst the dead standing trunks of *Corymbia polycarpa* fringing Lake Crocodylus. However, according to the Australian Virtual Herbarium (avh.ala.org.au), there are no apparent records for the coastal region between approximately

Burketown, Queensland in the east, and Darwin, Northern Territory in the west, and this record represents a considerable extension of the distributional range of this species along the southern shoreline of the Gulf.

Fam. POACEAE

Sporobolus virginicus (L.) Kunth: This rhizomatous, perennial grass formed low, dense mats at the landward margins of the mangroves and among the saltmarsh plants along the tidal reaches of the Calvert River. *Sporobolus virginicus* occurs in all Australian states and is widespread in south-east Asia and the Pacific Islands (Wightman, 2006).

Late Holocene climate and environmental history of Pungalina Station, Gulf coastlands, northern Australia

Shulmeister, J.[1], Welsh, K.[2], Murphy, J.[1] and Stutsel, B.[1]

1. School of Geography, Planning and Environmental Management, University of Queensland, St Lucia 4072, Qld
2. School of Earth Sciences, University of Queensland, St Lucia 4072, Qld

Abstract Pungalina Station in the Gulf Coastal Bioregion of the Northern Territory is an AWC property about 60 km south of the Gulf of Carpentaria. As part of a Royal Geographical Society of Queensland expedition in June and July 2012, a series of cores was retrieved from semi-permanent lakes, billabongs and seasonal swamps. The best records were recovered from Jabiru Lagoon and Fern Springs. Here we present charcoal and LOI records from these water bodies. These records currently lack a chronological control, however they do indicate that water levels and fire histories have fluctuated in the recent past in this region. We recognise at least three zones of burning and organics. These are an upper zone of high frequency of charcoal and high organics. An intermediate zone of low burning and low organics and a lower zone (at Fern Springs only) of high burning and intermediate organics. We infer that the upper zone of burning is probably post-European but the lower zone of burning is interpreted as a signal of a period of stronger monsoon activity. Further analyses of these cores including radiocarbon dating will better constrain climate evolution and human impacts at these sites.

Introduction

Monsoonal northern Australia is a critical region for the future prosperity of Australia as it is the only substantial area of the continent with significant rainfall that has not been extensively developed and it is also a resource rich region in terms of both extractable resources and biodiversity reserves. It might be expected that a major climate system such as the North Australian Monsoon would be relatively well understood but the climate teleconnections are debated with the Australian Summer Monsoon alternatively related to forcing from the East Asian Winter Monsoon (e.g. Shaiu et al., 2011), the Indian Summer Monsoon (e.g. Mohtadi et al., 2011) and/or the southern hemisphere westerlies (e.g. Wyrwoll et al., 2012) and interannual changes are correlated with regions as remote as the north Pacific (Zhu and Wang, 2010). Consequently there is very little confidence in predictions on the annual range and variability of the monsoon let alone longer term trends. Paleo-monsoon data, especially data covering the latter half of the Holocene (modern conditions) are desperately required. The Gulf Coastal Bioregion in the Gulf of Carpentaria lies in the core of the monsoonal region but has received little attention. The purpose of this paper is to describe the Late Quaternary environmental history of part of the Gulf Coastal Bioregion.

The underlying rocks at Pungalina are a Proterozoic sedimentary sequence dominated by shallow marine sandstones of the Echo Sandstone and dolostones of the Karns Dolomite with undifferentiated Cenozoic sands covering them (Rawlings, 2002). Sandstone plateaus on which wetlands are situated rise up to 100m above the adjoining plains Baker et al., 2005.

They lie within the north Australian monsoonal zone with a bi-modal climate. In the Gulf Coastal Bioregion a wet season extends from November to March and accounts for more than 90% of the total rainfall (Bastin, 2008) (between 800 and 1000mm pa) while the dry season can be broken into an early dry which is relatively cool and the 'build-up' which precedes the start of the 'wet' and is characterised by high temperatures and humidities but little rain. The dry season is dominated by the south-east trade winds while the wet is characterised by low wind speeds except when monsoons reach the area.

The rainfall is unreliable as the wet is strongly affected by the strength of the Indonesian Monsoon and that in turn is impacted by ENSO and the Indian Ocean Dipole (IOD) (Hesse et al., 2004).

The Gulf Coastal Bioregion supports a diverse range of vegetation types including savannah, heath, shrublands, and mangroves swamps (Woinarski et al 2007). The most common vegetation community in the region is savannah woodland usually comprising of dry sclerophyll *Eucalyptus* forest (Bowman et al 2010). Soil type and lithology are the primary determinant factors of savannah vegetation. Regions with oligotrophic sandy soils have a higher proportion of sclerophyll shrubs (e.g. Grevilleas) with the ground layer dominated by *Triodia* (spinifex). In areas of clay rich substrates, tree species including *Melaleuca, Bauhinia and Vachellia* tend to dominate over Eucalypts (Bowman et al 2010). To the south and west in the Barkly Tableland, Mitchell grass *(Astrebla sp.)* dominates the open plains.

The Calvert River rises on Pungalina Station and base flow in the Calvert and Robinson rivers is predominantly sourced from the Karns Dolomite (Tickell, 2008). According to Zaar (2009) there is a large aquifer associated with the limestones in the region and there are a number of permanent (or semi-permanent) springs in the study area. Aquifer recharge is linked with variations in the strength of the monsoon and prevalence of tropical cyclones, for example during the wet season 2000/2001 where high baseline flows were noted in the Calvert River and Lake Crocodylus in the centre of the study area filled to the greatest extent in recent years (Zaar, 2009).

Existing late Quaternary environmental records

There are no prior studies of late Quaternary environmental change published from the Gulf Coastal Bioregion. In fact, paleoclimatic studies are rare across the whole of the Carpentaria Gulf country and in Arnhemland. The nearest studies are from Vanderlin Island where Prebble et al. (2004) recovered a 9,200 year record from a 92 cm core. For the early Holocene they interpret a gradual intensification of the North Australian Monsoon following Shulmeister's and Lees' (1995) work from Groote Eylandt while Prebble et al. attribute late Holocene changes to changes in the local fire regime. They concluded local dune stabilisation occurred between 4,500 and 7,500 yr BP which they related to the cessation of sea-level rise.

The other near complete Holocene record comes from Groote Eylandt (Shulmeister, 1992; Shulmeister and Lees, 1995). They concluded that the early Holocene was marked by a gradual intensification of the monsoon with a major change at about 4,000 yr BP relating to the switching on, or intensification of ENSO. The only other paleoecological studies on land within the wider region are from Rowe (2008) from Torres Straits at the northern tip of the Cape York Peninsula. The vegetation record there is dominated by sea-level rise effects in the early to mid-Holocene. Like Prebble et al. (2004) she inferred human impacts on the vegetation record in the later Holocene.

In contrast to terrestrial work there is a plethora of data from the Gulf of Carpentaria itself and in particular from paleo-lake Carpentaria (e.g. Torgerson et al., 1988; Reeves et al., 2008). These papers provide detailed records of the last glacial cycle but the Holocene is largely ignored or missing in their records.

In summary, very little paleoenvironmental work relevant to the Gulf Coastal Bioregion has been undertaken. In order to fill this gap in climatic archives we have retrieved seven sedimentary cores from swamps, billabongs and springs in the Pungalina-Seven Emu Sanctuary nature reserve in the Northern Territory approximately 60 km west of the Queensland border and 5 km south west of the coast (16°43'17"S 137°24'57"E) (see Figure 1, page 79). The cores range in length between 40 cm and 1.05 m and were collected along a transect through a single drainage that ultimately connects to the Calvert River, from a currently dry swamp (informally named Brown Snake Swamp) a semi-permanent lake (Jabiru Lagoon) and an apparently permanent freshwater spring (Fern Springs) (see Figure 1, page 79). The sites were chosen to show a range of sensitivities to changing precipitation regimes. In this paper we report on two cores from Fern Springs and Jabiru Lagoon.

Methods

1-2 m metal exhaust pipes were used as core barrels. The barrels were several millimetres thick. The pipe was hand pushed into the peaty top sediment layers until a tight layer was reached whereupon a post-hole driver was used to gradually sink the metal tube into the sediment profile. Extraction of the cores was

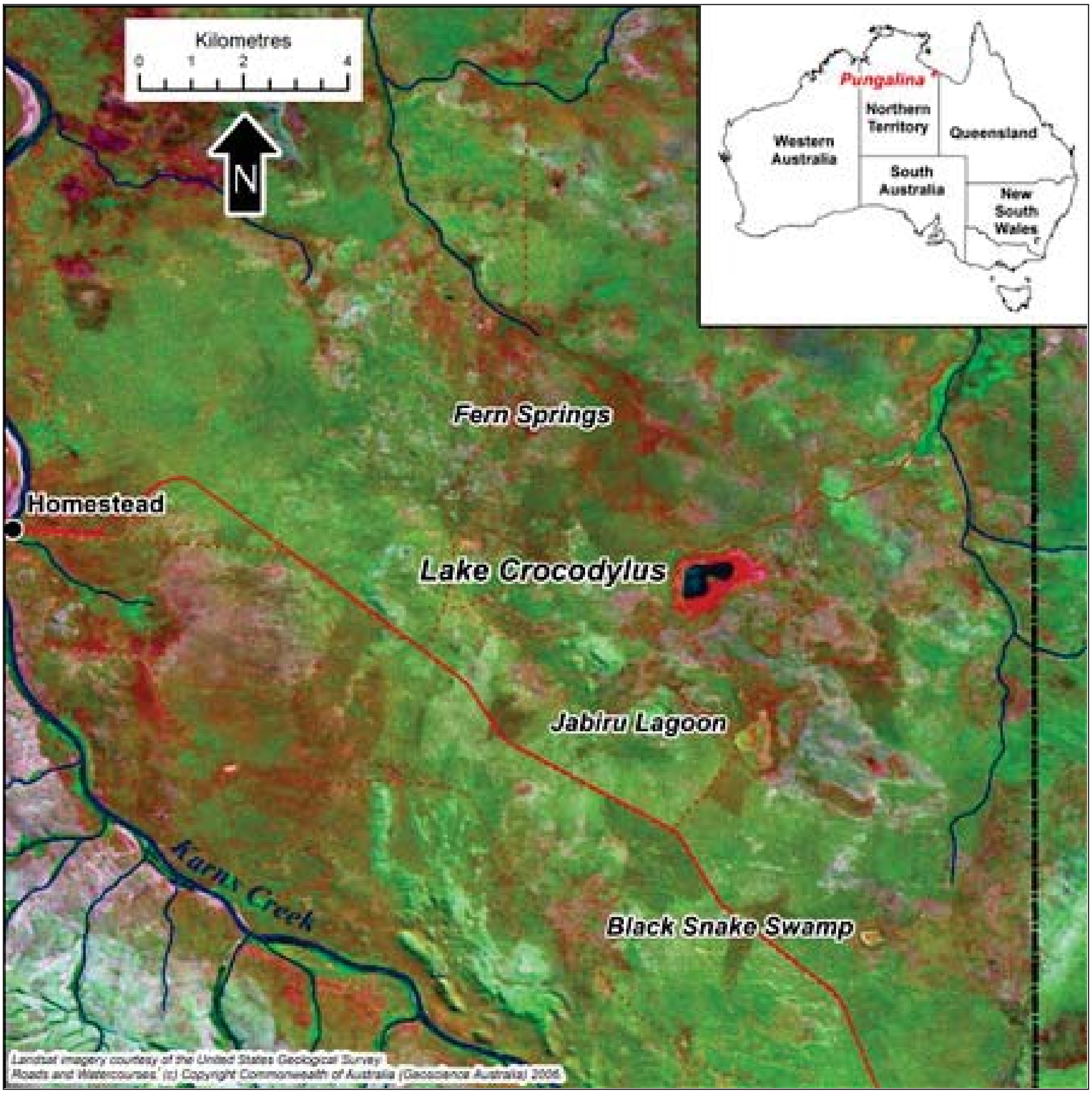


Figure 1. Google Earth image of part of the Gulf Coastal Bioregion around the Pungalina AWC wildlife reserve.

achieved using a high lift jack to provide sufficient vertical force to force the core upwards. This was challenging in lake environments and the assistance of an A team from the Royal Geographical Society of Queensland was needed (the OBs). Figure 2, page 80 shows K. Welsh holding a core retrieved from Jabiru Lagoon.

Once the extraction was complete, both ends of the core were capped and taped to avoid any sediment being lost and desiccation. The cores were returned to the University of Queensland for analysis, where they were stored at room temperature before opening and then transferred to a refrigerator at 4°C to protect against deterioration. For these preliminary analyses we undertook sediment description, loss on ignition (LOI) and macro-charcoal analyses. Two samples were submitted for radiocarbon dating but these results are not yet available.

The sediment was described using the constituent elements under the Troels-Smith classification scheme (Troels-Smith, 1955) and sediment colour was determined moist using Munsell colour charts.

Samples were divided into 1cm³ blocks at 1 or 2 cm intervals. Samples were weighed. They were placed in a drying oven at 60ºC for 24 hours and then re-weighed. They were then placed into a furnace (muffle) oven at 450ºC for 24 hours. They were moved to a desiccator to

Figure 2. Core sample recovered from Jabiru Lagoon. The centre of the lagoon was covered by a thick sedge bed. Water depths were about 70 cm at the time of sampling.

cool to ensure moisture content did not increase during cooling, altering their final weights. At Jabiru Lagoon sampling for both LOI and macro-charcoal was every centimetre for the first 27 centimetres and from this point onwards every two centimetres until 77 cm. This yielded 54 samples. At Fern Springs all samples were recovered at 1 cm intervals.

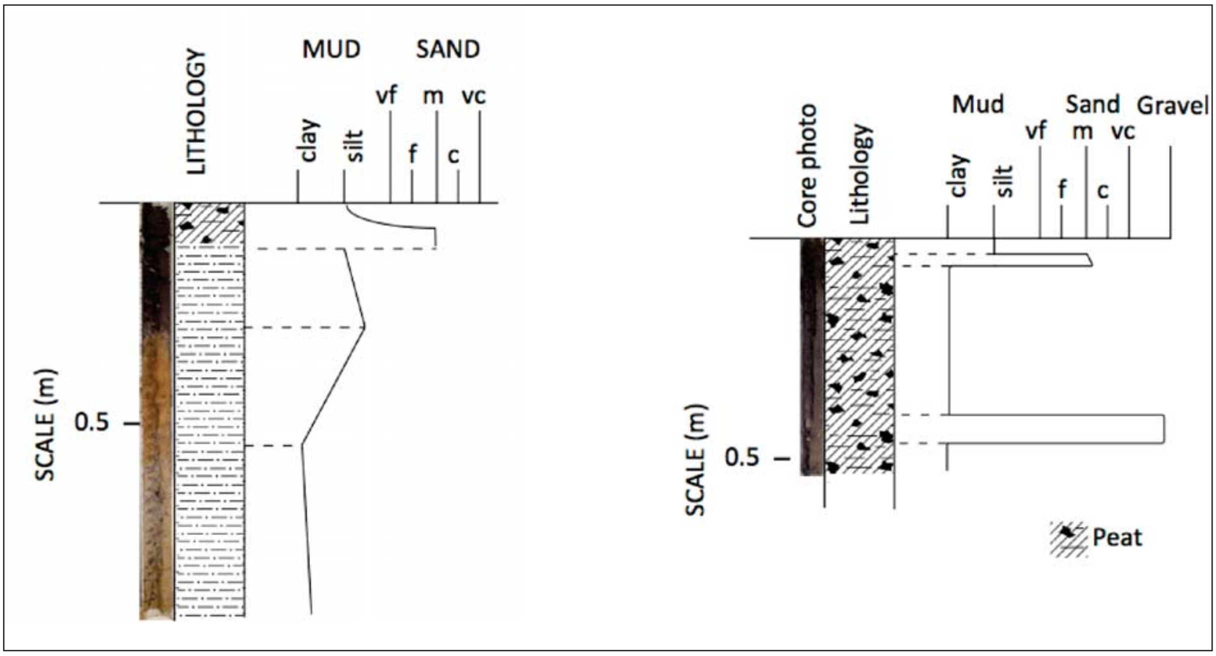
Macroscopic charcoal is significant as it provides insight into historical fire regimes through the quantity and type of charcoal fragments preserved (Mooney and Tinner, 2010). Samples of 1cm³ were recovered. To prepare samples for charcoal analysis material was sieved through a 250µm sieve to remove fine particulate matter. After sieving, a 10% sodium pyrophosphate solution was applied to all samples to disaggregate clays. A 10% concentration of hydrogen peroxide was then added which left the charcoal as the sole unbleached component and therefore countable (Sclachter and Horn, 2008). The charcoal fragments were then counted under a dissecting microscope.

Results

Cores from Fern Springs are composed of organic rich/peaty clays, which have layers of dispersed gravel and sands (see Figure 3, page 81). This area is a spring, which directly feeds a tributary of the Calvert River, and as such it is likely to have been predominantly waterlogged in the recent past. The Fern Springs cores show small fragments of freshwater mollusc species throughout (likely *Velesunio angasi*). Cores from Jabiru Lagoon display clear variations in composition/lithology from organic rich peat at the top of the Jabiru Lagoon core to silty clays with dispersed sand nearer the base. Fragmentary organic matter is seen throughout.

At Jabiru Lagoon, Loss on Ignition (LOI) is high (above 20%) for the top 8 cm (Figure 4, page 82). Values are generally low below this depth (10% or less) but there is a major spike at 45 cm depth to 65%. This is a minor peak in LOI between 16-17 cm. For macro-charcoal the top of the core has many values greater than 60 particles. Charcoal counts are close to zero for much of the core but there are broad peaks between 2-7 cm with a maximum of about five particles, 8-9 cm with 20 particles and ten particles at 16-17 cm. There are spot peaks at 25, 28, 45 and 52 cm.

At Fern Springs LOI values are generally lower with all values below 10% with the exception of 5 cm where values reached 16% (Figure 4, page 82). The samples were re-run and reliability between the two runs is high except that the 16% peak disappeared. Overall LOI gradually declines from 8-9% at the top of the core to



Figures 3A and 3B present summary lithological information from Jabiru Lagoon and Fern Springs respectively. At Jabiru, the top of the core is highly organic but lower layers are more strongly oxidised. At Fern Springs organic levels are higher throughout and carbonates are present.

about 2 % at 32 cm and then gradually increases to above 4% at 47 cm. Charcoal values display three clear zones. From 0-10 cm charcoal values are variable but generally high with values up 112 particles per sample. From 11-39 cm values are typically zero with no sample higher than three particles. From 40-49 cm higher values occur ranging from 11 -31 with a mean of about 31 particles per sample.

Discussion

Macroscopic charcoal is an indicator of local fires and is now widely preferred to microscopic charcoal for paleoenvironmental work as it is believed to be less easily transported and reworked (Lynch et al., 2004). For macroscopic charcoal to be recorded at a site requires fire to penetrate the site or at least very close to the site. The presence of charcoal indicates burnt vegetation. Our sites are semi-permanent lakes or springs and therefore there are several ways to interpret the charcoal data:

- If the water body is permanent it might be expected that fire cannot penetrate the lake/spring. In this case the highest charcoal values will be associated with periods when the lake or spring dries out. If the lake or spring dries out then the expectation is that the LOI would reduce (as organic matter was either not deposited or unlikely to be preserved) and that the Troels-Smith analyses would indicate largely inorganic sediments during periods of macroscopic charcoal peaks.
- An alternative model is that for fire to penetrate the site there must be enough vegetation to actually burn. Under this model periods that are continuously dry might be expected to have low charcoal, periods that are continuously wet might also have low charcoal and periods of high variability would have the highest charcoal values. This is because wet years provide the biomass to burn, while the dry years give the best opportunity for burns to occur. Under this model periods of high charcoal might be associated with relatively high LOI and the presence of organics in the Troels-Smith analyses as the fires coincide with high vegetation cover.

The models are not mutually exclusive and may apply differently at different sites. Examining the Fern Springs site it is apparent that the zones of highest charcoal, at the top and the bottom of the record, coincide with phases of higher organic sedimentation as reflected through both the Troels-Smith and LOI data. These results indicate that the most likely model is that there are periods of greater variability in the recent past and the oldest part of the record. The intermediate zone is characterised by almost pure inorganic silts. We conclude that at Fern Springs we are recording a change from wet conditions at

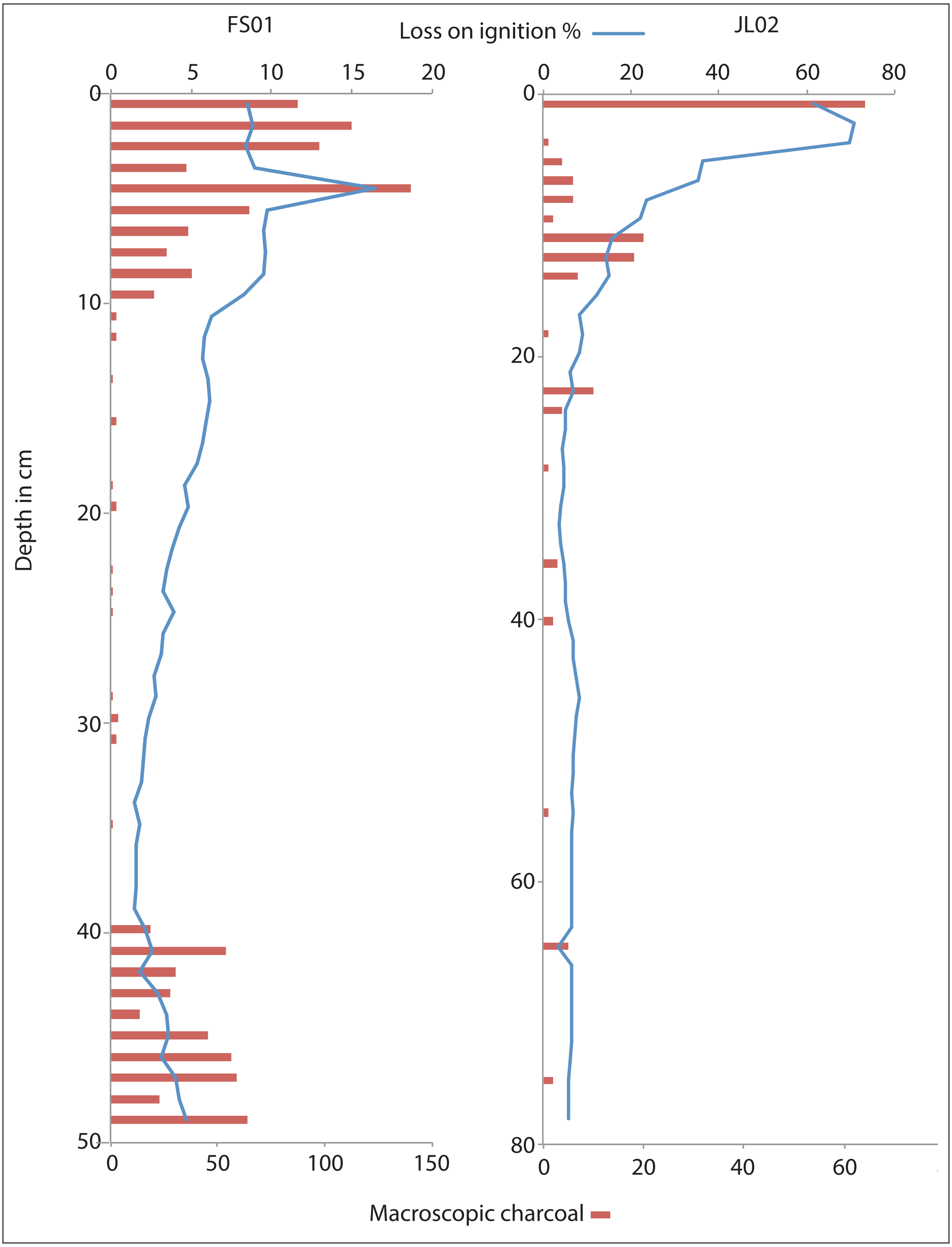


Figure 4a and Figure 4b Macroscopic Charcoal counts and LOI data for a) Fern Springs and b) Jabiru Lagoon. Note the three clear zones at Fern Springs with high charcoal and higher organic contents at the top and bottom, whereas Jabiru Lagoon has high values at the top only and spot events further down the core.

the base through a drier phase when the springs did not operate at modern levels. The top of the core coincides with a wet phase which is quite apparent at the present time. This implies that either:

- there has been an alternating of climate from wet-dry and back to wet again during deposition or
- that the position of the spring is changing.

The latter can probably be discounted as the spring-line is at the base of a low hill and there is no obvious reason why the position of the spring would change. We believe that we have identified a change in the local hydrology driven by changes in the monsoon.

As noted earlier, Jabiru Lagoon is part of the same drainage system as Fern Springs and they are likely to be connected during the wet season. Jabiru Lagoon and the adjacent billabong, Lake Crocodylus though currently perennial have dried out in recent times. Lake Crocodylus was dry in 1999 (Zaar, 2009). Unlike Fern Springs where it is reasonable to expect that the site was permanently a swamp, it is likely that Jabiru Lagoon has alternated between a semi-permanent lake, a seasonal swamp and a dry depression. LOI and charcoal in the top 12 cm is very similar to Fern Springs suggesting that they have both had similar recent histories. Below this level however, there are fewer indications of either high charcoal or organic sedimentation at Jabiru Lagoon with only two events that might be considered as high charcoal episodes (from 16-17 cm and 53 cm). Again, however, there is a positive relationship between the LOI, Troels-Smith descriptions and charcoal, indicating that the periods of greatest charcoal production are not periods of absolute drought but rather periods of variability.

Human impacts

Aboriginals have been active in northern Australia for an extended period, at least 50,000 years (Turney et al., 2001) and possibly much longer. During that time climate along the Gulf coast has varied dramatically and the Australian Monsoon has waxed and waned. There is very little evidence for the length of human occupation of the Barkly Tableland but it is quite likely that it has been continuous throughout the period. Aboriginal impacts on Australian ecosystems are profound but of such long standing that they are not easy to unravel. In general, however, there is widespread evidence for intensification of aboriginal occupation in the late Holocene in many parts of Australia including the tropical north. In contrast the effect of European settlement is well known and easily dated. At Pungalina the station was developed some decades ago and remained in commercial use until taken over by the AWC in 2009. The primary aim of the original station's owners was to develop grazing lands for cattle. Fire was a principal tool and the fire regime at Pungalina almost certainly increased substantially after the station was set up. What is not clear from our data set is whether we can distinguish two phases of fire activity. It is tempting to ascribe the single high peak at the top of the Jabiru record to European burning. The impact of aboriginal intensification is uncertain but because the high fire regime period at the top of both records (top 10 cm) coincides with higher organic content in the sediment and aboriginal burning in the main is cautious and very early season (e.g. Yibarbuk et al., 2001) it is highly unlikely that the overall high fire period at the tops of the record is simply a human artefact.

Conclusions

There is an excellent record of environmental change recorded from the lake and spring sites on the Pungalina property. The pilot work presented here demonstrates that significant changes in fire frequency have occurred around the lakes and springs. These are likely related to both changes in human usage and the reliability of the Australian monsoon. Recent grant success means that we will now be able to undertake radiocarbon dating and to geochemically analyse the cores. We expect to be able to produce a high quality record of late Holocene climate change from these sites.

Acknowledgements

We thank the RGSQ and in particular the team that organised and operated the field camps at Pungalina for outstanding support during and after our fieldwork. Special thanks to the OBs who retrieved the core we left stuck in Jabiru Lagoon and to Bruce, Kevin and the boys who towed our broken down vehicle to the track head so it could be carted back to Mt Isa and to Brian who drove us many hours to Doomadgee to catch a plane out. It was a lot of fun. We also thank the AWS (John Kanowski and Herman and Sharyn, the station managers) for allowing us permission to do this work and lots of help and advice.

References

Baker, B., Price, O., Woinarski, J., Gold, S., Connors, G., Fisher, A., and Hempel, C. 2005. *Northern Territory Bioregions - assessment of key biodiversity values and threats*. Darwin: Northern Territory Department of Natural Resources, Environment and the Arts.

Bastin G and the ACRIS Management Committee, 2008. *Rangelands 2008 — Taking the Pulse. Bioregion Appendix: Gulf Coastal*. National Land and Water Resources Audit, Canberra

Bowman, D. M. J. S., Nelson, G., Brown, J.R., Braby, M.F. Brown, G.K. Ladiges, P.Y., McBride, J., Joseph, L., Isagi, Y., Hughes, J., Haberle, S., Ford, F., Crisp, M.D. and Cook, L.G. 2010. Biogeography of the Australian Monsoon Tropics. Journal of Biogeography 37: 201-216.

Hesse, P.P., Magee, J.W., and van derKaars, S. 2004. Late Quaternary climates of the Australian arid zone: a review. Quaternary International 118/119:87-102.

Lynch, J. A., Clark, J.S. and Stocks, B.J. 2004. Charcoal production, dispersal, and deposition from the Fort Providence experimental fire: interpreting fire regimes from charcoal records in boreal forests. Canadian Journal of Forest Research 34: 1642-1656.

Mooney, S. D. and W. Tinner. 2010. The analysis of charcoal in peat and organic sediments. Mires and Peat 7, article 9:1-18.

Rawlings, D.J. 2002. Robinson River SE 53-4 1:1250 000 Geological Series. Edition 2. Northern Territory Geological Survey.

Rowe, C. 2008. Holocene vegetation on Mua. Memoirs of the Queensland, Cultural Heritage Series 4: 469-480

Reeves, J.M., Chivas, A.R., Garcia, A., Holt, S., Couapel, M., Jones, B.G., Cendon, D. and Fink, D. 2008. The sedimentary record of paleoenvironments and sea-level change in the Gulf of Carpentaria, Australia, through the last glacial cycle. Quaternary International 183: 3-22.

Shiau, L-J., Chen, M-T., Clemens, S.C., Huh, C-A., Yamamoto, M., and Yokoyama, Y. 2011. Warm pool hydrological and terrestrial variability near southern Papua New Guinea over the past 50k. Geophysical Research Letters., 38, L00F01, doi:10.1029/21010GL045309.

Shulmeister, J. 1992. A Holocene Pollen Record from Lowland Tropical Australia. The Holocene 2,2:107-116.

Shulmeister, J. 1999. Australasian evidence for mid-Holocene climate change implies precessional control of Walker Circulation in the Pacific. Quaternary International 57/58:81-91.

Shulmeister, J. and B.G. Lees. 1995. Pollen evidence from tropical Australia for the onset of an ENSO dominated climate at circa 4000 BP. The Holocene, 5:10-18.

Tickell, S. 2008. Explanatory notes to the Groundwater Map of the Northern Territory. Northern Territory Government Department of Natural Resources the Environment The Arts and Sport, Technical Report No. 12/2008D

Turney, C. S. M., Bird, M.I., Fifield, L.K., Roberts, R.G., Smith, M., Dortch, C.E., Grun, R., Lawson, E., Ayliffe, L.K., Miller, G.H., Dortch J. and R. G. Cresswell 2001. Early human occupation at Devil's Lair, southwestern Australia 50,000 years ago Quaternary Research 55: 3-13.

Woinarski, J. C. Z., John Woinarski, Larelle McMillan, and Barry Traill. *The Nature of Northern Australia: natural values, ecological processes and future prospects*. Canberra: ANU E Press, 2007.

Yibarbuk, D., Whitehead, P.J., Russell-Smith, J., Jackson, D., Godjuwa, C., Fisher, A., Cooke, P., Choquenot, D., Bowman, D.M.J.S. 2001. Fire ecology and Aboriginal land management in central Arnhem Land, northern australia: A tradition of ecosystem management. Journal of Biogeography 28:325-343.

Zaar, U. 2009. Gulf water study : Robinson and Calvert Rivers Region. Darwin: Department of Natural Resources, Environment the Arts and Sport

Assemblage Pattern in the Vertebrate Fauna of Pungalina-Seven Emu Reserve, Northern Territory

Eric Vanderduys*, Genevieve Perkins, Justin Perry, Anders Zimny
(*Corresponding author)

All authors: CSIRO Land and Water, ATSIP PMB PO, Aitkenvale, Queensland, Australia 4814.

Abstract This report presents the results of a short vertebrate fauna survey conducted at Pungalina–Seven Emu Wildlife Sanctuary, in the Gulf Plains, Northern Territory. We investigated the pattern in the fauna assemblage, using data collected from 15 standardised trapping quadrats across a range of available coastal and near-coastal vegetation types and landforms. Sites were established and surveyed over a 4 night/5 day interval in June-July 2012. Standardised sampling included Elliott, cage, pitfall and funnel trapping, repeated bird counts and timed active searches (diurnal and nocturnal). Basic structural and habitat variables were also recorded for each site. A total of 1008 records representing 127 species of vertebrate fauna was recorded using standardised sampling techniques. These comprised nine mammal species, 85 birds, 25 reptiles and eight amphibians. An additional 36 species were recorded during incidental searches. Two undescribed species of reptile were recorded. Statistical analysis of these multivariate data using analysis of similarity indicated that landform most significantly categorised the differences in composition between the sites (R=0.86). One habitat type had reduced vertebrate abundance, richness and diversity when compared to similar habitats occupying a similar climatic zone on Cape York Peninsula.

Introduction

The Gulf Plains bioregion that straddles the coastal border between the Northern Territory and Queensland remains a poorly surveyed part of Australia. Generally low-lying topography and strongly seasonal rainfall patterns mean access is difficult for much of the year. The tyranny of distance further exacerbates this effect. To some extent areas of the "Top End" of the Northern Territory, to the west of the Gulf Plains have been surveyed well for vertebrates (Friend and Taylor 1985; Woinarski *et al.* 1999; Woinarski *et al.* 2001), while areas to the east, on western Cape York Peninsula are less well surveyed, but work is ongoing (Kutt *et al.* 2011; CSIRO unpubl. data). Surveys within the Gulf Plains themselves are limited and there are few published surveys in the scientific literature, though there are numerous reports in the grey literature (e.g. Kutt *et al.* 2009a; Preece 2009) and three specific reports on vertebrate fauna of Pungalina–Seven Emu conducted by Australian Wildlife Conservancy staff (Kanowski *et al.* 2009, 2010, 2011). The results of the survey documented here provide an excellent opportunity to begin to compare fauna patterns across broad areas of the Australian Tropical Savannas, which has rarely occurred before except in a general sense (Woinarski *et al.* 2005).

The Gulf Plains is a region where relatively arid conditions of the Australian inland bioregions approach the coast, because of the southern extent of the Gulf of Carpentaria. This means that arid-adapted species often reach closer to the coast than in most other regions, while mesic-adapted species often reach the end of their known range in this region, or have disjunctions or narrowing of their ranges through the Gulf Plains (range maps presented in field guides provide a good general overview of this; Menkhorst and Knight 2011; Pizzey and Knight 1997; Slater *et al.* 2003; Vanderduys 2012; Wilson 2005; Wilson and Swan 2013). This makes for a mix of Timorien, Torresian and Eyrean influences (Horton 1973) which is unique in Australia.

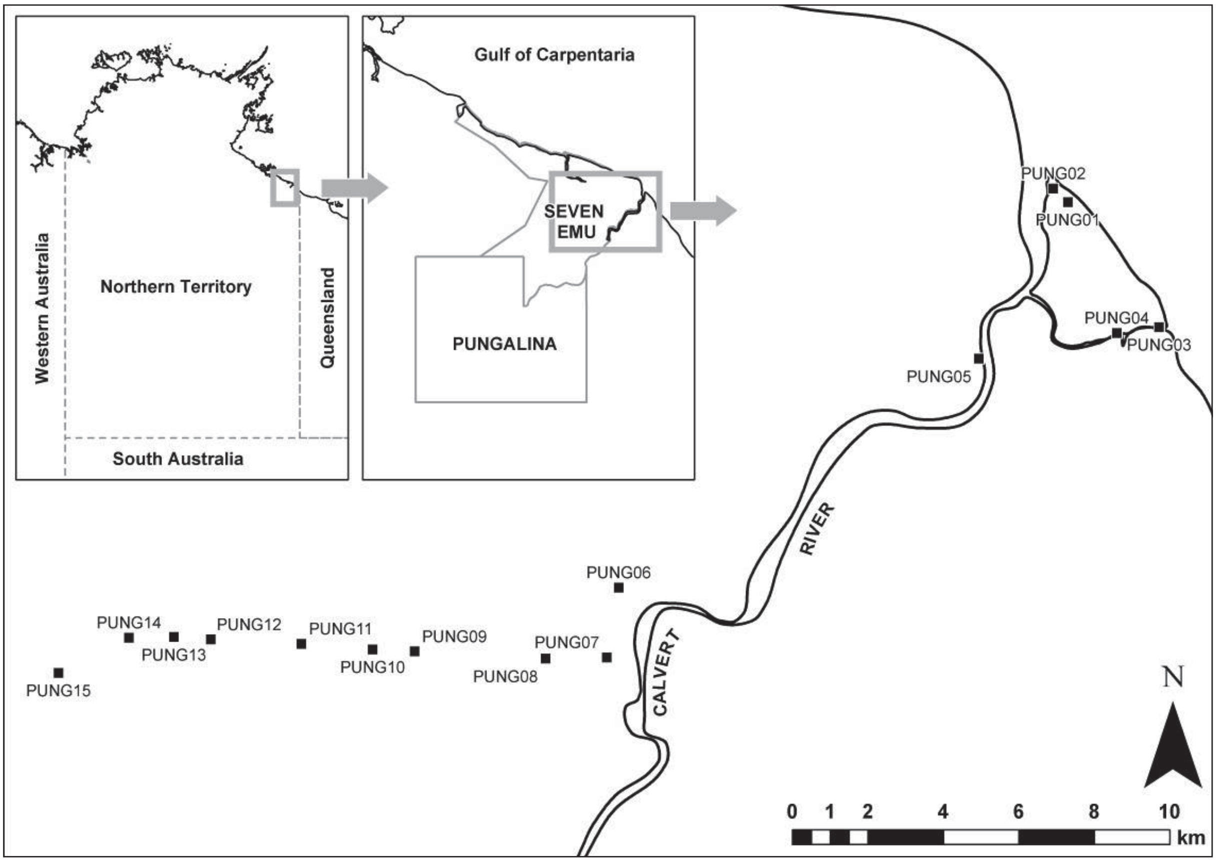


Figure 1. Location of vertebrate fauna sampling sites at Pungalina–Seven Emu.

Methods

Study location

Pungalina–Seven Emu is a private conservation reserve owned by the Australian Wildlife Conservancy situated in the Gulf Plains bioregion adjacent to the Gulf of Carpentaria, Northern Territory. The reserve is made up of two pastoral leases, Pungalina and part of Seven Emu, and is within the rectangle 16° 2' to 16º 50' S; 137º 7' to 137º 44' E. Prior to Australian Wildlife Conservancy's interest, low intensity cattle grazing was the primary enterprise on both Pungalina and Seven Emu stations. We use the general term Pungalina hereafter to refer to the combined-property reserve. Pungalina covers 306,000 ha and is located within the Gulf Coast Bioregion of the Northern Territory (Figure 1, page 86). Our survey was conducted on the eastern side of Seven Emu, primarily in *Eucalyptus* woodlands and coastal dune vine scrub. Pungalina has numerous habitat types within the reserve boundaries. Further information can be found at:

http://www.australianwildlife.org/Pungalina/Property-Profile.aspx
Hyperlink

Study sites and sampling

A systematic vertebrate fauna survey was conducted from 29 June – 03 July 2012. Fifteen standardised sites (Figure 1, page 86) were established and surveyed over a 4 night/5 day interval. Sites were located in a variety of habitat types (Appendix 1, starting page 99) with the majority in *Eucalyptus tetrodonta* dominated forest. Sites were surveyed using a standard protocol for surveying vertebrates in northern Australia (Vanderduys *et al.* 2011). This incorporates four pitfall traps arranged in a 'T' configuration (20 and 10 m of drift fence), six funnel traps, 20 small Elliott traps and two cage traps placed in a 50 x 50 m square. All Elliott and cage traps were baited with a mix of peanut butter, oats and honey and every second Elliott trap and all cage traps had dry dog food added. All traps were checked early morning, around midday and in the afternoon.

In addition to the trapping, standard searches and observations were undertaken. Eight 10-minute bird counts were conducted within a hectare centred on the Elliott trap array. Timing of bird counts was rotated to reduce early morning (i.e. favourable condition) bias. Three active searches were conducted at each site, generally

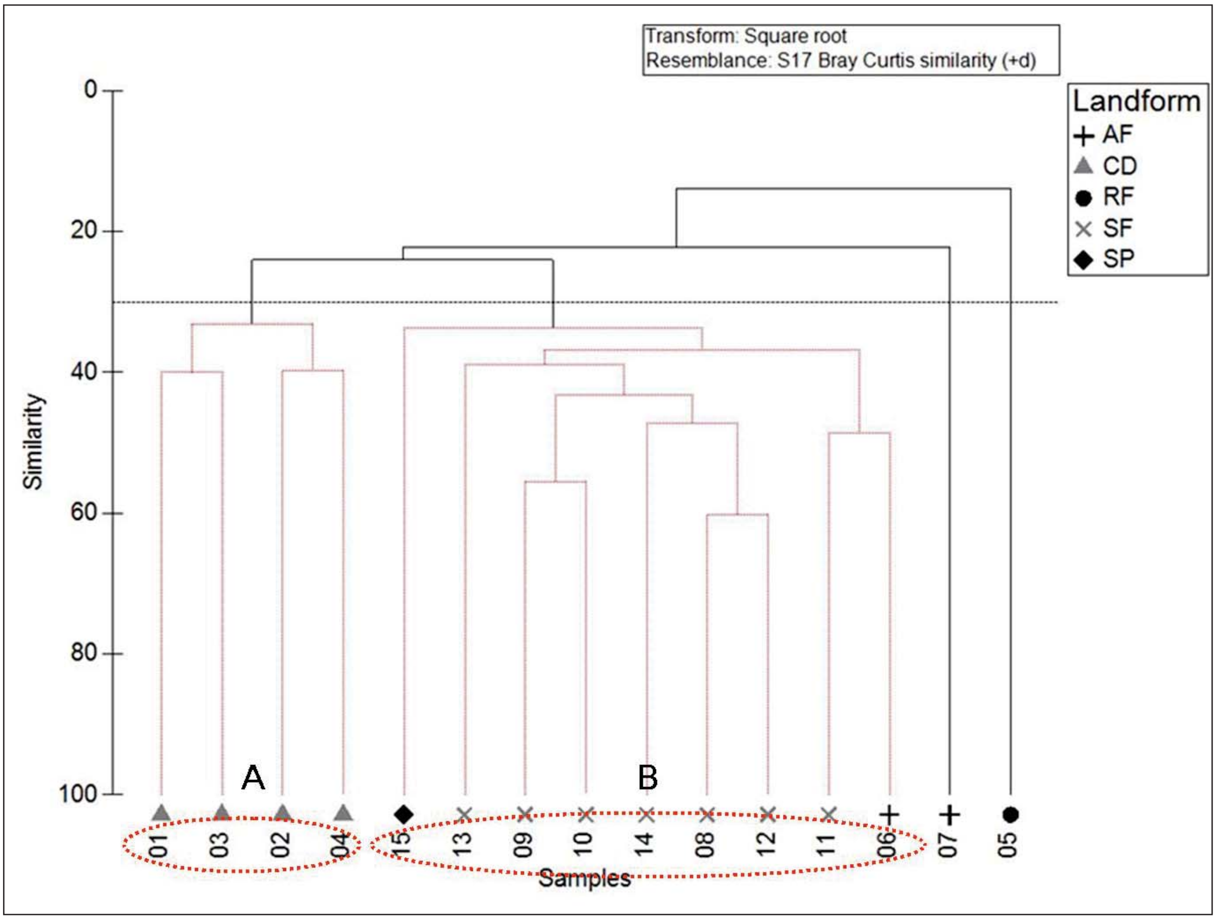


Figure 2. Cluster diagram of sites by landform. Sites joined below dashed horizontal line at 30% similarity are significant clusters A and B (in red, dashed ovals) that are further described in Table 1. Black lines are not significant. Landform codes are AF = alluvial flat, CD = coastal dune, FL = flat, RF = riparian flat, SF = sand flat, SP = sandstone pavement.

one in the morning, one around midday, and one in the afternoon. Active searches involved 20 person-minutes turning logs, rocks, raking leaf litter and grass cover, peeling bark and shuffling through undergrowth and spinifex hummocks. Two night-time spotlight searches, each of 20 person-minutes, were conducted at each site. All searches were restricted to the same hectare as for the bird counts.

Habitat variables were measured following a simplified version of the methods outlined in Eyre *et al*. (2006) and Neldner *et al.* (2005), and sampled along a 100 m line running through the centre of the survey hectare. Ground cover percentage of six variables was visually estimated using 5 x 1 m² quadrats placed at the 25, 35, 45, 55 and 65 m marks of the line. The ground cover variables assessed were litter, native perennial tussock grasses, hummock grasses (spinifex, e.g. *Triodia pungens*), native annual plants, bare ground and rock. Other categories used by Eyre *et al*. (2006) and Neldner *et al.* (2005) were not present at our survey sites. Average height for three tree layers (canopy, secondary and regrowth), the shrub layer and ground cover were measured along the central 100 m line. Percentage projected cover for three tree and one shrub layer were also measured along this line. Estimates of Dry Matter Yield (DMY: kg/ha) for each site were made independently by two experienced observers with reference to photo standards presented in Karfs *et al*. (2009), and the average value calculated for each site. While recognising that the photo standards provided in Karfs *et al.* (2009) are for a different region of Australia, they provide a useful reference point for comparison to create a DMY index.

Fire frequency over the preceding 13 years and time since last fire for each site were derived remotely from MODIS satellite imagery. The thirteen year time period for fire scars was used because standardised 250 m resolution month-by-month fire scar imagery became available in 2000 (NAFI 2013). Sites were assigned an *Atlas of Australian Soils Classification* (Northcote *et al.* 1960-1968) as well as a field vegetation and landform classification (Appendix 1, starting page 99).

Our survey produced large multivariate datasets and therefore we chose to analyse the data using the PRIMER 6.0 software package (Plymouth Marine Laboratory) which is designed to carry out non-parametric analyses on multivariate data. Analysis of similarity (ANOSIM) was undertaken to assess the efficacy of different site characteristics to distinguish fauna composition (Clarke and Gorley 2006a). ANOSIM statistically compares pair-wise R values, to measure similarity between groups. R is distributed around zero with zero indicating completely random grouping, while the higher the value for R the greater the separation of replicates between groups (Clarke and Gorley 2006b). Site characteristics included 11 environmental variables listed in the BIOENV sections (below), landform, soil classification (Northcote *et al.* 1960-1968) and field vegetation classification. Continuous environmental variables were categorised into five equal categories for the purposes of the ANOSIM. To test the effect of landscape features on fauna assemblage we assessed the composition of all fauna species and all classes separately. We subsequently analysed birds separately to the combined group of reptiles + amphibian + mammals (RAM) after individual analysis for the latter three classes showed a low level of resolution between sites because of many zero counts (Kutt *et al.* 2009b). No further analysis was conducted on each of these classes individually.

We investigated the species assemblage patterns in the sites using non-metric multi-dimensional scaling (nMDS) in Primer (Clarke and Gorley 2006a). In doing so we examined hierarchical clustering (Clarke and Warwick 2001) based on assemblage patterns derived from fourth root transformed and presence/absence transformed abundance data. We did this for all fauna, birds and RAM. We used a Bray-Curtis similarity matrix to examine how clusters of sites were arranged with respect to all environmental, habitat and remotely derived data retained after removing correlated variables (see below).

To test the significance of the clustering visible in the nMDS plots, we ran the Type 1 SIMPROF test in PRIMER (Clarke and Gorley 2006a), which informs whether clusters are significantly different from random. When we had determined significant clusters, we undertook ANOSIM to determine which species in our data set were driving the significant clustering. We did this for all fauna, birds, and RAM.

We examined the correlations between all environmental variables using draftsmen plots, to define a subset of uncorrelated factors. We used a cut-off correlation of score 0.6 (+ or -) leaving us with 11 environmental variables in our analysis hummock grass %, annual grasses, herbs and forbs %, bare ground % (which did not include rock), projected cover of the second and third canopy layers (T2 % and T3 %), projected cover of the shrub layer (SH %), average height of the canopy (T1 ht), shrub (SH ht) and ground layers (GR ht), dry matter yield estimate (DMY) and time since last fire (TSLF).

The relationship between the nMDS assemblage patterns and the 11 environmental variables (above) associated with those samples was also examined using the BIOENV routine in PRIMER (Clarke and Gorley 2006a). Using rank correlations and permutation tests, BIOENV compares the relationship between the environmental resemblance matrix (normalised and transformed data (Clarke and Gorley 2006b) and the species resemblance matrix. A search for all possible combinations is made, and the smallest subset of environmental variables that best "explains" the species data is reported (i.e. minimum set and Global R correlation).

Comparison with Cape York Peninsula

While undertaking fauna surveys, we noticed apparently low abundance and richness of vertebrates when compared with similar habitats on Cape York Peninsula (CYP). To check the validity of this perception, we used unpublished CYP site data from three separate surveys; Pormpuraaw (western CYP), Mungkan-Kandju National Park (northern CYP) and Strathburn Station (central CYP). These three areas of CYP share similar total rainfall and temperature patterns with Pungalina although Pungalina is generally drier and has greater temperature seasonality (Bureau of Meteorology 2013). All surveys were conducted by the same staff, using the same methodology and at a similar time of year (May–July) to the Pungalina survey. Only CYP sites designated as *Eucalyptus tetrodonta* woodlands and forests on sand that were structurally similar to our Pungalina *Eucalyptus tetrodonta* woodland sites were compared.

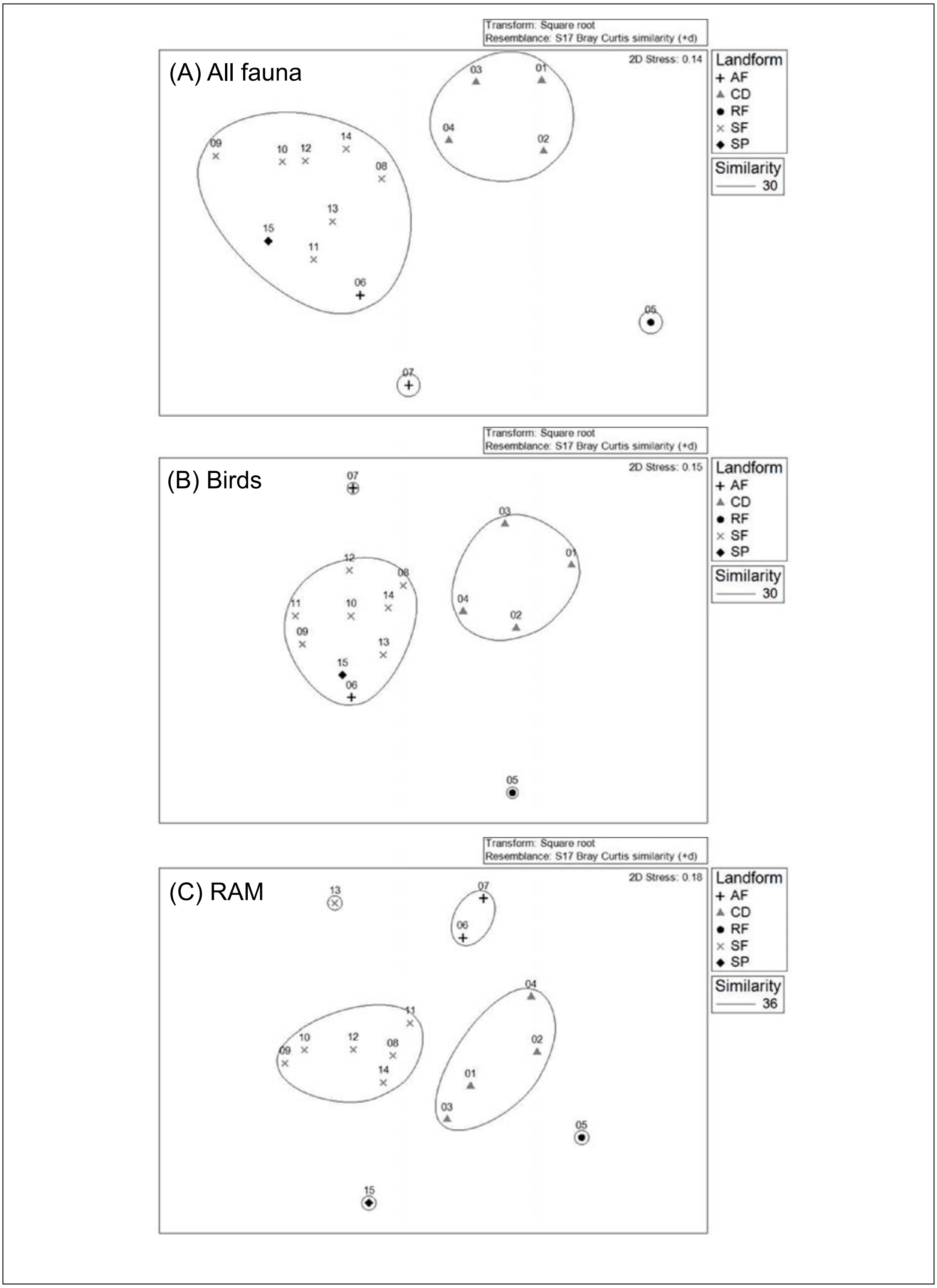


Figure 3. nMDS plots of vertebrate composition of the standardised sampling sites (01-15) designated by landform. Landform codes are; AF = alluvial flat, CD = coastal dune, RF = riparian flat, SF = sand flat, SP = sandstone platform. Bubbles show significantly clustered groups derived from SIMPROF test.

We used a t test to determine whether significant differences existed in the average richness, abundance and diversity (see below) of Pungalina *Eucalyptus tetrodonta* sites (n = 3) and CYP sites (n = 21).

Because we tested a small set of sites from this survey and the CYP surveys, we tested all vertebrates and did not test for birds or RAM separately.

For diversity comparison between Pungalina and CYP we used the Shannon-Weiner diversity index for all fauna and took the mean for each respective survey. Because the Shannon-Weiner diversity index is non-linear, we created an "effective number of species" (Jost 2006), to more accurately reflect diversity for each site, using the exponential of each site's Shannon-Weiner index. Again these values were averaged across respective surveys.

Results

Species

A total of 1008 records representing 127 species of vertebrate fauna was recorded using standardised sampling techniques. These comprised nine mammal species, 85 birds, 25 reptiles and eight amphibians. An additional three mammal, 18 bird, 14 reptile and one amphibian were recorded as incidental records (Appendix 2, starting page 103).

The most abundant species recorded for each class were:

- mammals: *Macropus agilis* (four), *Planigale maculata*, *Pseudomys nanus*, *Sus scrofa* and *Felis catus* (two of each);
- birds: brown honeyeater (51), white-throated honeyeater and mistletoebird (48), striated pardalote (42), Australasian figbird (35);
- reptiles: *Carlia amax* (74), *Oedura rhombifer* (24), *Cryptoblepharus pannosus* (19), *Diporiphora bilineata* (17), *Gehyra dubia* (11);
- amphibians: *Rhinella marina* (31), *Uperoleia lithomoda* (23), *Litoria bicolor* (15), *Litoria caerulea* (three), *Limnodynastes convexiusculus* (two).

The most frequently recorded species in each vertebrate class, that is, the most ubiquitous species, were:

- mammals: *Macropus agilis* (four), *Sus scrofa*, *Felis catus* and *Pteropus scapulatus* (two sites each), and several species recorded at just one site each;
- birds: brown honeyeater (13), white-throated honeyeater, mistletoebird and striated pardalote (11 sites each), weebill and peaceful dove (10 sites each);
- reptiles: *Carlia amax* (11), *Diporiphora bilineata* (11), *Cryptoblepharus pannosus* (10), *Heteronotia binoei* (nine), *Oedura rhombifer* (eight);
- amphibians: *Rhinella marina*, *Litoria bicolor*, *Limnodynastes convexiusculus*, and several species recorded at just one site each.

Introduced species featured strongly in the mammal and amphibian fauna, with four mammals and one amphibian (the cane toad, *Rhinella marina*) recorded, though of the mammals only *Felis catus* and *Sus scrofa* were recorded during systematic surveys. The cane toad was the most numerous and most ubiquitous amphibian recorded.

Only one threatened species, the sandstone antechinus, *Pseudantechinus mimulus*, was recorded (one record, site 15). This species is listed as near-threatened under Northern Territory legislation and vulnerable under Commonwealth legislation. Two undescribed taxa (*Ctenotus* and *Lerista*) and one uncertain species (*Delma* sp.) were recorded, with one record of each. More information on these is presented in the discussion.

Species composition

Our fourth root transformed site fauna data significantly clustered sites by landform. Furthermore, only landform returned a sensible grouping of sites in the nMDS plot, and there were few outliers (Figure 2, page 87, and Figure 3, page 89). For all vertebrates there are only two sites that group unexpectedly with respect to landform, an alluvial flat and the sandstone platform site that group in with the sand flat sites (Figure 3 (A), page 89). This pattern held fairly strongly when birds were considered separately (Figure 3 (B), page 89). The RAM nMDS plot had only one outlier with respect to landform, a sand flat site that fell away from the remaining sand flat sites (Figure 3 (C), page 89). Outliers were Site 07 (alluvial flat) which fell away from the only other alluvial flat site (06), which itself clustered significantly with the seven sand flat sites and the only sandstone pavement site.

When all fauna were considered, generally the presence/absence transformed fauna assemblage data resulted in lower resolution of groupings by any of the habitat or environment measures we used. However, different landforms tended to cluster significantly together, as

Table 1. Species defining 80% of the similarity within each of the significant clusters A and B.

Species	Average abundance	% contribution to similarity
Coastal dunes (Cluster A)		
Mistletoebird	2.50	18.94
Red-headed honeyeater	1.39	10.60
Cryptoblepharus pannosus	1.21	9.22
Carlia amax	1.37	7.98
Rhinella marina	1.95	6.29
White-gaped honeyeater	1.14	5.33
Black-faced cuckoo-shrike	1.04	5.10
Amphibolurus gilberti	1.00	4.43
Lerista orientalis	0.93	4.43
Heteronotia binoei	0.75	3.77
Macropus agilis	0.75	3.77
Sand flats, one alluvial flat, sandstone (Cluster B)		
Carlia amax	2.40	15.61
White-throated honeyeater	2.05	14.75
Striated pardalote	2.02	14.28
Weebill	1.68	12.01
Diporiphora bilineata	1.04	5.88
Brown honeyeater	1.55	4.97
Oedura rhombifer	1.13	4.68
Rufous whistler	0.96	4.56
Peaceful dove	0.92	3.22
Mistletoebird	1.07	2.88

with fourth root transformed data, and time since last fire had one category (unburnt for 13 years), which grouped significantly apart from all others. When just birds, and RAM were considered separately, there was less consistent clustering by any environmental or habitat variables than for fourth root transformed data. Thus, we did not use them further in our analysis.

The most abundant species for the two significant clusters (Table 1, page 91) and the two ungrouped sites according to nMDS are listed below:

- Cluster A:
  - mammals: *Macropus agilis*, *Sus scrofa* and *Felis catus*;
  - birds: Australasian figbird, mistletoebird, variegated fairy-wren, rufous whistler, brown honeyeater;
  - reptiles: *Carlia amax*, *Cryptoblepharus pannosus*, *Amphibolurus gilberti*, *Lerista orientalis*, *Heteronotia binoei*;
  - amphibians: *Rhinella marina*, *Litoria bicolor*, *Litoria caerulea*.
- Cluster B:
  - mammals: *Pteropus scapulatus*, *Pseudomys delicatulus, Pseudantechinus mimulus* and *Felis catus*;
  - birds: brown honeyeater, white-throated honeyeater, striated pardalote, weebill and mistletoebird;
  - reptiles: *Carlia amax*, *Oedura rhombifer*, *Diporiphora bilineata*, *Cryptoblepharus metallicus*, *Cryptoblepharus pannosus* and *Ctenotus spaldingi*;
  - amphibians: *Rhinella marina* with many records, and several native species with just one record.

Table 2. Correlations between environmental variables and species composition. ANOSIM testing three categorical site site variables (landform, soil and vegetation) against composition of all species, birds, and RAM. The BIOENV rows indicate the combined environmental factors with greatest correlation with the fauna composition. Data represent the Global R statistic. Figures in bold have the following significance values: *p<0.05, **p<0.01, ***p<0.001.

		All species	Birds	RAM
ANOSIM	Landform	**0.86****	**0.76*****	**0.7*****
	Soil class	0.27	0.27	0.18
	Vegetation	**0.62***	**0.48***	**0.68***
BIOENV	TSLF	**0.51****	**0.45****	**0.44*****
	Hummock %	0	0.12	0.32
	Annual %	0.31	0.3	0.21
	Bare %	0.14	0.09	0.26
	T2 %	0.29	0.25	0.17
	T3 %	0.22	0.15	0.24
	SH %	0.37	0.37	0.12
	T1 ht	**0.29***	0.18	**0.42***
	SH ht	0.19	0.23	0.03
	GR ht	0.31	0.1	0.19
	DMY	**0.39***	0.25	**0.5***

- Riparian flat (Site 05):
  - mammals: *Planigale maculata*, *Pseudomys nanus*;
  - birds: Golden-headed cisticola, red-backed fairy-wren, brolga, whistling kite, masked woodswallow;
  - reptiles: *Diporiphora bilineata* and *Heteronotia binoei*;
  - amphibians: *Rhinella marina*.
- Alluvial flat (Site 07):
  - mammals: *Macropus agilis*;
  - birds: white-winged triller, red-collared lorikeet, brown quail, white-breasted woodswallow, white-throated honeyeater;
  - reptiles: *Gehyra dubia*, *Cryptoblepharus pannosus*, *Carlia munda*, *Diporiphora bilineata*, *Cryptoblepharus metallicus*;
  - amphibians: *Limnodynastes convexiusculus*.

The ANOSIM tests showed that of the remotely derived categorical indicators, landform and vegetation were not random with respect to fauna assemblages (Table 2, page 92). Our measures of dry matter yield (DMY) and top-most canopy layer average height (T1 ht) were useful for categorising fauna assemblages, but random with respect to only the bird assemblage. Landform had the strongest relationship with all species (0.86), birds (0.76) and reptiles, amphibians and mammals (RAM) combined (0.7) (Table 2, page 92). Of the 11 numeric environmental factors tested for their correlation with fauna assemblage using BIOENV in PRIMER (nMDS, Figure 2, page 87), T ht, dry matter yield and time since last fire provide the best significant explanatory power for the observed fauna assemblage (P = 0.786).

Numerous environmental variables were strongly correlated. For example, the remote sensed fire frequency over 13 years correlated with dry matter yield (0.71), and, not surprisingly strongly negatively correlated with time since last fire (-0.80). We were hesitant to remove some of these variables from our analysis because they all seem intuitively to be important to fauna, especially ground dwelling species. However, these three particular variables are likely telling the same story: high dry matter yield enables a high fire frequency, and though fire consumes the dry matter, such habitats recover quickly to redevelop their ground cover. It is only if time since last fire is very low (usually since the last wet season) that such sites will have a low dry matter yield.

Comparison with Cape York Peninsula

Our comparison of Pungalina and CYP sites was based on perceived similarity between habitat and structural variables on sites in *Eucalyptus tetrodonta* forests. General patterns of

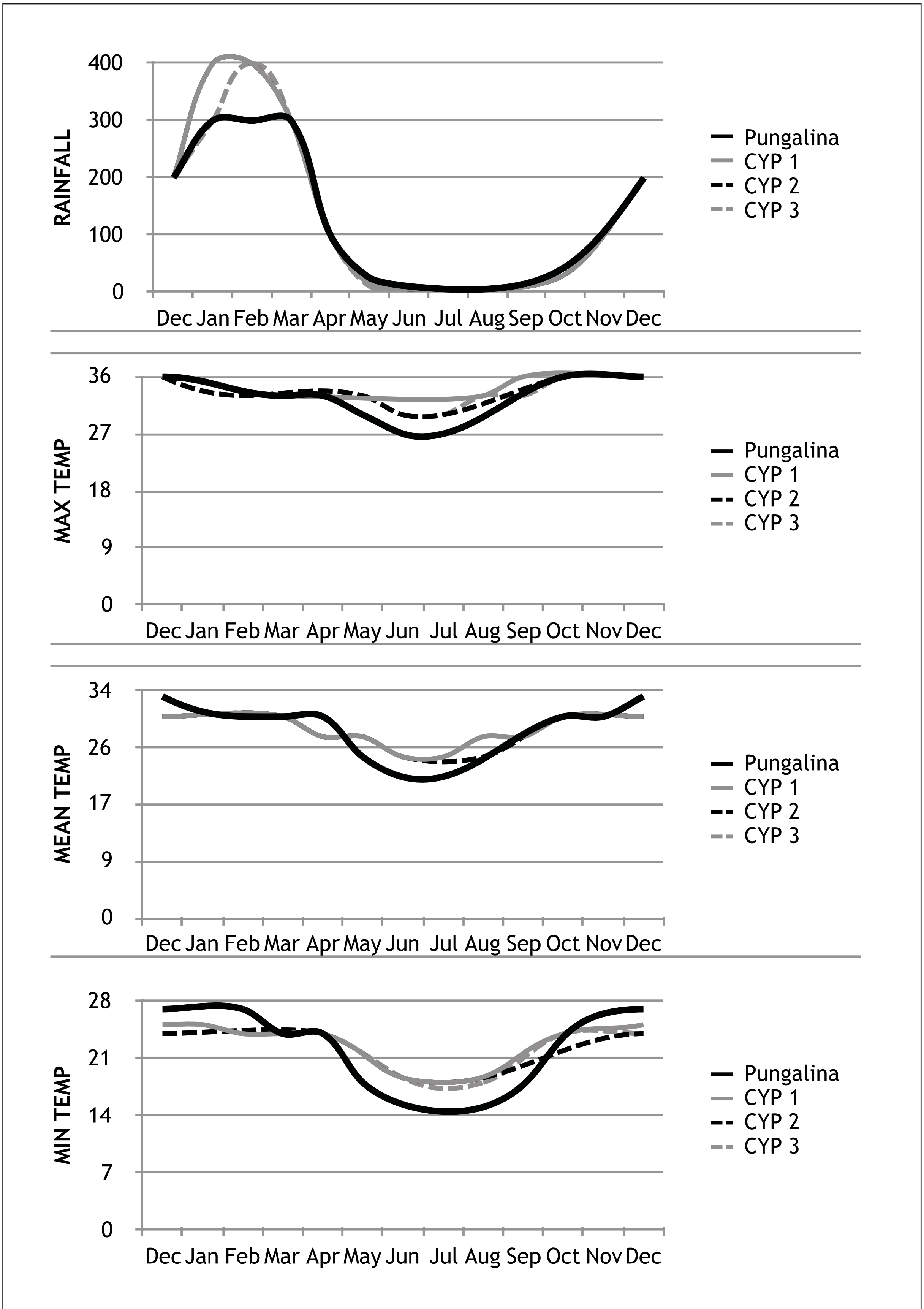


Figure 4. Graphs showing average 30 year monthly rainfall (mm) and temperature (°C) maxima, means and minima for Pungalina and CYP *Eucalyptus tetrodonta* sites.

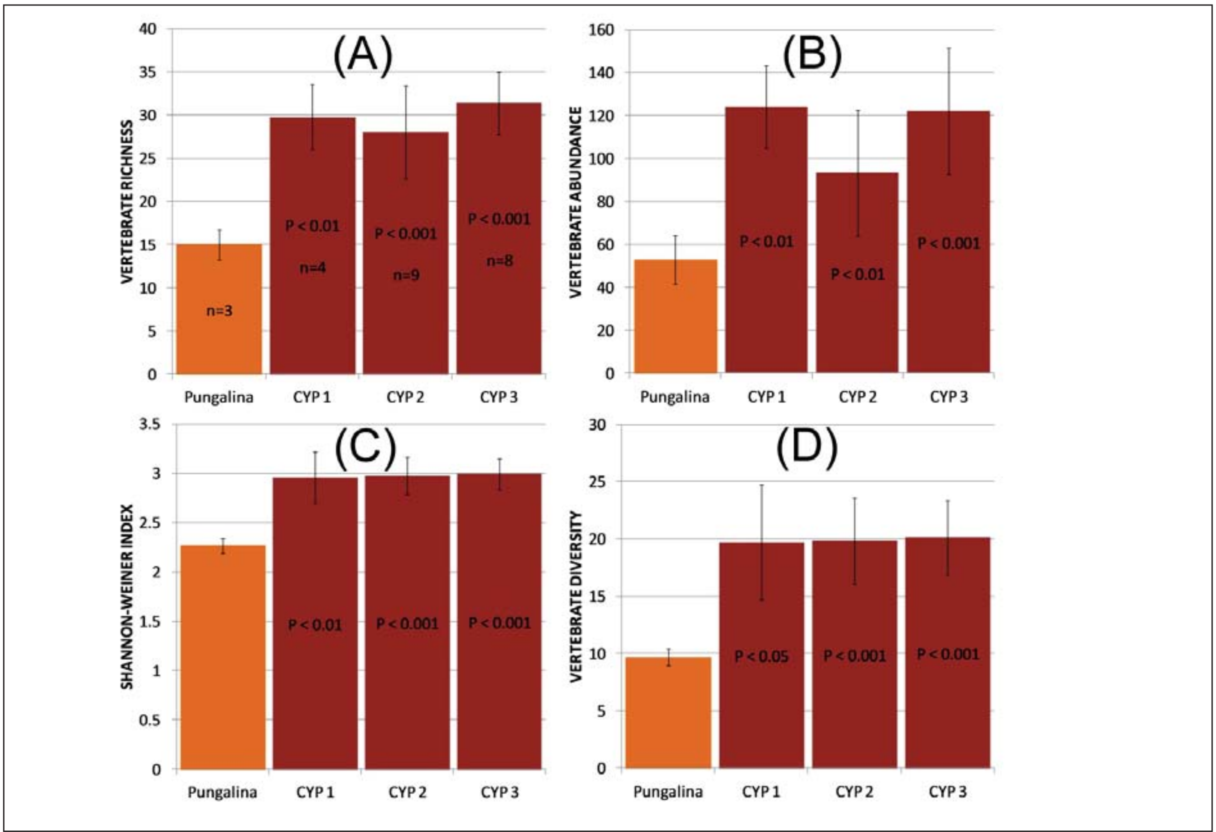


Figure 5. Histograms comparing all vertebrate richness (A), abundance (B), Shannon-Weiner index (C) and diversity (effective number of species (D)) of Pungalina *Eucalyptus tetrodonta* sites to Cape York Peninsula (CYP 13) sites. CYP sites are: 1. Pormpuraaw, 2. Mungkan Kandju NP, 3. Strathburn Station. Significance (P) using a t test of each CYP survey against the equivalent Pungalina values is presented. Number of sites (n) for each comparison is given in the first histogram.

temperature and rainfall were similar for both regions (Figure 4, page 93). Although the power of the Pungalina and Cape York Peninsula comparison was limited by the low numbers of comparable sites (less than ten per location), there were significant differences in richness, abundance, Shannon-Weiner index and diversity, with the three CYP locations greater than Pungalina (Figure 5, page 94). There were no statistically significant differences between CYP locations in any measures.

Discussion

Snapshot studies such as this are necessarily opaque windows into the fauna assemblages in an area. Stronger patterns emerge spatially and temporally with increasing survey effort and over longer time spans. Patterns may change seasonally or on yearly, decadal or even longer scales. However, because of the standardised methodology employed, studies such as this can help begin understanding differences between seemingly similar habitats in different regions (e.g. Gulf Plains versus Cape York Peninsula).

Vertebrate fauna assemblage patterns in this study were strongly linked to landform, and this has been demonstrated in our previous studies using the same methodology across different landscapes in northern Australia (e.g. Kutt *et al.* 2005, 2009b; Vanderduys *et al.* 2011, Vanderduys *et al.* 2013; CSIRO unpubl. data). Despite the very limited nature of this survey, our experience from extensive surveys elsewhere in the wet-dry tropics and savannas has shown that with greater surveying effort, resolution between fauna assemblages becomes increasingly visible (Vanderduys *et al.* 2013; CSIRO unpubl. data). For this reason, we suggest that further surveys in the differing habitats within Pungalina would serve to strengthen our understanding of fauna assemblage separation between those habitat types. Kanowski *et al.* (2009, 2010, 2011) have previously surveyed the terrestrial vertebrate fauna from a wider range of sites than we did and have qualitatively

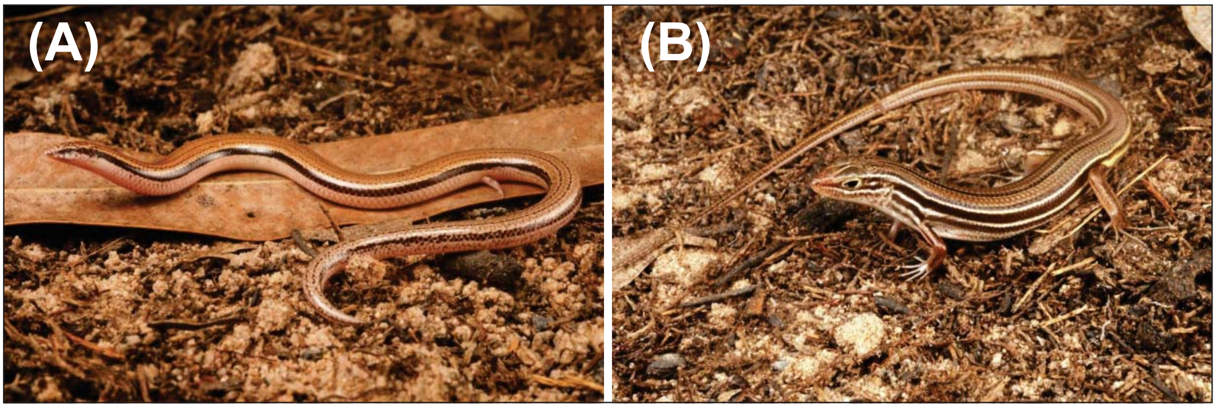


Figure 6. *Lerista* sp. (A) and *Ctenotus* sp. (B) captured in *Eucalyptus tetrodonta* woodland.

characterised the vertebrate fauna of five of the main habitats (primarily based on underlying geology) Similarly, further surveying would likely highlight the differences in assemblage patterns across broad regions (e.g. in comparison with CYP).

The fauna assemblages recorded on this survey were characterised by relatively low abundance, richness and diversity. This relative paucity partly contributes to the uniqueness of the assemblage, and when combined with species turnover across northern Australia, further emphasises the Gulf Plains' uniqueness and influences from three broad biogeographic regions (Timorien, Torresian and Eyrean; Horton 1973) add to this.

Despite this apparent paucity, significant species add further value and uniqueness to Pungalina–Seven Emu, particularly from a conservation perspective. For example, there are threatened species of limited range (*Pseudantechinus mimulus*); undescribed species (*Ctenotus* sp., *Lerista* sp.); undescribed species or species in unusual habitat associations (e.g. *Planigale* sp. associated with sandstone reported in Kanowski *et al.* 2011) and species near the geographic limits of their known ranges (e.g. *Crinia bilingua* (Vanderduys 2012), *Varanus baritji*, *Delma nasuta* (Wilson and Swan 2013), partridge pigeon (Pizzey and Knight 1997)). Thus, despite the reduced diversity recorded in one habitat type in this survey when compared to similar habitats on CYP, Gulf Plains habitats should be considered as unique and with their own character, rather than depauperate.

Our study recorded 11 of the 30 mammals (28 in 2011 list plus feral cats, *Felis catus* and cattle, *Bos* sp. discussed in reports) that have previous confirmed records on Pungalina, 95 of the 172 species of birds, 35 of the 70 reptiles, and eight of the 14 frogs (Kanowski *et al.* 2009, 2010, 2011). However, we recorded 13 species that had not previously been recorded despite extensive surveys by experienced AWC ecologists (Kanowski *et al.* 2009, 2010, 2011), suggesting that there may be many more species undetected on Pungalina. Previously undetected species that we recorded were: one mammal (water buffalo, *Bubalus bubalis*); eight birds (eastern reef egret, striated heron, eastern curlew, partridge pigeon, shining flycatcher, mangrove fantail, Australasian pipit, yellow white-eye); three reptiles *Delma nasuta* (probably, see below), *Ctenotus* sp., *Lerista* sp.) and one frog (*Crinia bilingua*).

The *Delma* sp. listed in Appendix 2, starting page 103 was of uncertain identity. It was identified on the basis of a large (length of almost-entire body portion approx. 100 mm) sloughed skin found in a *Triodia pungens* hummock growing over rock sandstone. The size and mid-body scale count (16) strongly suggest *Delma nasuta*, and there are no other described *Delma* sp. from the northeast Northern Territory that have these characteristics. Pungalina is on the very edge of the known range of *D. nasuta*. *Triodia* spp. hummock grasslands are preferred habitat for this *D. nasuta* (Wilson and Swan 2013; E. Vanderduys, CSIRO unpubl. data).

Two reptile species (*Lerista* sp. and *Ctenotus* sp.) captured and vouchered with the Museum and Art Gallery of the Northern Territory, warrant further discussion as they are almost certainly undescribed taxa. Requisition numbers and exact details of the morphology will not be disclosed because we fear so-called taxonomic vandalism (summarised in Kaiser *et al.* 2013), which is active in Australian herpetology. Nevertheless, some details are presented here to convince the reader of our assertion of their novel status.

Lerista sp. (Figure 6 (A), page 95) was captured in *Eucalyptus tetrodonta* forest on sandy soil. Superficially it resembles *L. carpentariae* in size (SVL 62 mm, TL 53 mm) and pattern. *Lerista carpentariae* occurs within about 90 km of Pungalina on the Sir Edward Pellew group of islands in the Gulf of Carpentaria and about 250 km west on the mainland (ALA 2013). However, scalation, nature of the limb reduction, and number of toes immediately exclude *L. carpentariae* as a diagnosis. No other Australian *Lerista* sp. matches the combination of characters on the specimen we collected.

Ctenotus sp. (Figure 6 (B), page 95) was captured in *Eucalyptus tetrodonta* forest on sandy soil. It resembles *C. piankai* in size (SVL 51 mm, TL 122 mm), most pattern and some scalation features, but differs significantly in some build, a few pattern features, and some scalation. *Ctenotus piankai* is also generally restricted to arid or semi-arid *Triodia* habitats (Kutt *et al.* 2009b; Wilson and Swan 2013; E. Vanderduys pers. obs.), which differ markedly from where we collected the specimen on Pungalina–Seven Emu. The nearest records of *Ctenotus piankai* are over 400 km south of this *Ctenotus* record, near the southern edge of the Barkly Tableland (ALA 2013; Wilson and Swan 2013).

We are planning further work in order to clarify the status of both the *Ctenotus* and *Lerista* sp. and this would be coordinated with AWC management.

Conclusion

This brief survey in the Gulf Plains bioregion added significantly to previous surveys conducted by AWC staff on Pungalina–Seven Emu reserve. Because of its short duration our survey was a necessarily brief window into the terrestrial vertebrate fauna, and species assemblage patterns of Pungalina. However, it conformed to the general principle present across northern Australian savannas, that fauna composition is strongly dictated by landform and habitat. In particular it highlighted strong differences in the fauna composition signal from coastal dunes versus inland forest and woodland systems.

Records of two new reptile species during this survey highlight the importance of continued fauna surveys, both from an inventory point of view and as a means to help understand fauna assemblage patterns.

Acknowledgements

The authors are extremely grateful to The Royal Geographic Society of Queensland and Australian Wildlife Conservancy for organising this expedition into such a remote location. Special thanks to Hayley Freemantle for organising so well from so far and for her patience. As is usual, the expedition was extremely well organised with staff and volunteers feeding, organising, accommodating, transporting and otherwise supporting us every step of the way. Such ventures would be impossible without them. AWC ecologists Dr John Kanowski and Dr Eri Mulder were helpful with advice and directing us to less well surveyed areas of Pungalina, and in doing so assisting us to make some significant new finds on the reserve. Dr John Kanowski also provided valuable feedback on the manuscript, as did Dr Chris Pavey (CSIRO). Their input is gratefully appreciated. Rigel Jensen and Jeanette Kemp provided valuable information on site floristics. We are grateful to Tony Hillier for supplying a boat that kept us above the crocodiles and made access to our coastal dunes sites possible. CSIRO Ecosystem Sciences and Building Resilient Australian Biodiversity Assets theme provided support for the field work. Field work was carried out under Northern Territory Parks and Wildlife Commission permit 44128 and CSIRO Ecosystem Sciences AEC 09-09.

References

ALA (2013). 'Atlas of Living Australia'. Accessed August 2013 from http://www.ala.org.au

Bureau of Meteorology (2013). 'Maps of average conditions'. Accessed September 2013 from http://www.bom.gov.au/climate/averages/maps.shtml

Clarke, K.R. & Warwick, R.N. (2001) Change in Marine Communities: An Approach to Statistical Analyis and Interpretation, 2nd edn. (PRIMER-E Ltd: Plymouth UK)

Clarke, K.R., and Gorley, R.N. (2006a) PRIMER 6 edn. (PRIMER-E Ltd: Plymouth UK)

Clarke, K.R., and Gorley, R.N. (2006b) 'PRIMER 6 User Manual/Tutorial.' (PRIMER-E Ltd: Plymouth UK)

Eyre, T.J., Kelly, A.L., and Neldner, V.J. (2006) 'BioCondition; a terrestrial vegetation condition assessment tool for biodiversity in Queensland. Field Assessment Manual. Version 1.5.' (Environmental Protection Agency: Brisbane)

Friend, G.R., and Taylor, J.A. (1985). Habitat preferences of small mammals in tropical open- forest of the Northern Territory. *Australian Journal of Ecology* , 173-185.

Horton, D. (1973). The Concept of Zoogeographic Subregions. *Systematic Zoology* 22, 191- 195.

Jost, L. (2006). Entropy and diversity. *Oikos* 113, 363-375.

Kaiser, H., Crother, B.I., Kelly, C.M.R., Luiselli, L., O'Shea, M., Ota, H., Passos, P., Schleip, W.D., and Wuster, W. (2013). Best Practices: In the 21st Century, Taxonomic Decisions in Herpetology are Acceptable Only When Supported by a Body of Evidence and Published via Peer-Review. *Herpetological Review* 44, 8-23.

Kanowski, J., Jensen, R., Lloyd, R., Middleton, J., Lawler, W., and Legge, S. (2009) Wildlife Surveu of Pungalina-Seven Emu. Australian Wildlife Conservancy, Perth.

Kanowski, J., Mulder, E., Jensen, R., Lloyd, R., Murphy, S., and Legge, S. (2010) Pungalina- Seven Emu Survey May-June 2010. Australian Wildlife Conservancy, Perth.

Kanowski, J., Mulder, E., and Jensen, R. (2011) Pungalina-Seven Emu Wildlife Sanctuary: 2011 Survey Report. Australian Wildlife Conservancy, Perth.

Karfs, R.A., Holloway, C., Pritchard, K., and Resing, J. (2009) 'Land Condition Photo Standards for the Burdekin Dry Tropics Rangelands: a guide for practitioners.' (NQ Dry Tropics)

Kutt, A., E., V., Colman, N., Perry, J., and Perkins, G. (2009a) Healthy Country and Healthy Biodiversity in Queensland Rangelands: (iii) the Gulf Plains Bioregion. Technical manual. NQ Dry Tropics.

Kutt, A., Vanderduys, E., Hines, H., Gynther, I., and Absolon, M. (2009b) Assemblage pattern in vertebrate fauna of Cravens Peak, far western Queensland. In 'Cravens Peak Scientific Study Report. Vol. 13 (Geography Monograph Series).' pp. 235-252. (The Royal Geographic Society of Queensland Inc: Milton)

Kutt, A.S., Kemp, J.E., McDonald, K.R., Williams, Y., Williams, S.E., Hines, H.B., Hero, J.-M., and Torr, G. (2005). Vertebrate fauna survey of White Mountains National Park, Desert Uplands Bioregion, Queensland. *Australian Zoologist* 33, 17-38.

Kutt, A.S., Perkins, G.C., Colman, N., Vanderduys, E.P., and Perry, J.J. (2011). Temporal variation in a savanna bird assemblage: what changes over five years? *EMU* 112.

Menkhorst, P., and Knight, F. (2011) 'A Field Guide to the Mammals of Australia.' 3rd edn. (Oxford University Press: Melbourne)

NAFI (2013) Nortehrn Australian Fire Information. In '. Vol. 2012.' (Australian Government.)

Neldner, V.J., Wilson, B.A., Thompson, E.J., and Dillewaard, H.A. (2005) 'Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland. Version 3.1.' (Queensland Herbarium, Environmental Protection Agency: Brisbane)

Northcote, K.H., Beckmann, G.G., Bettenay, E., Churchward, H.M., Van Dijk, D.C., Dimmock, G.M., Hubble, G.D., Isbell, R.F., McArthur, W.M., Murtha, G.G., Nicolls, K.D., Paton, T.R., Thompson, C.H., Webb, A.A., and Wright, M.J. (1960-1968) 'Atlas of Australian Soils, Sheets 1 to 10. With explanatory data.' (CSIRO Aust. and Melbourne University Press: Melbourne)

Pizzey, G., and Knight, F. (1997) 'Field Guide to the Birds of Australia.' (Angus and Robertson: Sydney)

Preece, N. (2009) Northern Gulf Rapid Terrestrial Biodiversity Assessment. Northern Gulf Resource Management Group Ltd. Biome5 Environmental Consultants

Slater, P., Slater, P., and Slater, R. (2003) 'The Slater Field Guide to Australian Birds.' (New Holland Publishers: Sydney)

Vanderduys, E. (2012) ‘Field Guide to the Frogs of Queensland.’ (CSIRO Publishing: Collingwood)

Vanderduys, E.P., Kutt, A.S., and Kemp, J.E. (2011). Upland savannas: the vertebrate fauna of largely unknown but significant habitat in north-eastern Queensland. *Australian Zoologist*, in review.

Vanderduys, E.P., Zimny, A., Andersen, A., and Schatz, J. (2013) Fauna Survey of the Dhimurru Indigenous Protected Area.

Wilson, S. (2005) ‘A Field Guide to Reptiles of Queensland.’ (Reed New Holland Sydney)

Wilson, S., and Swan, G. (2013) ‘A Complete Guide to Reptiles of Australia.’ 4th edn. (Reed New Holland: Sydney)

Woinarski, J.C.Z., Fisher, A., and Milne, D. (1999). Distribution patterns of vertebrates in relation to an extensive rainfall gradient and variation in soil texture in the tropical savannas of the Northern Territory, Australia. *Journal of Tropical Ecology*, 381-398.

Woinarski, J.C.Z., Milne, D.J., and Wanganeen, G. (2001). Changes in mammal populations in relatively intact landscapes of Kakadu National Park, Northern Territory, Australia. *Austral Ecology*, 360-370.

Woinarski, J.C.Z., Williams, R.J., Price, O., and Rankmore, B. (2005). Landscapes without boundaries: wildlife and their environments in northern Australia.*Wildlife Research*, 377-388.

Appendix 1. Location of standardised trap sites, their location (GDA94), landform, habitat description, mapped soil type (Atlas of Australian Soils), and edited description of that soil type, with particularly relevant sections in bold.

Site	Latitude	Longitude	Landform	Site photograph
PUNG01	-16.27008°	137.75206°	Coastal dune	
Habitat: Mixed *Acacia* spp., mangrove and semi-evergreen vine thicket elements Mapped soil type: Io1 Salt pans and tidal flats inundated by seasonal high tides; numerous small tidal streams are usually closely associated and are often **fringed by mangrove swamps ... old beach ridges and sand dunes**				
PUNG02	-16.26686°	137.74855°	Coastal dune	
Habitat: Mixed *Acacia* spp., mangrove and semi-evergreen vine thicket elements Mapped soil type: Io1 Salt pans and tidal flats inundated by seasonal high tides; numerous small tidal streams are usually closely associated and are often fringed by mangrove swamps ... **old beach ridges and sand dunes**				
PUNG03	-16.29980°	137.77376°	Coastal dune	
Habitat: Mixed Acacia sp., mangrove, *Spinifex longifolius* and samphire elements Mapped soil type: Io1 **Salt pans and tidal flats inundated by seasonal high tides; numerous small tidal streams are usually closely associated and are often fringed by mangrove swamps ... old beach ridges and sand dunes**				
PUNG04	-16.30120°	137.76367°	Coastal dune	
Habitat: Mixed *Acacia* spp., mangrove and semi-evergreen vine thicket elements Mapped soil type: Io1 Salt pans and tidal flats inundated by seasonal high tides; **numerous small tidal streams are usually closely associated and are often fringed by mangrove swamps ... old beach ridges and sand dunes**				

Site	Latitude	Longitude	Landform	Site photograph
PUNG05	-16.30731°	137.73080°	Riparian flat	
Habitat: Grassland Mapped soil type: Tb135 … **heavy grey clay soils … occur near the coastal margins associated with salt pans**				
PUNG06	-16.36170°	137.64499°	Alluvial flat	
Habitat: Mixed *Eucalyptus* spp./*Corymbia* spp. woodland with heavy grass understorey Mapped soil type: Tb135 Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are **loamy and sandy mottled grey earths, mottled yellow earths**				
PUNG07	-16.37831°	137.64211°	Alluvial flat	
Habitat: Open *Eucalyptus* sp. woodland with heavy grass understorey Mapped soil type: Tb135 Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are loamy and sandy mottled grey earths, mottled yellow earths				
PUNG08	-16.37858°	137.62753°	Sand flat	
Habitat: *Eucalyptus tetrodonta* mixed forest with thick mid-storey of *Grevillea* sp. and other shrubs Mapped soil type: Tb135 Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are loamy and sandy mottled grey earths, mottled yellow earths				

Site	Latitude	Longitude	Landform	Site photograph
PUNG09	-16.37687°	137.59630°	Sand flat	
Habitat: *Eucalyptus tetrodonta* forest with moderate grass cover Mapped soil type: Tb135 Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are loamy and sandy mottled grey earths, mottled yellow earths				
PUNG10	-16.37639°	137.58632°	Sand flat	
Habitat: *Eucalyptus tetrodonta* forest with moderate grass cover Mapped soil type: Tb135 Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are loamy and sandy mottled grey earths, mottled yellow earths				
PUNG11	-16.37508°	137.56934°	Sand flat	
Habitat: *Eucalyptus tetrodonta*/*Callitris intratropica* forest with moderate grass cover Mapped soil type: Tb135 Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are loamy and sandy mottled grey earths, mottled yellow earths				
PUNG12	-16.37402°	137.54771°	Sand flat	
Habitat: *Eucalyptus tetrodonta*/*Callitris intratropica* open forest with moderate grass cover Mapped soil type: Tb135 Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are loamy and sandy mottled grey earths, mottled yellow earths				

<table>
<tr><th>Site</th><th>Latitude</th><th>Longitude</th><th>Landform</th><th>Site photograph</th></tr>
<tr><td>PUNG13</td><td>-16.37345°</td><td>137.53894°</td><td>Sand flat</td><td rowspan="2"></td></tr>
<tr><td colspan="4">Habitat:
Eucalyptus tetrodonta forest with mid-storey of Grevillea sp. and other shrubs

Mapped soil type: Tb135
Gently sloping plains traversed by numerous creeks; occasional low dunes may occur near the coast: dominant soils are probably acidic yellow mottled duplex soils with similar neutral and probably alkaline soils occurring nearer the coastal margins. Commonly associated are loamy and sandy mottled grey earths, mottled yellow earths</td></tr>
<tr><td>PUNG14</td><td>-16.37361°</td><td>137.52820°</td><td>Sand flat</td><td rowspan="2"></td></tr>
<tr><td colspan="4">Habitat:
Eucalyptus tetrodonta/Callitris intratropica forest with moderate grass cover

Mapped soil type: BA15
Soils are a variety of shallow, often gravelly and stony, sands.</td></tr>
<tr><td>PUNG15</td><td>-16.38198°</td><td>137.51144°</td><td>Sandstone platform</td><td rowspan="2"></td></tr>
<tr><td colspan="4">Habitat:
Mixed Eucalyptus sp. open woodland with Calytrix exstipulata shrub layer and Triodia pungens ground layer

Mapped soil type: BA15
… plateaux mainly on sandstones</td></tr>
</table>

Appendix 2. Complete site by species array for all trap sites, showing total abundance for each site.

A zero means that the species was recorded in similar habitat to that of the site, but off site. [I] = introduced species. Highlighted species have not been previously recorded on Pungalina (Kanowski et al 2009, 2010, 2011).

Family	Scientific name	Common name	Incidentals	Standardised sites (PUNG...)														
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Mammals																		
Dasyuridae	*Planigale maculata*	common planigale						2										
Dasyuridae	*Pseudantechinus mimulus*	Carpentarian antechinus																1
Macropodidae	*Macropus agilis*	agile wallaby			1	1	1			1								
Pteropodidae	*Pteropus scapulatus*	little red flying-fox											0				1	
Megadermatidae	*Macroderma gigas*	ghost bat	50															
Muridae	*Pseudomys delicatulus*	delicate mouse											1					
Muridae	*Pseudomys nanus*	western chestnut mouse	1					2										
Canidae	*Canis lupus*	dingo	2						0									
Felidae	*Felis catus*[I]	cat				1			1									
Bovidae	*Bos taurus*[I]	European cattle	6															
Bovidae	*Bubalus bubalis*[I]	water buffalo	1															
Suidae	*Sus scrofa*[I]	pig			1	1												
Birds																		
Casuariidae	*Dromaius novaehollandiae*	emu	2															
Phasianidae	*Coturnix ypsilophora*	brown quail								6								
Anatidae	*Tadorna radjah*	radjah shelduck			0													
Anhingidae	*Anhinga novaehollandiae*	Australasian darter							0									
Pelecanidae	*Pelecanus conspicillatus*	Australian pelican		2		3		1										
Ardeidae	*Egretta novaehollandiae*	white-faced heron				0												
Ardeidae	*Egretta sacra*	eastern reef egret				0												
Ardeidae	*Ardea sumatrana*	great-billed heron			0													
Ardeidae	*Ardea modesta*	eastern great egret								1								
Ardeidae	*Butorides striatus*	striated heron				1												
Accipitridae	*Pandion cristatus*	eastern osprey				2												
Accipitridae	*Milvus migrans*	black kite							0									
Accipitridae	*Haliastur sphenurus*	whistling kite			1		1	2		0	1							

Family	Scientific name	Common name	Inci-dentals	Standardised sites (PUNG...)														
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Accipitridae	*Haliastur indus*	brahminy kite				3												
Accipitridae	*Haliaeetus leucogaster*	white-bellied sea-eagle				0												
Accipitridae	*Accipiter fasciatus*	brown goshawk										1						
Accipitridae	*Accipiter cirrhocephalus*	collared sparrowhawk	1			1												
Falconidae	*Falco berigora*	brown falcon					1											
Falconidae	*Falco longipennis*	Australian hobby	1															
Gruidae	*Grus rubicunda*	brolga					1	3										
Otididae	*Ardeotis australis*	Australian bustard	1															
Scolopacidae	*Numenius madagascariensis*	eastern curlew	1			1												
Burhinidae	*Burhinus grallarius*	bush stone-curlew	1															
Burhinidae	*Esacus magnirostris*	beach stone-curlew	3			0												
Recurvirostridae	*Himantopus himantopus*	black-winged stilt						0										
Laridae	*Hydroprogne caspia*	Caspian tern				0												
Columbidae	*Phaps chalcoptera*	common bronzewing												1				
Columbidae	*Geophaps smithii*	partridge pigeon													1			
Columbidae	*Geopelia cuneata*	diamond dove									1		1					
Columbidae	*Geopelia striata*	peaceful dove	1		7	0	1		3	0	4		2	0	3			2
Columbidae	*Geopelia humeralis*	bar-shouldered dove			1	2				2								
Columbidae	*Ptilinopus regina*	rose-crowned fruit-dove			2		0											
Cacatuidae	*Calyptorhynchus banksii*	red-tailed black-cockatoo							10									
Cacatuidae	*Cacatua sanguinea*	little corella				0												
Cacatuidae	*Cacatua galerita*	sulphur-crested cockatoo	2						0	0						0		
Psittacidae	*Trichoglossus haematodus*	red-collared lorikeet							0	8	4	0			1		0	
Psittacidae	*Psitteuteles versicolor*	varied lorikeet	5								1				2			
Psittacidae	*Aprosmictus erythropterus*	red-winged parrot							8		0				0			
Psittacidae	*Platycercus venustus*	northern rosella								0				3	2			2
Cuculidae	*Scythrops novaehollandiae*	channel-billed cuckoo					5											
Cuculidae	*Chrysococcyx minutillus*	little bronze-cuckoo			1	0		0										

Family	Scientific name	Common name	Inci-dentals	Standardised sites (PUNG...)														
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Strigidae	*Ninox novaeseelandiae*	southern boobook	1															
Podargidae	*Podargus strigoides*	tawny frogmouth																1
Caprimulgidae	*Eurostopodus argus*	spotted nightjar	1															
Aegothelidae	*Aegotheles cristatus*	Australian owlet-nightjar							1									
Alcedinidae	*Ceyx azureus*	azure kingfisher	1															
Halcyonidae	*Dacelo leachii*	blue-winged kookaburra							0									
Halcyonidae	*Todiramphus chloris*	collared kingfisher	1	1														
Meropidae	*Merops ornatus*	rainbow bee-eater			5	3			2	0	1		0			1		1
Climacteridae	*Climacteris melanura*	black-tailed treecreeper	2															
Maluridae	*Malurus coronatus*	purple-crowned fairy-wren	5															
Maluridae	*Malurus lamberti*	variegated fairy-wren			16													4
Maluridae	*Malurus melanocephalus*	red-backed fairy-wren	1		5			3	4							3		3
Pardalotidae	*Pardalotus striatus*	striated pardalote				1			5	1	7	1	3	4	6	3	9	2
Acanthizidae	*Smicrornis brevirostris*	weebill							1	0	1	5	4	1	1	6	6	4
Acanthizidae	*Gerygone levigaster*	mangrove gerygone		4														
Acanthizidae	*Gerygone albogularis*	white-throated gerygone	1				0				0						3	
Meliphagidae	*Lichenostomus unicolor*	white-gaped honeyeater	3		2	3	2			0	1						2	
Meliphagidae	*Ramsayornis fasciatus*	bar-breasted honeyeater	2								1				6			
Meliphagidae	*Myzomela erythrocephala*	red-headed honeyeater		3	1	2	2											
Meliphagidae	*Cissomela pectoralis*	banded honeyeater	2								2				5	0		
Meliphagidae	*Lichmera indistincta*	brown honeyeater	5			6	2	0	0	0	19	0	4	0	4	10	6	0
Meliphagidae	*Melithreptus gularis*	golden-backed honeyeater	1															
Meliphagidae	*Melithreptus albogularis*	white-throated honeyeater					4		5	2	14	5	4	2	4	4	2	2
Meliphagidae	*Entomyzon cyanotis*	blue-faced honeyeater															0	
Meliphagidae	*Philemon argenticeps*	silver-crowned friarbird									10	0	4		2	0	0	

Family	Scientific name	Common name	Inci-dentals	Standardised sites (PUNG...)														
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Meliphagidae	*Philemon citreogularis*	little friarbird								0	1				0	0		2
Petroicidae	*Microeca fascinans*	jacky winter							3	1				1				
Petroicidae	*Microeca flavigaster*	lemon-bellied flycatcher			1			0										
Petroicidae	*Poecilodryas cerviniventris*	buff-sided robin	2															
Neosittidae	*Daphoenositta chrysoptera*	varied sitella							2					2				
Pachycephalidae	*Pachycephala rufiventris*	rufous whistler			7		3				2	3	1	1	3		3	
Pachycephalidae	*Colluricincla woodwardi*	sandstone shrike-thrush	1															
Monarchidae	*Myiagra alecto*	shining flycatcher	1															
Monarchidae	*Myiagra inquieta*	restless flycatcher					1			1					4			
Monarchidae	*Grallina cyanoleuca*	magpie-lark							0	1								
Rhipiduridae	*Rhipidura albiscapa*	grey fantail										1		0	3			
Rhipiduridae	*Rhipidura phasiana*	mangrove fantail			1													
Rhipiduridae	*Rhipidura rufiventris*	northern fantail	1															
Rhipiduridae	*Rhipidura leucophrys*	willie wagtail							7	1	1			3	3		0	0
Campephagidae	*Coracina novaehollandiae*	black-faced cuckoo-shrike		2	1	3			0	1	1		1		0		0	
Campephagidae	*Coracina papuensis*	white-bellied cuckoo-shrike								1		2			1			
Campephagidae	*Lalage sueurii*	white-winged triller								15								
Oriolidae	*Oriolus sagittatus*	olive-backed oriole																0
Oriolidae	*Sphecotheres vieilloti*	Australasian figbird			3	32		0										
Artamidae	*Artamus leucorynchus*	white-breasted woodswallow								4								
Artamidae	*Artamus personatus*	masked woodswallow	5					1		0					0	0		
Artamidae	*Artamus superciliosus*	white-browed woodswallow	9												0	0		
Artamidae	*Artamus cinereus*	black-faced woodswallow								1								
Artamidae	*Artamus minor*	little woodswallow	4							2					20			2
Artamidae	*Cracticus nigrogularis*	pied butcherbird							2			0	0	0	0	0	0	
Artamidae	*Cracticus tibicen*	Australian magpie							1		0					1		
Corvidae	*Corvus orru*	Torresian crow		0					0									

Family	Scientific name	Common name	Inci-dentals	Standardised sites (PUNG...)														
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Ptilonorhynchidae	*Ptilonorhynchus nuchalis*	great bowerbird	1															
Motacillidae	*Anthus novaeseelandiae*	Australasian Pipit						1										
Estrildidae	*Taeniopygia bichenovii*	double-barred finch			3												2	
Estrildidae	*Poephila acuticauda*	long-tailed finch	11															
Estrildidae	*Poephila personata*	masked finch	3															
Estrildidae	*Lonchura castaneothorax*	chestnut-breasted mannikin	12															
Nectariniidae	*Dicaeum hirundinaceum*	mistletoebird	1	9	8	3	6	0	2	1	8				7	1	3	
Megaluridae	*Cincloramphus mathewsi*	rufous songlark									1							
Sylviidae	*Cisticola exilis*	golden-headed cisticola						10		2								
Timaliidae	*Zosterops luteus*	yellow white-eye			3		2											
Reptiles																		
Crocodylidae	*Crocodylus johnstoni*	Australian freshwater crocodile	1															
Crocodylidae	*Crocodylus porosus*	estuarine crocodile	8															
Gekkonidae	*Gehyra borroloola*		13															2
Gekkonidae	*Gehyra dubia*		3			2		0	3	6				2				
Gekkonidae	*Heteronotia binoei*	Bynoe's gecko	1	0	1	1	1	1			2			1			1	1
Gekkonidae	*Oedura rhombifer*	zig-zag gecko	1		1		1		4			9	4	3		2		0
Gekkonidae	*Strophurus ciliaris*	spiny-tailed gecko	5															0
Pygopodidae	*Delma* sp.		1															
Pygopodidae	*Pygopus steelescotti*																1	
Scincidae	*Carlia amax*		41	3		4	3				5	14	12	5	7	2	15	4
Scincidae	*Carlia munda*						1			2						4		
Scincidae	*Cryptoblepharus metallicus*	metallic snake-eyed skink	1		1				1	1						1	2	3
Scincidae	*Cryptoblepharus pannosus*	ragged snake-eyed skink		1	1	2	2		3	5	1			2	1		1	
Scincidae	*Ctenotus inornatus*		1															2
Scincidae	*Ctenotus* sp.			site not specified														
Scincidae	*Ctenotus spaldingi*		3								2	1	3		1			
Scincidae	*Ctenotus striaticeps*																	1
Scincidae	*Eremiascincus isolepis*		1				1											
Scincidae	*Lerista orientalis*		4	1	3	1						2						1

Family	Scientific name	Common name	Inci-dentals	Standardised sites (PUNG...)														
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Scincidae	*Lerista* sp.			site not specified														
Scincidae	*Menetia greyii*						1		1			1						
Scincidae	*Morethia ruficauda*		1															
Scincidae	*Proablepharus tenuis*						2									1		
Agamidae	*Amphibolurus gilberti*	Gilbert's dragon		1	1	4								0				
Agamidae	*Chlamydosaurus kingii*	frilled lizard														1		
Agamidae	*Ctenophorus caudicinctus*	ring-tailed dragon	1															
Agamidae	*Diporiphora bilineata*	two-lined dragon	5	1		1		1	1	1	2		1	2	3	2	2	
Agamidae	*Diporiphora magna*		1															
Varanidae	*Varanus acanthurus*	ridge-tailed monitor	8															
Varanidae	*Varanus baritji*	Top End pygmy monitor	5															
Varanidae	*Varanus mertensi*	Mertens' water monitor	1															
Boidae	*Aspidites melanocephalus*	black-headed python	1															
Boidae	*Liasis mackloti*	water python				1												
Boidae	*Liasis olivaceus*	olive python	3															
Colubridae	*Dendrelaphis punctulata*	common tree snake	1															
Elapidae	*Demansia papuensis*	Papuan whip snake										2						
Elapidae	*Demansia quaesitor*		1															
Elapidae	*Furina ornata*	orange-naped snake	1															
Amphibians																		
Bufonidae	*Rhinella marina*[1]	cane toad	8	23	1		4	2	1								0	
Hylidae	*Litoria bicolor*	northern sedgefrog					14									1		
Hylidae	*Litoria caerulea*	common green treefrog					3											
Hylidae	*Litoria nasuta*	striped rocketfrog													1			
Hylidae	*Litoria rubella*	ruddy treefrog							1									
Hylidae	*Litoria tornieri*	black-shinned rocketfrog	1															
Limnodynastidae	*Limnodynastes convexiusculus*	marbled frog								1	1							
Myobatrachidae	*Crinia bilingua*	bilingual froglet															0	
Myobatrachidae	*Uperoleia lithomoda*	stonemason toadlet														23		

Semi-aquatic and Aquatic Bugs (Hemiptera: Heteroptera: Gerromorpha and Nepomorpha) of the AWC Pungalina-Seven Emu Sanctuary, Gulf Coastal Bioregion, Northern Territory

Tom A. Weir

Australian National Insect Collection, CSIRO Ecosystem Sciences, GPO Box 1700 Canberra, ACT 2601

Abstract Twenty-six species of semi-aquatic bugs in five families (Gerromorpha) and 27 species of aquatic bugs in eight families (Nepomorpha) were collected at 13 localities during the survey of the Australian Wildlife Conservancy recently acquired Pungalina-Seven Emu Sanctuary conducted by the Royal Geographical Society of Queensland during June/July 2012. Notes are given on the known distribution of each species and habitat preferences where known.

Introduction

The Pungalina-Seven Emu Sanctuary lies within the Gulf Coastal Bioregion of the Northern Territory, characterised by gently undulating plains with meandering rivers and coastal swamps. Numerous aquatic habitats are found within its borders. Little or no data on semi-aquatic and aquatic bugs is available for this bioregion, so the June/July survey of this area conducted by the Royal Geographic Society of Queensland provided an excellent opportunity to collect baseline data for the Australian Wildlife Conservancy. Other regions of the Northern Territory have been surveyed by the author over many years and especially the semi-aquatic bug fauna is reasonably well known with data being published in papers by Andersen and Weir (1994, 1997, 1998, 1999, 2000, 2001, 2003, 2004a, 2004b). General coverage of the NT was undertaken whilst the author was stationed in Darwin 1971 to 1974 and 1994 whilst at the ANIC in Canberra. Subsequent more targeted surveys were carried out in Keep River and Gregory National Parks in 2001 and the Gove Peninsula in 2007. The closest survey of semi-aquatic bugs to Pungalina-Seven Emu was carried out at Lawn Hill National Park (based on the Musselbrook section) in Queensland, some 250 km to the SSE, in 1995 (Weir, 1998) while the White Mountains National Park, also in Queensland, east of Hughenden, was surveyed in 2000 (Weir, 2003). Surveys of the aquatic bug fauna of the Northern Territory have been sparse and often specimens are collected as a result of collecting other aquatic and semi-aquatic fauna. Summaries of the distributions of the genera of both semi-aquatic and aquatic bugs at generic level can be found in Andersen & Weir 2004b.

The Australian waterbug fauna is large and diverse and is found in a wide variety of natural habitats from small temporary pools to larger ponds and lakes, from small streams to rivers and from inland freshwater bodies to coastal mangroves and tidal pools of coral reefs and even the open ocean (Andersen & Weir, 2004b). They are chiefly polyphagous predators or scavengers, feeding on any prey they can master, from tiny crustaceans and insects to tadpoles and small fish (Andersen & Weir, 2004b).

The Australian Gerromorpha fauna is represented by six families, 30 genera and some 129 described species (Andersen & Weir 2004b), of which the five freshwater families, nine genera and 26 species were recorded in this survey (see Table 2, page 112). They are referred to as semi-aquatic bugs and live upon the water surface, most having the ability to walk or run on the surface film due to various modifications to the legs. Wing polymorphism is common and populations can exist at any one time with combinations of winged, short winged or wingless adults of both males and females as well as developing nymphs with or without wing buds (Weir, 2003).

The Australian Nepomorpha fauna is represented by ten families, 25 genera and some 132 described species (Andersen & Weir, 2004b, Tinerella, 2013), of which eight families, 13

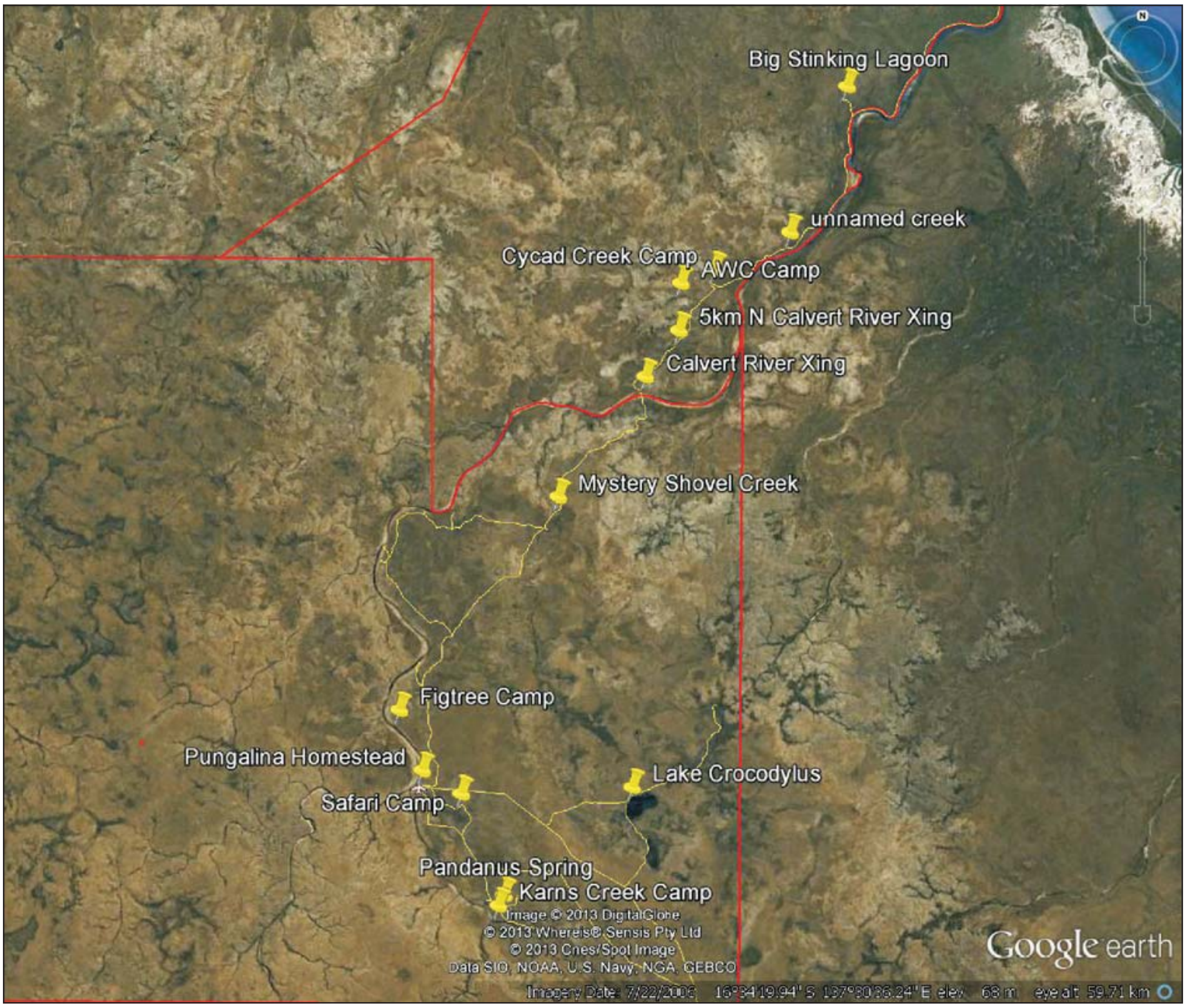


Figure 1. Collecting localities for Semi-aquatic and Aquatic bugs at Pungalina–Seven Emu, June/July 2012. Roads shown in yellow and Pungalina–Seven Emu boundaries shown in red.

genera and 27 species were recorded in this survey (see Table 3, page 115). They are referred to as aquatic bugs as all but two of the families live beneath the water surface—the Ochteridae and Gelastocoridae living terrestrially beside the water's edge. Each of these aquatic families has a distinctive type of respiration. Air layers adhere to these bugs when submerged and are renewed at the water surface through respiratory siphons (Nepidae) or air straps (Belostomatidae) arising from the abdominal end, the tip of the abdomen (Naucoridae, Notonectidae, Pleidae) or through spaces between the head and pronotum (Corixidae and Micronectidae) (Andersen & Weir, 2004b). Species of Aphelocheiridae have developed a physical gill which enables them to stay submerged indefinitely.

Methods

A combination of long handled water net and fine mesh strainer was used to sample the water surface, beneath the water surface and any emergent vegetation. This was supplemented by light trapping at Site 1 (Pungalina Homestead) and Site 2 (Cycad Creek Camp), but the returns from this method were poor due to the low night time temperatures. Only on one night (8 July at Pungalina Homestead) were the warm and humid night time conditions conducive to productive light trapping. Specimens were transferred to 100% ethanol for preservation, allowing for DNA sequencing in the future. Specimens were identified using the keys in Andersen & Weir, 1994, 1997, 1998, 1999, 2000, 2001, 2003, 2004a, 2004b, Tinerella 2013, the Australian National Insect Collection and the author's knowledge of the Australian fauna.

Table 1. Collecting site data for Semi-aquatic and Aquatic Bugs in the Pungalina–Seven Emu Sanctuary, Gulf Coastal Bioregion, Northern Territory, June/July 2012, as shown in Figure 1, page 110. Site descriptions are included in the text.

Site	Locality	Latitude	Longitude
1	Pungalina Homestead [Pungalina]	16° 43' 16"	137° 24' 55"
2	Karns Creek Camp, 9.6km SEbyS Pungalina Homestead [Pungalina]	16° 47' 30"	137° 27' 27"
3	Pandanus Spring, 8.9km SEbyS Pungalina Homestead [Pungalina]	16° 47' 10'	137° 27' 38"
4	Lake Crocodylus, 12.5km E Pungalina Homestead [Pungalina]	16° 43' 44"	137° 31' 49"
5	Mystery Shovel Creek, 17.7km NEbyN Pungalina Homestead [Pungalina]	16° 34' 38"	137° 29' 19"
6	Cycad Creek Camp, 33.7km NEbyN Pungalina Homestead [Seven Emu]	16° 27' 26"	137° 34' 23"
7	Safari Camp, 3km ESE Pungalina Homestead [Pungalina]	16° 43' 59"	137° 26' 12"
8	Figtree Camp, Calvert River, 3.4km NbyW Pungalina Homestead [Pungalina]	16° 41' 22"	137° 24' 09"
9	Big Stinking Lagoon, 47km NEbyN Pungalina Homestead [Seven Emu]	16° 21' 38"	137° 38' 42"
10	AWC Camp, 32km NEbyN Pungalina Homestead [Seven Emu]	16° 27' 53"	137° 33' 17"
11	unnamed creek north of Cycad Creek, 38km NEbyN Pungalina Homestead [Seven Emu]	16° 26' 15"	137° 36' 52"
12	Calvert River Xing, 26.3km NEbyN Pungalina Homestead [Seven Emu]	16° 30' 50"	137° 32' 09"
13	5km N Calvert River Xing, 28.8km NEbyN Pungalina Homestead [Seven Emu]	16° 29' 22"	137° 33' 14"

Localities

The 13 collecting localities are listed in Table 1 on page 111. They are all located within the Calvert River drainage basin and provided a variety of aquatic habitats. Sites 1 (Pungalina Homestead), 8 (Figtree Camp) and 12 (Calvert River Xing) were all situated on the Calvert River and provided a combination of flowing river edge and small and large still pools beside the river with varying amounts of aquatic vegetation, leaf packets and logs (see Figure 2 on page 113, Figure 3 on page 113 and Figure 4 on page 114). Site 2 (Karns Creek) was similar except situated on Karns Creek, a tributary of the Calvert River. Site 5 (Mystery Shovel Creek) was a large pool in a slow flowing creek with lots of aquatic vegetation. Sites 6 (Cycad Creek Camp) and 9 (Big Stinking Lagoon) were large billabongs with lots of aquatic vegetation (see Figure 5, page 116). Cycad Creek also provided a variety of pools in a drying creek bed, as did Site 11 (unnamed creek). Sites 3 (Pandanus Spring), 7 (Safari Camp) and 10 (AWC Camp) were fast flowing little streams with various amounts of aquatic and fringing vegetation (see Figure 6, page 117). Site 13 (5 km north of Calvert River Xing) was a large stagnant pool with lots of scum, floating debris and algal growth, while Site 4 (Lake Crocodylus) was a large shallow lake with receding water, degraded edges and little vegetation (see Figure 7, page 118).

Results

Gerromorpha (semi-aquatic bugs—Table 2, page 112)

Mesoveliidae (water treaders, pondweed bugs)

Mesoveliids live in moist surroundings, either marginal aquatic habitats or on water surfaces covered with floating leaves of water plants (Andersen & Weir 2004b). The three species of *Mesovelia* collected here viz *M. vittigera* Horvath (eight localities), *M. horvathi* Lundblad (six localities) and *M. ebbenielseni* Andersen & Weir (five localities) are all common across northern Australia. The first two share a widespread distribution in the Indo-Malayan region with vittigera extending to the western Pacific, southern Europe and the Middle East (Andersen & Weir, 2004a).

Table 2. Species of Semi-aquatic Bugs (Gerromorpha) collected in the Pungalina–Seven Emu Sanctuary, Gulf Coastal Bioregion, Northern Territory, June/July 2012. See Table 1 on page 111 for locality data.

Gerromorpha			**Localities**													**Locality/ Species**
Family	**Subfamily**	**Genus & Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
Mesoveliidae		*Mesovelia vittigera* Horvath	X			X		X	X	X	X			X	X	8
		Mesovelia horvathi Lundblad	X	X			X		X	X				X		6
		Mesovelia ebbenielseni Andersen & Weir	X	X			X				X			X		5
Hebridae		*Merragata hackeri* Hungerford	X	X			X	X		X	X			X	X	8
		Hebrus axillaris Horvath	X				X	X								3
Hydrometridae		*Hydrometra papuana* Kirkaldy	X	X						X				X		4
		Hydrometra orientalis Lundblad					X			X						2
		Hydrometra feta Hale							X							1
Veliidae	Microveliinae	*Microvelia (Picaultia) douglasi* Scott	X	X			X	X		X	X					6
		Microvelia (Picaultia) paramega Andersen & Weir	X									X				2
		Microvelia (Picaultia) justi Andersen & Weir	X													1
		Microvelia (Pacificovelia) oceanica Distant		X		X	X	X			X					5
		Microvelia (Pacificovelia) lilliput Andersen & Weir	X	X		X		X			X			X	X	7
		Microvelia (Pacificovelia) kakadu Andersen & Weir										X			X	2
		Microvelia (Austromicrovelia) australiensis Andersen & Weir	X	X			X		X			X			X	6
		Microvelia (Austromicrovelia) herberti Andersen & Weir	X	X			X		X	X				X		6
		Microvelia (Austromicrovelia) torresiana Andersen & Weir	X					X		X				X	X	5
		Microvelia (Austromicrovelia) odontogaster Andersen & Weir	X						X							2
		Microvelia (Barbivelia) falcifer Andersen & Weir		X												1
		Petrovelia katherinae Andersen & Weir		X												1
		Phoreticovelia rotunda Polhemus & Polhemus								X						1
Gerridae	Rhagadotarsinae	*Rhagadotarsus anomalus* Polhemus & Karunaratne	X				X			X						3
	Gerrinae	*Limnogonus fossarum gilguy* Andersen & Weir	X				X	X			X			X	X	6
		Limnogonus luctuosus Montrouzier	X		X		X	X	X	X		X	X	X	X	10
		Limnogonus hungerfordi Andersen	X													1
		Limnogonus windi Hungerford & Matsuda	X													1
Species/Locality			19	11	1	3	12	9	7	11	7	4	1	10	8	

Figure 2. Calvert River edge near crossing—typical of river edge habitat found at sites 1, 8, 12.

Figure 3. Calvert River at Figtree Camp—typical of still backwaters at sites 1, 8, 12.

Hebridae (velvet water bugs)

Hebrids also live in moist surroundings, preferring marginal aquatic habitats but sometimes rarely on water surfaces covered with floating plants (Andersen & Weir, 2004b). *Merragata hackeri* Hungerford (eight localities) is sparsely distributed in all Australian states except Tasmania while *Hebrus axillaris* Horvath (three localities) is the most widespread species of *Hebrus* in Australia, occurring in all states (Andersen & Weir 2004a).

Hydrometridae (water measurers, marsh treaders)

These extremely slender bugs also prefer marginal aquatic habitats or water surfaces covered with floating plants (Andersen & Weir, 2004b). *Hydrometra papuana* Kirkaldy (four localities) and *H. orientalis* Lundblad (two localities) are widely distributed across northern Australia and extend to South east Asia and the Indo-Malayan Archipelago, while *H. feta* Hale is widely distributed in northern and eastern Australia (Andersen & Weir, 2004a).

Veliidae (small water striders)

Veliid water bugs are common inhabitants of all sorts of freshwater bodies, both stagnant and flowing, but prefer the edges of the latter and spend most of their time on the water surface (Andersen & Weir, 2004b). *Microvelia* is the most speciose genus in Australia and is represented by four subgenera, all of which are now known to occur in Pungalina-Seven Emu. The three species of *Microvelia (Picaultia)*, *M. douglasi* Scott (six localities), *M. paramega* Andersen & Weir (two localities) and *M. justi* Andersen & Weir (one locality) all occur widely across northern Australia with *douglasi* being also widely distributed in the Oriental region. The subgenus *Pacificovelia* is represented by three species viz *M. oceanica* Distant (five localities), *M. lilliput* Andersen & Weir (seven localities) and *M. kakadu* Andersen & Weir (two localities). The first is one of the most widely distributed veliids in Australia, occurring over the whole continent and extending to several Pacific islands, while the other two, our smallest veliids at just over 1 mm in length, are known from various localities across northern Australia (Andersen & Weir, 2003). *Microvelia (Austromicrovelia)* is the most speciose sub genus in Australia and is represented here by four species viz *M. australiensis* Andersen & Weir (six localities), *M. herberti* Andersen & Weir (six localities), *M. torresiana* Andersen & Weir (five localities) and *M. odontogaster* Andersen & Weir (two localities). While the first three are known from many localities across northern Australia, *odonogaster* is known from only a handful of places in the Northern Territory. *Microvelia (Barbivelia) falcifer* Andersen & Weir (one locality) is arguably our rarest veliid, known from only four localities in Kakadu National Park, Northern Territory and only a handful of specimens, so it was exciting to collect one female of this species at Karns Creek Camp.

Figure 4. Waterlily pond near Calvert River Xing—typical habitat for mesoveliids and hydrometrids as found at sites 1, 8, 12.

Also at Karns Creek Camp was collected *Petrovelia katherinae* Andersen and Weir (one locality), a species known from a few localities in Northern Territory and the Kimberley Region of Western Australia. Members of this genus spend time resting on moist rocks and logs just above the water line and when disturbed, they rush on to the water surface before returning to their rocks and logs (Andersen & Weir, 2004a, 2004b). Specimens of *Phoreticovelia rotunda* Polhemus & Polhemus (one locality) were taken at Figtree Camp, Calvert River and is recorded from various localities across northern Australia. The genus *Phoreticovelia* is unique in several aspects, firstly the presence of large patches of waxy secretion on each side of the midline of the female and secondly the pronounced sexual size dimorphism where the female is approximately twice the size of the male. The generic name is derived from the male being phoretic, sitting in a depression on the female's back between the patches of waxy secretions (Andersen & Weir, 2001).

Gerridae (water striders, pond skaters)

Rhagadotarsus anomalus Polhemus & Karunaratne (three localities) is a small water strider that often occurs in large numbers on still or slow moving bodies of water. It is the only Australian member of the sub family Rhagadotarsinae, is widely distributed across much of northern Australia, extending into Papua New Guinea, and moves with a distinctive jerky motion across the water surface (Andersen & Weir, 1997, 2004b). The gerrine water striders are represented here by the four species of the genus *Limnogonus* viz *L. fossarum gilguy* Andersen & Weir (six localities), *L. luctuosus* Montrouzier (ten localities), *L. hungerfordi* Andersen (one locality) and *L. windi* Hungerford & Matsuda (one locality). All species are widely distributed across northern Australia, with *L. hungerfordi* and *L. windi* recorded from many fewer localities than either *L. fossarum gilguy* or *L. luctuosus*. The three species *L. fossarum gilguy, L. luctuosus* and *L. hungerfordi* are eurytopic and dimorphic, with habitats ranging from streams to temporary

Table 3. Species of Aquatic Bugs (Nepomorpha) collected in the Pungalina–Seven Emu Sanctuary, Gulf Coastal Bioregion, Northern Territory, June/July 2012. See Table 1, page 111 for locality data.

Nepomorpha			Localities													Locality/ Species
Family	**Subfamily**	**Genus & Species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
Nepidae	Ranatrinae	*Ranatra diminuta* Montandon	X					X		X		X		X		5
		Cercotmetus brevipes australis Lansbury		X												1
Belostomatidae	Belostomatinae	*Diplonychus rusticus* (Fabricius)	X	X				X			X			X		5
	Lethocerinae	*Lethocerus distinctifemur* Menke	X													1
Corixidae	Corixinae	*Agraptocorixa halei* Hungerford	X	X							X					3
		Agraptocorixa sp. [female]						X								1
Micronectidae		*Austronecta bartzarum* Tinerella						X								1
		Micronecta paragoga Tinerella					X									1
		Micronecta lubibunda Breddin									X					1
		Micronecta gracilis Hale	X													1
		Micronecta adelaidae Chen	X								X					2
		Micronecta virgata Hale	X	X							X					3
		Micronecta quadristrigata Breddin						X								1
		Micronecta sp. nov. DARK	X													1
Naucoridae		*Naucoris* sp. [nymph]						X								1
Ochteridae		*Ochterus baehri riegeri* Baehr						X						X		2
Notonectidae	Anisopinae	*Anisops semitus* Brooks	X			X		X			X		X			5
		Anisops nasutus Fieber											X			1
		Anisops tahitiensis Lundblad						X								1
		Anisops stali Kirkaldy		X				X								2
		Anisops occipitalis Breddin	X													1
		Anisops sp. nov. WIDEPRONG										X				1
	Notonectinae	*Nychia sappho* Kirkaldy	X	X								X				3
		Enithares loria Brooks	X			X		X			X			X		5
Pleidae		*Paraplea brunni* (Kirkaldy)	X	X				X	X		X				X	6
		Paraplea sp. nov. ANIC 1	X	X			X	X		X	X			X	X	8
		Paraplea sp. nov. ANIC 3		X			X	X		X	X					5
Species/Locality			14	9		2	3	14	1	3	10	3	2	5	2	

waterholes, while *windi* is predominantly apterous and prefers more permanent water bodies (Andersen & Weir, 1997, 2004b). It should be noted that Damgaard et al (2010) regard the Australian population of *Limnogonus luctuosus* as constituting a separate species from the populations extralimital to Australia.

Nepomorpha (aquatic bugs—Table 3, page 115)

Nepidae (water scorpions)

Only two genera of the subfamily Ranatrinae, *Ranatra* and *Cercotmetus* were collected during this survey. *Ranatra diminuta* Montandon (five localities) is a true "water stick insect" with elongate cylindrical body, long respiratory siphon and long slender legs and

Figure 5. Big Stinking Lagoon—assessing the situation before collecting. Note the reeds, waterlilies and submerged vegetation typical of sites 6 and 9.

usually lives amongst submerged vegetation at the edge of water bodies. It is recorded from numerous localities across northern Australia. *Cercotmetus brevipes australis* Lansbury (one locality) is a more robust species living in the same habitat as the previous species, but is more robust and better able to swim due to the presence of well developed swimming hairs on middle and hind tibiae. It is known from even fewer localities in north Queensland and the top end of Northern Territory (Andersen & Weir 2004b).

Belostomatidae (giant water bugs)

Members of the genus *Diplonychus* have a unique reproductive biology with the females, after mating, gluing the eggs to the dorsum of the male. They tend to live in still or stagnant shallow water bodies with vegetation. *Diplonychus rusticus* (Fabricius) (five localities) is recorded from many localities across northern Australia and extends outside from India through South east Asia to Papua New Guinea (Andersen & Weir, 2004b). *Lethocerus distinctifemur* Menke (one locality) is our largest water bug, reaching a length of 50–70mm, and is found in ponds and lakes. They are powerful swimmers and are often attracted to light as was the case here at Pungalina Homestead. This species is recorded from many localities over the northern two thirds of the Australian continent (Andersen & Weir, 2004b).

Corixidae (water boatmen)

Only one genus of Corixinae, *Agraptocorixa*, was collected at Pungalina-Seven Emu during this survey and members of this genus seem to prefer ponds or sluggish parts of streams. *Agraptocorixa halei* Hungerford (three localities) shows a distinctly northern distribution across Northern Territory, Queensland and the Kimberley region of Western Australia (Andersen & Weir, 2004b).

Micronectidae (pygmy water boatmen)

Until recently, these species were considered a subfamily of Corixidae, but are now recognised at the family level (Nieser, 1999). They are small to very small, ranging in size in Australia from 1.6 mm to 4.6 mm and are typically inhabitants of stagnant or still waters such as lakes, ponds and stream pools. Tinerella (2013)

Figure 6. Safari Camp—flowing spring fed stream with submerged and fringing vegetation found at site 7.

has recently revised the Australian fauna which now consists of two genera, *Micronecta* and *Austronecta,* both of which occur in Pungalina-Seven Emu. *Austronecta bartzarum* Tinerella (one locality) was described from numerous localities in Northern Territory and Western Australia. Five of the six species of *Micronecta* viz *M. paragoga* Tinerella (one locality), *M. lubibunda* Breddin (one locality), *M. adelaidae* Chen (two localities), *M. virgata* Hale (three localities) and *M. quadristrigata* Breddin (one locality) all show a northern distribution although only few localities were included in Tinerella, 2013. Extralimital distributions into South east Asia occur for *M. lubibunda, M. virgata* and *M. quadristrigata.* For *M. gracilis* Hale (one locality), Tinerella gives a wide distribution in NSW, Victoria and South Australia with northern extensions into Queensland and Northern Territory.

Two female specimens of *Micronecta* sp. nov. DARK were collected at Pungalina homestead. These do not fit any species in either of Tinerella's papers of the New Guinea and Australian fauna (2008, 2013), but until males are found, their status and relationships will remain unknown.

Naucoridae (creeping water bugs, saucer bugs)

Most species of *Naucoris* occur in stagnant waters or sluggish backwaters of streams with rich vegetation (Andersen & Weir, 2004b). The one nymphal specimen taken at Cycad Creek Camp indicates the presence of the family but does not allow for determination of which of the three species of *Naucoris* recorded from Northern Territory that it might be.

Ochteridae (velvety shore bugs)

As the common name implies, species of this family live at the margins of various bodies of freshwater and are mostly found in sandy or stony places with little vegetation. Their cryptic colouration makes them difficult to see and they can run rapidly, jump and fly when disturbed (Andersen & Weir, 2004b). *Ochterus baehri riegeri* Baehr (two localities) is recorded only from the Northern Territory while the other subspecies is restricted to north Queensland.

Figure 7. Lake Crocodylus—note shallow receding water with little vegetation found at site 4.

Notonectidae (backswimmers)

Notonectids are some of the most common and widespread waterbugs in Australia and as the common name implies they swim on their backs, a feature shared in Australia only with Pleidae. They are excellent swimmers and occur in a variety of freshwater habitats, although the quiet waters (sometimes stagnant) of pools, ponds and lakes are preferred (Andersen & Weir, 2004b). Species separation relies heavily on the males, and unassociated females were not assigned to species here. Anisopinae is represented here by six species of *Anisops* viz *A. semitus* Brooks (five localities), *A. nasutus* Fieber (one locality), *A. tahitiensis* Lundblad (one locality), *A. occipitalis* Breddin (one locality), *A. stali* Kirkaldy (two localities) and *Anisops* sp. nov. WIDEPRONG (one locality). Of these, the first four show a typical northern distribution pattern across Western Australia, Northern Territory and Queensland, while *A. stali* occurs over much of the Australian continent except Tasmania. *Anisops* sp. nov. WIDEPRONG is known in collections from three widely separated localities and its occurrence here at AWC Camp spans the gap between these localities. Extralimital distributions into South east Asia and the Pacific Islands are seen in four species: *A. nasutus, A. tahitiensis, A. stali* and *A. occipitalis* (Andersen & Weir, 2004b). Nepinae are here represented by the genera *Enithares* and *Nychia. Enithares loria* Brooks (five localities) and *Nychia sappho* Kirkaldy (three localities) are both found widely across northern Australia with the former also occurring in Papua New Guinea and the Solomons, while the latter is widely distributed in the Oriental region and Papua New Guinea (Andersen & Weir, 2004b).

Pleidae (pygmy backswimmers)

The pygmy backswimmers owe their name to their small size (1.5 mm to 2.0 mm) and habit of swimming on their back. They look like small compact notonectids without the elongated back legs and are good swimmers. Typically, they inhabit stagnant water bodies with rich vegetation in which they hide (Andersen & Weir, 2004b). *Paraplea* is the only genus found in Australia and three species were collected during this survey: *P. brunni* (Kirkaldy) (six localities), *Paraplea* sp. nov. ANIC 1 (eight localities) and *Paraplea* sp. nov. ANIC 3 (five localities). The first two species are widely distributed across northern Western Australia, Northern Territory and Queensland, with *P. brunni* extending southwards in Queensland. *Paraplea* sp. nov. ANIC 3 was known from a few localities in north Queensland before this survey, so their being found here has added greatly to our knowledge of this undescribed species.

Discussion

Most of the Gerromorphan and Nepomorphan bugs collected during this survey fall into the northern distribution pattern of Andersen & Weir, 2004b, with some having a wider distribution over the Australian continent. Examples of the latter are *Hebrus axillaris, Microvelia (Pacificovelia) oceanica, Limnogonus fossarum gilguy* and *Rhagadotarsus anomalus* in the Gerromorpha and *Lethocerus distinctifemur, Micronecta gracilis, Anisops stali* and *Paraplea brunni* in the Nepomorpha. Further species exhibit a strong oriental element with wide ranging distributions to our north. These species are exemplified by *Mesovelia horvathi, Mesovelia vittigera, Hydrometra papuana* and *Hydrometra orientalis, Rhagadotarsus anomalus, Limnogonus fossarum gilguy* and *Limnogonus hungerfordi* in the Gerromorpha and *Diplonychus rusticus, Micronecta lubibunda, Micronecta virgata, Micronecta quadristrigata, Anisops nasutus, Anisops tahitiensis, Anisops stali, Anisops occipitalis, Enithares loria* and *Nychia sappho* in the Nepomorpha.

If we compare the Gerromorphan fauna collected during the 1995 RGSQ scientific study of the Musselbrook/Lawn Hill area, 250 km SSE of Pungalina–Seven Emu with that collected during the 2012 survey here, we find that there are 15 species common to both areas, out of a total of 22 species at Musselbrook/Lawn Hill and 26 species at Pungalina–Seven Emu. Some of the species listed in Weir, 1998 were coded and these codes are now known to apply to the following species:

- *Microvelia* sp. nov. D = *Microvelia (Pacificovelia) kakadu* Andersen & Weir
- *Microvelia* sp. nov. B = *Microvelia (Austromicrovelia) herberti* Andersen & Weir
- *Microvelia* sp. nov. K = *Microvelia (Austromicrovelia) torresiana* Andersen & Weir
- *Microvelia* sp. nov. M2 = *Microvelia (Picaultia) paramega* Andersen & Weir
- *Microvelia* sp. nov. O = *Microvelia (Austromicrovelia) australiensis* Andersen & Weir
- *Microvelia* sp. nov. NTMD 1 = *Microvelia (Austromicrovelia) malipatili* Andersen & Weir
- *Mesovelia* sp. nov. = *Mesovelia stysi* Polhemus & Polhemus
- *Hebrus* sp. = *Hebrus nourlangiei* Lansbury

Others have since been synonymised:

- *Hydrometra risbeci* Hungerford = *Hydrometra strigosa* (Skuse)
- *Hydrometra halei* Hungerford & Evans = *Hydrometra feta* Hale

At Pungalina–Seven Emu we have two species that exhibit the most common vicariance pattern for Australian water bugs i.e. across the Gulf of Carpentaria, separating northeastern Queensland and Cape York Peninsula from the northeastern-most parts of Northern Territory and Western Australia (Andersen & Weir, 2004b). *Petrovelia katherinae* forms a sister pair with *Petrovelia agilis* Andersen and Weir, while *Microvelia (Barbivelia) falcifer* forms a sister pair with *Microvelia (Barbivelia) barbifer* Andersen & Weir. Other examples of this vicariance, not collected at Pungalina-Seven Emu, are *Tenagogerris pallidus* Andersen & Weir from Northern Territory and Western Australia and *Tenagogerris euphrosyne* (Kirkaldy) from Queensland, New South Wales, Victoria, South Australia and *Aquarius fabricii* Andersen from Northern Territory and Western Australia and *Aquarius antigone* (Kirkaldy) from Queensland, New South Wales, Victoria, South Australia. Of note is that *T. euphrosnyne* was taken in numbers at Border Waterhole in the Musselbrook section of Lawn Hill National Park, but not in this survey despite the existence of suitable habitats, indicating that Border Waterhole could be the real western limit of its distribution.

Considering the number of species per locality for the 13 localities sampled here, the most speciose locality by far was Pungalina Homestead (Site 1) with 33 species, followed by Cycad Creek Camp (Site 6) with 23 species, Karns Creek Camp (Site 2) with 20 species, Big Stinking Lagoon (Site 9) with 17 species, Mystery Shovel Creek (Site 5) and Calvert River Xing (Site 12) both with 15 species and Figtree Camp, Calvert River (Site 8) with 14 species. This is not surprising as all of these sites provided a variety of habitats including flowing rivers or creeks, small and large still pools with lots of aquatic vegetation and temporary pools in drying creek beds or depressions. The fast flowing springs at Pandanus Spring (Site 3—one species), Safari Camp (Site 7—eight species) and AWC Camp (Site 10—seven species) yielded many fewer species due to the lack of still waters available while the degraded and receding Lake Crocodylus (Site 4) produced only four species. The stagnant pool with lots of scum, floating debris and algal growth, 5 km north of Calvert River (Site 13), produced more than first expected with ten species while the small pools in the drying creek bed in the unnamed creek north of Cycad Creek (Site 11) yielded only three species.

Of particular interest in the Gerromorpha is the discovery of a single specimen of *Microvelia (Barbivelia) falcifer* at Karns Creek Camp, this being only the fifth known and most easterly locality for this species. The finding of *Petrovelia katherinae,* also at Karns Creek Camp is also the most easterly record of this species by far. *Phoreticovelia rotunda* from Figtree Camp, Calvert River, also taken at Lawn Hill National Park in 1995, fills another gap between the western and eastern distribution of this species. In the Nepomorpha, the most interesting find was that of the new species of *Micronecta, M.* sp. nov. DARK from Pungalina Homestead. This large, dark species does not fit the descriptions of any species described in either of Tinerella's papers on the micronectid fauna of Papua New Guinea (Tinerella 2008, 2013), but unfortunately only two female specimens were collected and species separation depends heavily on the male genitalia in this genus. Hopefully males can be collected at some time in the future to allow description. *Anisops* sp. nov. WIDEPRONG is known in collections from only three sites— Musselbrook section of Lawn Hill National Park, Queensland, Coburg Peninsula, Northern Territory and Keep River National Park, Northern Territory. Its collection at AWC Camp aligns with that at Musselbrook and confirms its easterly distribution in Northern Territory.

Pungalina–Seven Emu Sanctuary is an important area of the Northern Territory for the preservation of a variety of habitats for semi-aquatic and aquatic bugs as shown by the number of species collected during this short two week survey, and distributions have been extended in many cases. More species can be expected to be collected at habitats not sampled during this visit, especially the coastal and mangrove habitats which can be expected to yield near shore and estuarine species of *Halobates* (Gerridae: Halobatinae – sea skaters) and *Halovelia* and *Xenobates* (Veliidae: Haloveliinae - coral bugs). Other omissions of expected fauna include the widespread water scorpion *Laccotrephes tristis* (Stal) (Nepidae: Nepinae), members of the genus *Nerthra* (Gelastocoridae), further species of *Anisops* (Notonectidae: Anisopinae), and adults of *Naucoris* (Naucoridae) which will allow species identification.

Acknowledgements

I wish to thank the Australian Wildlife Conservancy for the opportunity to sample their recently acquired Pungalina–Seven Emu Sanctuary, The Royal Geographical Society of Queensland for providing the infrastructure that made the survey possible, CSIRO Ecosystem Sciences for making available transport and necessary field equipment and fellow CSIRO Ecosystem Sciences travellers for their support in the field.

References

Andersen N.M. & Weir, T.A. 1994. The sea skaters, genus *Halobates* Eschscholtz (Hemiptera: Gerridae) of Australia: taxonomy, phylogeny and zoogeography. *Invertebrate Taxonomy* 8: 861-909.

Andersen, N.M. & Weir, T.A. 1997. The gerrine water striders of Australia (Hemiptera: Gerridae): Taxonomy, distribution and ecology. *Invertebrate Taxonomy* 11: 203-299.

Andersen, N.M.& Weir, T.A. 1998. Australian water striders belonging to the subfamilies Rhagadotarsinae and Trepobatinae (Hemiptera: Gerridae). *Invertebrate Taxonomy* 12: 509-544.

Andersen, N.M. & Weir, T.A. 1999. The marine Haloveliinae (Hemiptera: Veliidae) of Australia, New Caledonia and southern New Guinea. *Invertebrate Taxonomy* 13: 309-350.

Andersen, N.M. & Weir, T.A. 2000. The coral treaders, *Hermatobates* Carpenter (Hemiptera: Hermatobatidae), of Australia and New Caledonia, with notes on biology and ecology. *Invertebrate Taxonomy* 14: 327-345.

Andersen, N.M. & Weir, T.A. 2001. New genera of Veliidae (Hemiptera: Hetetroptera) from Australia, with notes on the generic classification of the Microveliinae. *Invertebrate Taxonomy* 15: 217-258.

Andersen, N.M. & Weir, T.A. 2003. The genus *Microvelia* Westwood in Australia (Hemiptera: Heteroptera: Veliidae). *Invertebrate Taxonomy* 17: 261-348.

Andersen, N.M. & Weir, T.A. 2004a. The families Mesoveliidae, Hebridae and Hydrometridae of Australia (Hemiptera: Heteroptera: Gerromorpha) with a reanalysis of phylogenetic relationships between families. *Invertebrate Taxonomy* 18: 467-522.

Andersen, N.M. & Weir, T.A. 2004b. *Australian Water Bugs. Their biology and identification (Hemiptera: Heteroptera: Gerromorpha & Nepomorpha).* Entomonograph 14, Apollo Books, Kirkeby Sand 19, DK-5771 Stenstrup, Denmark. 344pp.

Damgaard, J., Buzzetti, F.M., Mazzucconi, S.A., Weir, T.A. and Zettel, H. 2010. A molecular phylogeny of the pan-tropical pond skater genus *Limnogonus* Stal, 1868 (Hemiptera-Heteroptera: Gerromorpha-Gerridae). *Molecular Phylogenetics and Evolution* 57(2): 669-677.

Nieser, N. 1999. Introduction to the Micronectidae (Nepomorpha) of Thailand. *Amemboa* 3: 9-12.

Tinerella, P.P. 2008. Taxonomic revision and systematics of New Guinea and Oceania pygmy water boatmen (Hemiptera: Heteroptera: Corixoidea: Micronectidae). *Zootaxa* 1797: 1-66.

Tinerella, P.P. 2013. Taxonomic revision and systematics of continental Australian pygmy water boatmen (Hemiptera: Heteroptera: Corixoidea: Micronectidae). *Zootaxa* 3623: 1-121.

Weir, T.A. 1998. Semi-aquatic bugs (Insecta: Hemiptera: Gerromorpha) of the Musselbrook area. *Musselbrook Reserve Scientific Study Report. Geography Monograph Series No. 4. Royal Geographical Society of Queensland* 305-310.

Weir, T.A. 2003. Semi-aquatic bugs (Insecta: Hemiptera: Gerromorpha) of the White Mountains National Park area. *White Mountains Scientific Study Report. Geography Monograph Series No. 9. Royal Geographical Society of Queensland* 125-131.

Avian Fauna Survey of Pungalina-Seven Emu Wildlife Sanctuary

Dezmond R. Wells (BSc, GradDipEd, AssDipAppSc)
BirdLife Australia Southern Queensland

32 Panoramic Dr, Narangba, QLD 4504, Australia.
Email: dez.wells@bigpond.com

Abstract Point count surveys are widely used for monitoring avian communities. The traditional method used by BirdLife Australia involves obtaining present-absence data and abundance data by sighting or hearing birds within a defined area for a defined time period. However, many species are difficult to observe, habitat cannot be easily traversed and call-song is dependent on time of day. Passive acoustic monitoring provides another tool by which sounds can be collected and analysed for determining avian presence. Avian communities were studied across two areas of Pungalina–Seven Emu Wildlife Sanctuary, using the point counts method and acoustic monitors. A total of 78 two hectare 20 minute surveys, 93 five hundred metre radius area surveys, 335 five kilometre drive through area surveys, 15 incidental surveys, 880 one hour acoustic day surveys and 80 acoustic night surveys were conducted and observations made (Appendix 1, starting page 132). Bird species were identified, counted and recorded. 167 bird species were positively identified over 13 days. 26 species were confirmed for the property considered possible or likely in the 2009 AWC survey, while two species not considered in the 2009 report have been identified as present. A further 14 unverified bird species tentatively recorded on Pungalina-Seven Emu Wildlife Sanctuary during the survey have been sent to BirdLife Australia's rarity committee for verification. Some of these species have photo evidence and sound evidence collected. Seven of these species sent for verification were considered possible or likely in the 2009 report, while another seven species were not considered in the 2009 report. The unverified species have not been included in the analysis for this report.

Introduction

This paper reviews the avian fauna of Pungalina-Seven Emu Wildlife Sanctuary based on new data collected during 13 days of surveying on the property from the 24th June to 6th July 2012. Details of all birds recorded are provided and information on the frequency of occurrence in the region and habitat selection is summarised and distribution maps created for species occurring at greater than two sites. Recent AWC avifauna surveys occurred in May-June 2009 on Pungalina-Seven Emu Wildlife Sanctuary, when a total of 151 species was confirmed (Kanowski et al., 2009). The Pungalina entrance to Pungalina-Seven Emu Wildlife Sanctuary is located about 45 km along Highway 1 from the Queensland–Northern Territory border. The sanctuary boundaries however start well north of this entrance.

The 300,000 ha reserve lies in the catchments of the Calvert and Robinson Rivers, Northern Territory. Ecosystems include savannah woodlands, rocky escarpments and freshwater springs in the upper reaches of the catchments, riverine habitats, and cypress pine woodlands, grasslands, saline flats and monsoon forests on the coastal plains (Appendix 3, starting page 146). Pungalina-Seven Emu Wildlife Sanctuary is located in the Gulf Coastal bioregion of northern Australia.

The multiple aims of this paper are:

- To give an account of the avifauna species richness of Pungalina-Seven Emu Wildlife Sanctuary, as a subset of its two areas, Pungalina and Seven Emu Wildlife Sanctuary.
- To compare patterns of species diversity between vegetation communities and general feeding habits.

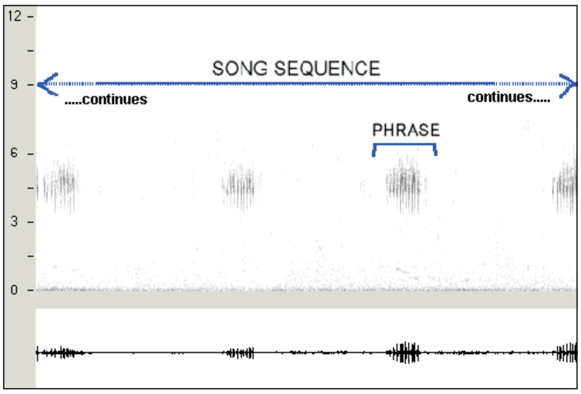


Figure 1. Graph showing a 20 second fragment over a one minute song and identifies a phrase.

- To identify species of notable conservation status.

Surveys were carried out by walking defined areas and recording bird species presence–absence data and abundance.

Passive acoustic monitoring offered an alternative method where visual surveying in situations was difficult due to habitat structure, and where species were considered to be visually cryptic. Many avian species are visually cryptic: for example, they may be small ground-based species, or species that are camouflaged, or species that live in thick foliage where they are difficult to sight, or species that are nocturnal, or species that are small in population size and thus less likely to be encountered (Marques et al., 2023).

Passive acoustic monitoring provided an opportunity to sample these visually cryptic species. Eight passive acoustic monitors were placed in distinct habitat types to sample the soundscape over a ten day period.

The soundscape captures bird vocalisation. A bird vocalises to communicate with others of the same species. This communication can be divided into two types, songs and calls. Calls tend to be shorter and simpler, while songs tend to be long, complex vocalisations. Most birds that sing have more than one song. Versions of songs are called song types. Bird songs can be analysed by looking at the structure of the song. A song can consist of a number of sections, these are called phrases. Each phrase can be further divided into a series of units called syllables. Syllables can be complex or simple; when complex the syllables can be further divided into elements. An element can be defined as a single line on a sonogram (Catchpole and Slater, 2008).

Bird song varies with species and within species at both a regional and subspecies level.

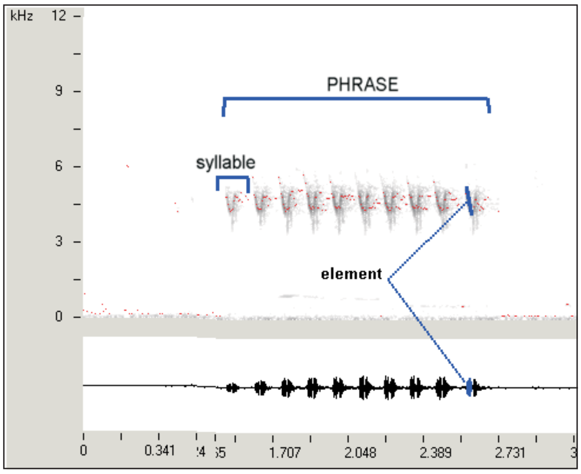


Figure 2. This graph expands one phrase of the same song shown in Figure 2 and shows the ten syllables constituting it (each syllable is composed by two elements) (Dragonetti, M. 2013).

Little classification of Australian species' songs has been made to date and this report attempts to add to the knowledge of bird song in the Northern Territory.

Methods

Location of survey sites

A stratified sampling method was used to select sites for field surveys using accessibility and National Vegetation Information System (NVIS) to select the widest geographical spread of sites across the major vegetation communities. The location of sites is shown in Figure 3, page 125 and the site detail is revealed in Appendix 1, starting on page 132.

Bird survey methodologies

Survey methodologies used in this report are based on The New Atlas of Australian Birds (Barrett et al. 2003). Avian communities were surveyed using the following four Birdlife Australia Atlas methods:

- **Two hectare 20 min Search** This method involved searching a two ha area for a set period of 20 minutes. Two hectares was generally defined as a circular area contained within a radius of 80 m from a central GPS location. However, sites situated on creeks varied in shape, being 400 m along the creek and 25 m either side (i.e. 400 m x 50 m). Bird species and numbers of each species were recorded. Only birds within the two ha area were recorded. Birds flying over were included in the count (e.g. foraging birds of prey). Waterbirds flying through not usually associated with the habitat being

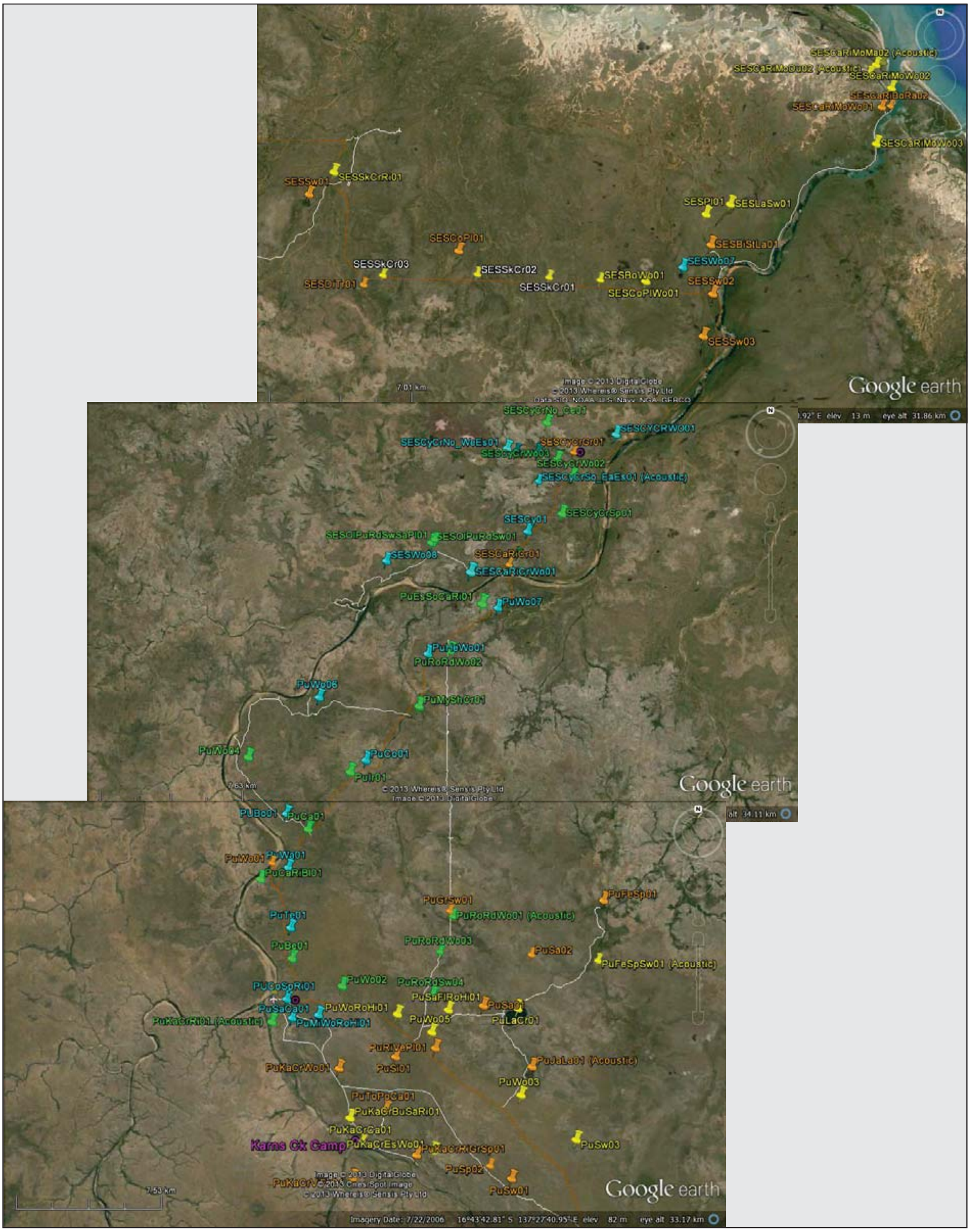


Figure 3. Sites selected for the field survey. See Appendix 1, starting on page 132, for site details.

surveyed were not included (e.g. a pelican would not normally be associated with a dune). A habitat form was completed for each 2 ha site surveyed.

• **Five hundred metre Area Search** This method involved searching a circular area contained within a radius of 500 m from a central GPS location. The presence of bird species was recorded. A 500 m Area Search was conducted at each two ha site. The two ha survey was conducted prior to the 500 m survey. The standard procedure was for surveyors to search for birds over a period of one hour, and:

- If no new species was found in the last 15 minutes then the search was concluded at one hour.
- If a new species was found in the last 15 minutes then the surveyor continued searching for another 15 minutes after the one hour.
- If a new species was found in the next 15 minutes, then the surveyor continued for another 15 minutes.

This survey technique was continued until no new species was found.

• **One Minute Grid Surveys (5 km Area Survey)** This method was used while surveyors travelled from one site to the next over a period of ten days. A surveyor would record all birds sighted within defined one minute grids. The standard procedure was that all vehicles travelling in a group would radio birds sighted to the lead vehicle as vehicles passed through defined grid zones. A new one minute grid zone was identified each time the minute on a GPS changed for either latitude or longitude and the lead vehicle would inform the other vehicles of a new survey. Over ten days, a list of birds was identified for each one minute grid zone providing a wide-ranging representation of avifauna using particular vegetation communities.

• **Incidental Surveys** This method was used to survey areas of interest such as lagoons and lakes if they were larger than contained within a 500 m Area Survey. All bird species seen were recorded and waterbird numbers counted.

• **Acoustic Surveys** Songmeter SM2+ units mounted with two SMX-II microphones (Wildlife Acoustics, Massachusetts) were located at eight sites on the property at a height of 1.5 m. Each songmeter was fitted with two 32 GB SDHC memory cards for storage of time stamped recordings. Each songmeter was manually operated to commence recording once installed and was retrieved after ten days. The soundscape was stored internally in stereo MP3 format, 128 Kb/s, 22050 Hz with 16-bit precision. Spectrograms of bird calls were produced using Raven Pro 1.4 with a Hann window function, DFT size of 512 points, grid spacing of 43.1 Hz, 3 dB filter bandwidth of 61.9 Hz, overlap of 80%. Spectrograms were viewed in Copper colour scheme, with contrast adjusted to 96 and brightness as required to reduce noise. Songmeter data was analysed by tagging species heard during one hour segments of recording for sites, producing 880 one–hour acoustic day surveys and 80 acoustic night surveys. This method was used at eight habitat sites.

Taxonomy, population categories and feeding guilds

Species and sub-species taxonomy was based on the Cornell Lab of Ornithology's Clements Checklist 6.7. Family names and common names were based on the BirdLife Australia's "Working List of Australian Birds", 2013.

Each species was placed into the following population categories as defined below:

• **Endemic**: Taxa that occur only in Australia (including territorial islands e.g. Norfolk, Christmas, etc.).

• **Australian**: Taxa that occur in Australia and elsewhere, but which breed in Australia.

• **Introduced**: Non-indigenous taxa introduced to Australia by people.

• **Domestic**: Non-indigenous taxa that do not have self-sustaining wild populations in Australia.

• **Sedentary**: Taxa that are present in the region throughout the year.

• **Nomadic**: Taxa whose occurrence in the region is dependent on unpredictable factors (e.g. rainfall). These species are often irruptive, so when present occur in large numbers.

• **Summer Migrant**: Taxa that migrate to the study area and are present in the study area between August and April.

• **Winter Migrant**: Taxa that migrate to the study area and are present in the study area between April and August.

• **Vagrant**: Taxa that occurs irregularly outside the normal identified range for the species.

Each bird species was placed into primary feeding habits as defined below. However, most species will opportunistically eat a number of these food types:

• **Insectivorous**: consumes insects or other arthropods/small crustaceans.

• **Nectivorous**: consumes the sugar-rich nectar produced by flowering plants.

• **Granivorous**: selectively consumes the nutrient-rich seeds produced by plants.

• **Herbivorous**: consumes plants (e.g. grass or aquatic plants).

• **Carnivorous**: consumes meat.

• **Frugivorous**: consumes fruit.

• **Omnivorous**: consumes a variety of plant and animal material.

Results

A total of 167 species of birds distributed among 56 families and 16 orders was recorded as verified on Pungalina-Seven Emu Wildlife Sanctuary during the study period (Appendix 2, starting on page 138 and Appendix 4, starting on page 148). Another 14 species awaiting verification have been included in Appendix 6, page 169. Property distribution maps for species have been included in Appendix 7, starting page 170.

There was no difference in the number of bird family groups present on the properties, with 52 groups of birds recorded on Pungalina compared to 53 groups of birds on Seven-Emu Wildlife Sanctuary. 129 species were identified on Pungalina compared with 155 species on Seven-Emu Wildlife Sanctuary. Honeyeater (HC) constituted the largest representation in both properties at 14 and 13 species respectively, followed by Birds of Prey (EKGO/Fal) at nine species and 14 species, on Pungalina-Seven Emu Wildlife Sanctuary, respectively (Figure 4, page 128).

Wetter ecosystems (swamps and creeks/springs) contained more species (109 species on average) than sites of woodland (63 species on average), which contained more species than open ecosystems like grasslands, dunes and chenopod flats (42 species on average). Ecosystems with more vegetation strata provided more habitats for use by birds. Those ecosystems with four or more strata held on average 86 species, three strata on average 60 species and two or fewer strata on average 34 species.

Sonograms of birds of Pungalina-Seven Emu Wildlife Sanctuary showed a range of complexity and frequency as described in Appendix 5 (Sonograms) starting on page 164.

A range of species could be found across habitats (Table 1, starting page 129). The Honeyeaters group was present in all ecosystems surveyed.

The graphs in Figure 5, page 131, show that the majority of the birds at Pungalina-Seven Emu Wildlife Sanctuary are sedentary (64%) and either insectivorous (45%) or carnivorous (26%) in feeding habit.

Discussion

The survey, while conducted at a large number of sites, was not a comprehensive survey of Pungalina-Seven Emu Wildlife Sanctuary. Large areas of Pungalina to the south-west of the Calvert River were inaccessible, distance prevented the team from accessing the ecosystems associated with the Robinson River, access by boat to the shorebird communities along the beach was stopped by inclement weather and fire prevented the team from reaching areas associated with western escarpment country on Seven Emu. The survey did not sample migratory waders that would normally inhabit the coastal regions, sandbars and chenopod flats, as these species would already have left on their northward migration. Sites containing *Acacia auriculiformis* mixed closed forest, *Tecticornia indica* low sparse samphire shrubland, *Casuarina equisetifolia* woodland, *Vetiveria elongate* tussock grassland, *Canarium australianum* mixed closed forest, and *Callitris intratropica* woodland could not be sampled or were poorly sampled. Future surveys should focus on these areas to enhance the understanding of avian use of the properties.

Sonograms showed a range of dominant frequencies based on habitat preference. Further work on sonograms recorded at Pungalina-Seven Emu Wildlife Sanctuary will occur over several years as species are identified and classified. Several species were identified from the sonograms but not from traditional survey methods. As the recordings are analysed, several more species could potentially be identified and added to the list.

Conclusion

Important Bird Areas (IBAs) are sites of global bird conservation importance (Birdlife Australia, online 2013). They are priority areas for bird conservation. Pungalina-Seven Emu Wildlife Sanctuary meets IBA criteria and should be managed to conserve the birds identified as globally threatened, restricted-range and biome-restricted. A site is defined as "Globally threatened" if it is known or thought regularly to hold significant numbers of a globally threatened species, or other species of global conservation concern. Pungalina birds identified during this survey in this category are Gouldian Finch, Beach Stone-curlew and Bush Stone-curlew.

A site is defined as "Restricted-range" if it is known or thought to hold a significant component of a group of species whose breeding distributions define an Endemic Bird Area or Secondary Area. Endemic Bird Areas are defined as places where two or more species of restricted-range occur together. Secondary Areas

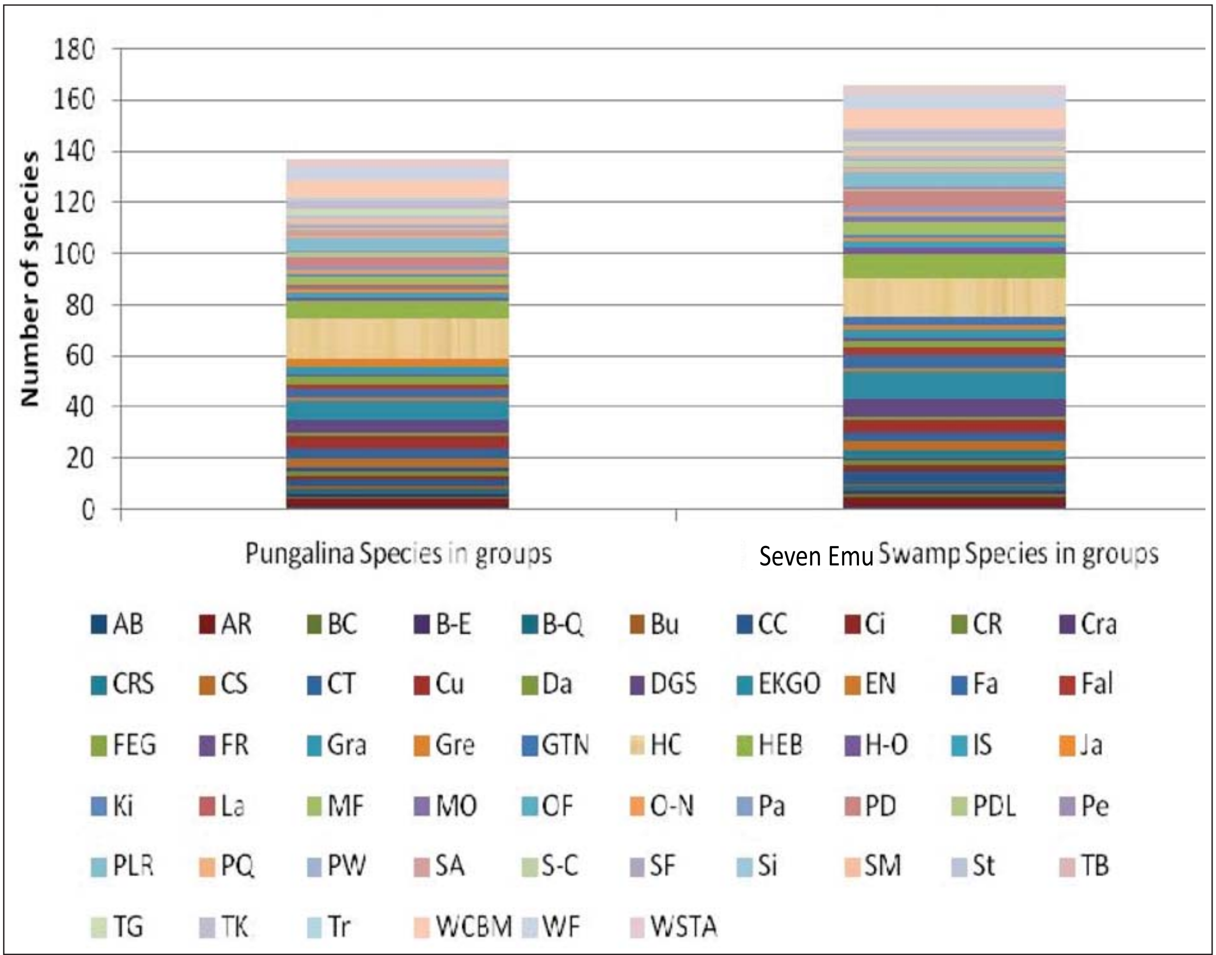


Figure 4. Bird Family groups on Pungalina and Seven Emu Wildlife Sanctuary.
PQ–Pheasants and Quail, **DGS**–Ducks, Geese and Swans, **Gre**-Grebes, **PD**–Pigeons and Doves, **FR**-Frogmouths, **EN**–Eared Nightjars, **O-N**–Owlet-nightjars, **Da**–Darter, **CS**–Cormorants and Shags, **Pe**–Pelican, **St**–Storks, **HEB**–Herons, Egrets and Bitterns, **IS**–Ibis and Spoonbills, **EKGO**–Eagles, Kites, Goshawks and Osprey, **Fal**–Falcons, **Cr**–Cranes, **CRS**–Crakes, Rails and Swamphens, **Bu**–Bustards, **S-C**–Stone-curlews, **SA**–Stilts and Avocets, **PDL**–Plovers, Dotterel and Lapwings, **Ja**–Jacanas, **B-Q**–Button-quail, **GTN**–Gulls, Terns and Noddies, **CC**–Cockatoos and Corellas, **PLR**–Parrots, Lorikeets and Rosellas, **Cu**–Cuckoos, **H-O**–Hawk-Owls, **MO**–Masked Owls, **Ki**–Kingfishers, **TK**–Tree Kingfishers, **B-E**–Bee-eaters, **Do**–Dollarbird, **Tr**–Treecreepers, **BC**–Bowerbirds and Catbirds, **FEG**–Fairy-wrens, Emu-wrens and Grasswrens, **TG**–Thornbills and Gerygones, **Pa**–Pardalotes, **HC**–Honeyeaters and Chats, **AB**–Australian Babblers, **Si**–Sittellas, **CT**–Cuckoo-shrikes and Trillers, **WSTA**–Whistlers, Shrike-thrushes and allies, **OF**-Orioles and Figbirds, **WCBM**–Woodswallows, Currawongs, Butcherbirds and Magpie, **Fa**–Fantails, **CR**–Crows and Ravens, **MF**–Monarch and Flycatchers, **AR**–Australian Robins, **La**–Larks, **Ci**–Cisticolas, **Gra**–Grassbirds, **TB**–True Babblers, **SM**–Swallows and Martins, **SF**–Sunbirds and Flowerpeckers, **WF**–Weaver Finches, and **PW**–Pipits and Wagtails.

usually have just one restricted-range species confined to the area. Pungalina-Seven Emu Wildlife Sanctuary would be defined as an Endemic Bird Area as it contains more than one restricted-range species—the Australian Bustard and Purple-crowned Fairywren.

A site is defined as "Biome-restricted" if it is known or thought to hold species whose distributions are largely or wholly confined to one biome. Pungalina-Seven Emu Wildlife Sanctuary falls under the Australian tropical savannah biome and birds identified at Pungalina-Seven Emu Wildlife Sanctuary falling into this category are the Varied Lorikeet, Northern Rosella, Silver-crowned Friarbird, White-gaped Honeyeater, Yellow-tinted Honeyeater, Bar-breasted Honeyeater, Banded Honeyeater, Buff-sided Robin, Sandstone Shrike-thrush, Masked Finch, Long-tailed Finch, Yellow White-eye and Grey-headed Honeyeater.

Pungalina-Seven Emu Wildlife Sanctuary, with 167 species is a site of Australian and global conservation significance for the birds.

Acknowledgements

This research was conducted with the help of surveyors Eric Anderson, Diana O'Connor, Graeme & Sandra Gallienne, Andrew McCutcheon, Greg Neil, Neil Humphris, Glen

Table 1: Dominant vegetation and species at Pungalina-Seven Emu Wildlife Sanctuary

Vegetation	Location (number of sites)	Dominant vegetation height (m)	Number of vertical strata	No. of species	Dominant Plant	Dominant species (occurring at 60% of sites of this type or only at this site)
Eucalyptus mid woodland\ *Bossiaea* tall sparse shrubland\ *Eriachne* low sparse tussock grassland	Seven-Emu Wildlife Sanctuary (13) & Pungalina (33)	12-15	3	75	*Eucalyptus tetrodonta*	Black-faced Cuckoo-shrike, Brown Honeyeater, Buff-sided Robin, Jacky Winter, Little Friarbird, Mistletoebird, Peaceful Dove, Pied Butcherbird, Northern Fantail, Rainbow Lorikeet, Red-winged Parrot, Rufous Whistler, Striated Pardalote, Silver-crowned Friarbird, Varied Lorikeet, Weebill, White-bellied Cuckoo-shrike, White-throated Gerygone, White-throated Honeyeater, Willie Wagtail
Corymbia low open woodland\ *Acacia* tall open shrubland\ *Triodia* mid open hummock grassland	Seven-Emu Wildlife Sanctuary (9) & Pungalina (5)	12-15	3-4	65	*Corymbia dichromophloia*	Banded Honeyeater, Brown Honeyeater, Jacky Winter, Long-tailed Finch, Little Woodswallow, Mistletoebird, Northern Fantail, Peaceful Dove, Red-backed Fairywren, Rufous Whistler, Rufous-throated Honeyeater, Singing Honeyeater, Striated Pardalote, Weebill, White-throated Honeyeater,
Eucalyptus low open woodland\ *Carissa* mid sparse shrubland\ *Chrysopogon* low tussock grassland	Seven-Emu Wildlife Sanctuary (14)	8-10	3-4	73	*Eucalyptus microtheca*	Banded Honeyeater, Bar-breasted Honeyeater, Blue-winged Kookaburra, Brown Goshawk, Brown Honeyeater, Brown Quail, Double-barred Finch, Jacky Winter, Little Friarbird, Little Woodswallow, Mistletoebird, Northern Fantail, Northern Rosella, Pied Butcherbird, Rainbow Lorikeet, Rainbow Bee-eater, Rufous Whistler, Rufous-throated Honeyeater, Silver-crowned Friarbird, Striated Pardalote, Weebill, Whistling Kite, White-gaped Honeyeater, White-throated Honeyeater, White-winged Triller, Willie Wagtail,
Eucalyptus mid woodland\ *Flueggea* mid sparse shrubland\ *Sehima* mid tussock grassland	Seven-Emu Wildlife Sanctuary (4)	12-18	4	69	*Eucalyptus tectifica*	Bar-breasted Honeyeater, Black-faced Cuckoo-shrike, Blue-winged Kookaburra, Brown Honeyeater, Double-barred Finch, Grey Fantail, Little Woodswallow, Northern Rosella, Olive-backed Oriole, Paperbark Flycatcher, Rufous Whistler, Silver-crowned Friarbird, Striated Pardalote, Whistling Kite, White-faced Heron, White-necked Heron, White-throated Gerygone, White-throated Honeyeater, White-winged Triller, Willie Wagtail

Vegetation	Location (number of sites)	Dominant vegetation height (m)	Number of vertical strata	No. of species	Dominant Plant	Dominant species (occurring at 60% of sites of this type or only at this site)
Pandanus low sparse palmland\ *Chrysopogon* mid tussock grassland	Seven-Emu Wildlife Sanctuary (4)	7-15	3	49	*Pandanus spiralis*	Australian Yellow White-eye, Bar-breasted Honeyeater, Grey Fantail, Lemon-bellied Flycatcher, Northern Fantail, Paperbark Flycatcher, Rainbow Bee-eater, Rainbow Lorikeet, Red-backed Fairywren, Rufous Whistler, Tree Martin, Whistling Kite, White-bellied Sea-eagle, White-gaped Honeyeater, White-throated honeyeater, Willie Wagtail
Tecticornia low sparse samphire shrubland	Seven-Emu Wildlife Sanctuary (1)	0.5 -1	1	29	*Tecticornia indica*	Australian Yellow White-eye, Brown Honeyeater, Grey Fantail, White-gaped Honeyeater, Whistling Kite
Avicennia low closed forest\ *Ceriops* low open forest*Avicennia* low open shrubland	Seven-Emu Wildlife Sanctuary (1)	4-6	2	40	*Avicennia marina*	Australian Yellow White-eye, Northern Fantail, Mangrove Grey Fantail, Mangrove Golden Whistler, Red-headed Honeyeater, Brown Honeyeater, White-throated Honeyeater, Arafura Fantail, Whistling KiteWhite-gaped Honeyeater, Shining Flycatcher
Canarium australianum/ *Ficus virens*/ *Diospyros humilis* closed forest	Seven-Emu Wildlife Sanctuary	15-30	2	-	*Canarium australianum*	Not surveyed
Acacia mixed closed Vine-thicket forest	Seven-Emu Wildlife Sanctuary	8-10	1	-	*Acacia torulosa*	Not surveyed
Melaleuca low open woodland\ *Pandanus*\ *Chrysopogon* mid tussock grassland	Pungalina (7)	15-20	3	58	*Melaleuca viridiflora*	Australian Magpie, Blue-faced Honeyeater, Brown Honeyeater, Brown Quail, Jacky Winter, Northern Fantail, Pied Butcherbird, Red-winged Parrot, Rufous Whistler, Silver-crowned Friarbird, Striated Pardalote, Weebill, White-throated Honeyeater, Willie Wagtail

Fergus, Jenny Curnow, Fay Hill, Sheena Gillman, David Stewart, Jim Butler, Clifford Grant, Kathy & Peter Wilk and Rod & Eve Kavanagh. I thank them for their tireless efforts and expert birding prowess and photographic skills over the thirteen days. Sadly, one of our team was injured early in the survey and I thank Peter Madvig for his effort in travelling up and initial surveying. Special thanks also goes to BirdLife Australia Southern Queensland for field and financial support, to the Norman Wettenhall Foundation for support through a $5000 grant and to Jason Wimmer from QUT for the use of acoustic monitors. We would also like to acknowledge the Australian Wildlife Conservancy and RGSQ for jointly organising the expedition.

References

Barrett, Geoff & Royal Australasian Ornithologists' Union. 2003. *The New Atlas of Australian Birds*, Royal Australasian Ornithologists Union, Hawthorn East, Vic

Birdlife Australia. Online, 2013. *Important Bird Areas*. http://www.birdlife.org.au/projects/important-bird-areas

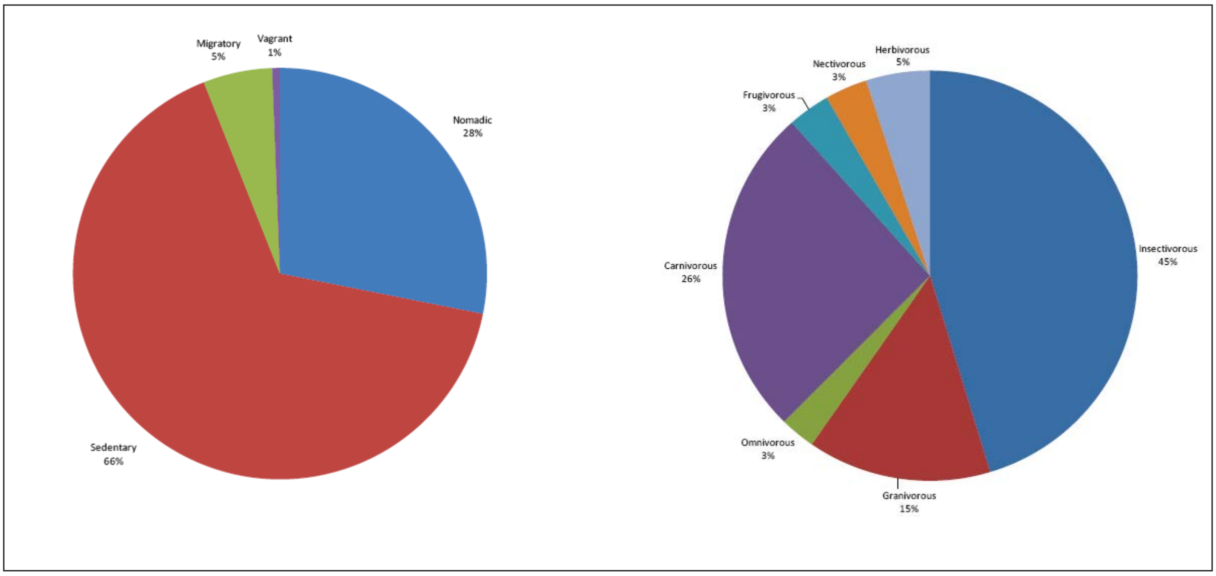


Figure 5. Graphs showing Categories of Population (left) and Feeding Habits.

Birdlife Australia. Online, 2013 *Working List of Australian Birds*. http://www.birdlife.org.au/conservation/science/taxonomy

Catchpole, C. & Slater, P.J.B. 2008. *Bird Song: Biological Themes and Variations*, Cambridge [England], Cambridge University Press.

Clements, J. Laboratory Of Ornithology & American Birding Association 2007, (online 2013). *The Clements Checklist of Birds of the World*. v6.7, http://www.birds.cornell.edu/clementschecklist.

Dragonetti, M. Online 2013. Bird songs and calls with spectrograms of southern Tuscany – Bird vocalisation. http://www.birdsongs.it/birdvoc/birdvoc.html

Field, S.A., Tyre, A.J. & Possingham, H.P. 2002. Estimating bird species richness: How should repeat surveys be organized in time? Austral Ecology, 27, 624-629.

Kanowski, J., Jensen, R., Lloyd, R., Middleton, J., Lawler, W. & Legge, S. 2009. *Wildlife Survey of Pungalina - Seven Emu - Report of a Survey,* May - June 2009. http://www.shapeourworld.com.au/_public/download/Pungalina_Seven_Emu_2009_Survey.pdf

Marques, T.A., Thomas, L., Martin, S.W., Mellinger, D.K., Ward, J.A., Moretti, D.J., Harris, D. & Tyack, P.L. 2013. Estimating animal population density using passive acoustics. *Biological Reviews*, 88, 287-309.

Pizzey, Graham (Graham Martin) & Knight, Frank, 1941- & Pizzey, Sarah 2012, *The Field Guide to the Birds of Australia,* 9th ed, HarperCollins Publishers, Sydney

Schodde, Richard & Tidemann, Sonia & Bell, Harry L & Reader's Digest Services 1986, *Reader's Digest Complete Book Of Australian Birds,* 2nd ed, Reader's Digest, Sydney

Wildlife Acoustics. Online 2013. *Bioacoustic Monitoring Systems*. http://www.wildlifeacoustics.com

Appendix 1. Sites

Each survey site was identified with a set code. Codes as shown below:
PU – Pungalina; SES – Seven Emu Wildlife Sanctuary; Ca – Calvert; Ri – River; Mo – Mouth; Ma – Mangrove; Sa – Sand; Du – Dune; Ka – Karnes; Cr – Creek; Wo – Woodland; Es – Escarpment

Site ID	Site Name	Survey Type	Number of Surveyors	Latitude	Longitude
16°16'00"S 137°44'00"E	16°16'00"S 137°44'00"E	Cell	4	16°16'00"S	137°44'00"E
16°17'00"S 137°43'00"E	16°17'00"S 137°43'00"E	Cell	4	16°17'00"S	137°43'00"E
16°17'00"S 137°44'00"E	16°17'00"S 137°44'00"E	Cell	4	16°17'00"S	137°44'00"E
16°18'00"S 137°43'00"E	16°18'00"S 137°43'00"E	Cell	4	16°18'00"S	137°43'00"E
16°19'00"S 137°27'00"E	16°19'00"S 137°27'00"E	Cell	5	16°19'00"S	137°27'00"E
16°19'00"S 137°28'00"E	16°19'00"S 137°28'00"E	Cell	5	16°19'00"S	137°28'00"E
16°19'00"S 137°41'00"E	16°19'00"S 137°41'00"E	Cell	4	16°19'00"S	137°41'00"E
16°19'00"S 137°42'00"E	16°19'00"S 137°42'00"E	Cell	4	16°19'00"S	137°42'00"E
16°19'00"S 137°43'00"E	16°19'00"S 137°43'00"E	Cell	4	16°18'00"S	137°43'00"E
16°20'00"S 137°27'00"E	16°20'00"S 137°27'00"E	Cell	5	16°20'00"S	137°27'00"E
16°20'00"S 137°28'00"E	16°20'00"S 137°28'00"E	Cell	5	16°20'00"S	137°28'00"E
16°20'00"S 137°38'00"E	16°20'00"S 137°38'00"E	Cell	4	16°22'00"S	137°38'00"E
16°20'00"S 137°40'00"E	16°20'00"S 137°40'00"E	Cell	4	16°20'00"S	137°40'00"E
16°20'00"S 137°41'00"E	16°20'00"S 137°41'00"E	Cell	4	16°20'00"S	137°41'00"E
16°21'00"S 137°26'00"E	16°21'00"S 137°26'00"E	Cell	5	16°21'00"S	137°26'00"E
16°21'00"S 137°28'00"E	16°21'00"S137°28'00"E	Cell	5	16°21'00"S	137°28'00"E
16°21'00"S137°38'00"E	16°21'00"S137°38'00"E	Cell	5	16°21'00"S	137°38'00"E
16°21'00"S137°39'00"E	16°21'00"S137°39'00"E	Cell	4	16°21'00"S	137°39'00"E
16°21'00"S137°40'00"E	16°21'00"S137°40'00"E	Cell	4	16°21'00"S	137°40'00"E
16°22'00"S137°28'00"E	16°22'00"S137°28'00"E	Cell	5	16°22'00"S	137°28'00"E
16°22'00"S137°29'00"E	16°22'00"S137°29'00"E	Cell	5	16°22'00"S	137°29'00"E
16°22'00"S137°30'00"E	16°22'00"S137°30'00"E	Cell	5	16°22'00"S	137°30'00"E
16°22'00"S137°31'00"E	16°22'00"S137°31'00"E	Cell	5	16°22'00"S	137°31'00"E
16°22'00"S137°32'00"E	16°22'00"S137°32'00"E	Cell	5	16°22'00"S	137°32'00"E
16°22'00"S137°33'00"E	16°22'00"S137°33'00"E	Cell	5	16°22'00"S	137°33'00"E
16°22'00"S137°34'00"E	16°22'00"S137°34'00"E	Cell	5	16°22'00"S	137°34'00"E
16°22'00"S137°35'00"E	16°22'00"S137°35'00"E	Cell	5	16°22'00"S	137°35'00"E
16°22'00"S137°36'00"E	16°22'00"S137°36'00"E	Cell	5	16°22'00"S	137°36'00"E
16°22'00"S137°37'00"E	16°22'00"S137°37'00"E	Cell	5	16°22'00"S	137°37'00"E
16°22'00"S137°38'00"E	16°22'00"S137°38'00"E	Cell	9	16°22'00"S	137°38'00"E
16°22'00"S137°39'00"E	16°22'00"S137°39'00"E	Cell	5	16°22'00"S	137°39'00"E
16°22'00"S137°40'00"E	16°22'00"S137°40'00"E	Cell	4	16°22'00"S	137°40'00"E
16°23'00"S137°38'00"E	16°23'00"S137°38'00"E	Cell	4	16°23'00"S	137°38'00"E
16°24'00"S137°38'00"E	16°24'00"S137°38'00"E	Cell	4	16°24'00"S	137°38'00"E
16°25'00"S137°37'00"E	16°25'00"S137°37'00"E	Cell	4	16°25'00"S	137°37'00"E
16°25'00"S137°38'00"E	16°25'00"S137°38'00"E	Cell	4	16°25'00"S	137°38'00"E
16°26'00"S137°33'00"E	16°26'00"S137°33'00"E	Cell	5	16°26 00"S	137°33'00"E
16°26'00"S137°34'00"E	16°26'00"S137°34'00"E	Cell	5	16°26 00"S	137°34'00"E
16°26'00"S137°35'00"E	16°26'00"S137°35'00"E	Cell	4	16°26 00"S	137°35'00"E
16°26'00"S137°36'00"E	16°26'00"S137°36'00"E	Cell	4	16°26 00"S	137°36'00"E
16°26'00"S137°37'00"E	16°26'00"S137°37'00"E	Cell	4	16°27'00"S	137°35'00"E
16°27'00"S137°34'00"E	16°27'00"S137°34'00"E	Cell	4	16°27'00"S	137°34'00"E
16°27'00"S137°35'00"E	16°27'00"S137°35'00"E	Cell	4	16°27'00"S	137°35'00"E
16°28'00"S137°33'00"E	16°28'00"S137°33'00"E	Cell	4	16°28'00"S	137°33'00"E
16°29'00"S137°32'00"E	16°29'00"S137°32'00"E	Cell	4	16°29'00"S	137°32'00"E

Site ID	Site Name	Survey Type	Number of Surveyors	Latitude	Longitude
16°29'00"S137°33'00"E	16°29'00"S137°33'00"E	Cell	4	16°29'00"S	137°33'00"E
16°29'00"S137°35'00"E	16°29'00"S137°35'00"E	Cell	5	16°29'00"S	137°35'00"E
16°30'00"S137°30'00"E	16°30'00"S137°30'00"E	Cell	5	16°30'00"S	137°30'00"E
16°30'00"S137°31'00"E	16°30'00"S137°31'00"E	Cell	4	16°30'00"S	137°31'00"E
16°30'00"S137°32'00"E	16°30'00"S137°32'00"E	Cell	4	16°30'00"S	137°32'00"E
16°31'00"S137°32'00"E	16°31'00"S137°32'00"E	Cell	4	16°31'00"S	137°32'00"E
16°32'00"S137°30'00"E	16°32'00"S137°30'00"E	Cell	4	16°32'00"S	137°30'00"E
16°32'00"S137°31'00"E	16°32'00"S137°31'00"E	Cell	5	16°30'00"S	137°32'00"E
16°33'00"S137°29'00"E	16°33'00"S137°29'00"E	Cell	5	16°33'00"S	137°29'00"E
16°33'00"S137°30'00E	16°33'00"S137°30'00"E	Cell	5	16°33'00"S	137°30'00"E
16°34'00"S137°29'00"E	16°34'00"S137°29'00"E	Cell	4	16°34'00"S	137°29'00"E
16°35'00"S137°23'00"E	16°35'00"S137°23'00"E	Cell	5	16°35'00"S	137°23'00"E
16°35'00"S137°28'00"E	16°35'00"S137°28'00"E	Cell	4	16°35'00"S	137°28'00"E
16°35'00"S137°29'00"E	16°35'00"S137°29'00"E	Cell	5	16°35'00"S	137°29'00"E
16°36'00"S137°27'00"E	16°36'00"S137°27'00"E	Cell	5	16°36'00"S	137°27'00"E
16°36'00"S137°28'00"E	16°36'00"S137°28'00"E	Cell	4	16°36'00"S	137°28'00"E
16°37'00"S137°27'00"E	16°37'00"S137°27'00"E	Cell	4	16°37'00"S	137°27'00"E
16°38'00"S137°25'00"E	16°38'00"S137°25'00"E	Cell	4	16°38'00"S	137°25'00"E
16°38'00"S137°26'00"E	16°38'00"S137°26'00"E	Cell	4	16°38'00"S	137°26'00"E
16°39'00"S137°25'00"E	16°39'00"S137°25'00"E	Cell	4	16°39'00"S	137°25'00"E
16°40'00"S137°25'00"E	16°40'00"S137°25'00"E	Cell	5	16°40'00"S	137°25'00"E
16°41 00"S137°25'00"E	16°41'00"S137°25'00"E	Cell	4	16°41'00"S	137°25'00"E
16°41'00"S137°34'00"E	16°41'00"S137°34'00"E	Cell	5	16°41'00"S	137°34'00"E
16°42'00"S137°25'00"E	16°42'00"S137°25'00"E	Cell	4	16°42'00"S	137°25'00"E
16°42'00"S137°29'00"E	16°42'00"S137°29'00"E	Cell	4	16°42'00"S	137°29'00"E
16°42'00"S137°32'00"E	16°42'00"S137°32'00"E	Cell	5	16°42'00"S	137°32'00"E
16°42'00"S137°33'00"E	16°42'00"S137°33'00"E	Cell	5	16°42'00"S	137°33'00"E
16°42'00"S137°34'00"E	16°42'00"S137°34'00"E	Cell	5	16°42'00"S	137°34'00"E
16°43'00"S137°24'00"E	16°43'00"S137°24'00"E	Cell	4	16°43'00"S	137°24'00"E
16°43'00"S137°25'00"E	16°43'00"S137°25'00"E	Cell	4	16°43'00"S	137°25'00"E
16°43'00"S137°26'00"E	16°43'00"S137°26'00"E	Cell	4	16°43'00"S	137°26'00"E
16°43'00"S137°27'00"E	16°43'00"S137°27'00"E	Cell	5	16°43'00"S	137°27'00"E
16°43'00"S137°28'00"E	16°43'00"S137°28'00"E	Cell	5	16°43'00"S	137°28'00"E
16°43'00"S137°29'00"E	16°43'00"S137°29'00"E	Cell	5	16°43'00"S	137°29'00"E
16°43'00"S137°30'00"E	16°43'00"S137°30'00"E	Cell	5	16°43'00"S	137°30'00"E
16°43'00"S137°31'00"E	16°43'00"S137°31'00"E	Cell	5	16°43'00"S	137°31'00"E
16°43'00"S137°32'00"E	16°43'00"S137°32'00"E	Cell	5	16°43'00"S	137°32'00"E
16°44'00"S137°25'00"E	16°44'00"S137°25'00"E	Cell	4	16°44'00"S	137°25'00"E
16°44'00"S137°26'00"E	16°44'00"S137°26'00"E	Cell	4	16°44'00"S	137°26'00"E
16°44'00"S137°28'00"E	16°44'00"S137°28'00"E	Cell	5	16°44'00"S	137°28'00"E
16°44'00"S137°29'00"E	16°44'00"S137°29'00"E	Cell	5	16°44'00"S	137°29'00"E
16°44'00"S137°31'00"E	16°44'00"S137°31'00"E	Cell	5	16°44'00"S	137°31'00"E
16°44'00"S137°32'00"E	16°44'00"S137°32'00"E	Cell	5	16°44'00"S	137°32'00"E
16°45'00"S137°26'00"E	16°45'00"S137°26'00"E	Cell	5	16°45'00"S	137°26'00"E
16°45'00"S137°27'00"E	16°45'00"S137°27'00"E	Cell	5	16°45'00"S	137°27'00"E
16°45'00"S137°28'00"E	16°45'00"S137°28'00"E	Cell	5	16°45'00"S	137°28'00"E
16°45'00"S137°29'00"E	16°45'00"S137°29'00"E	Cell	5	16°45'00"S	137°29'00"E
16°45'00"S137°30'00"E	16°45'00"S137°30'00"E	Cell	5	16°45'00"S	137°30'00"E
16°45'00"S137°31'00"E	16°45'00"S137°31'00"E	Cell	5	16°45'00"S	137°31'00"E
16°45'00"S137°32'00"E	16°45'00"S137°32'00"E	Cell	5	16°45'00"S	137°32'00"E
16°46'00"S137°27'00"E	16°46'00"S137°27'00"E	Cell	5	16°46'00"S	137°27'00"E

Site ID	Site Name	Survey Type	Number of Surveyors	Latitude	Longitude
16°46'00"S137°28'00"E	16°46'00"S137°28'00"E	Cell	4	16°46'00"S	137°28'00"E
16°46'00"S137°29'00"E	16°46'00"S137°29'00"E	Cell	5	16°46'00"S	137°29'00"E
16°46'00"S137°30'00"E	16°46'00"S137°30'00"E	Cell	5	16°46'00"S	137°30'00"E
16°46'00"S137°31'00"E	16°46'00"S137°31'00"E	Cell	5	16°46'00"S	137°31'00"E
16°46'00"S137°32'00"E	16°46'00"S137°32'00"E	Cell	5	16°46'00"S	137°32'00"E
16°47'00"S137°27'00"E	16°47'00"S137°27'00"E	Cell	5	16°47'00"S	137°27'00"E
16°47'00"S137°28'00"E	16°47'00"S137°28'00"E	Cell	5	16°47'00"S	137°28'00"E
16°47'00"S137°29'00"E	16°47'00"S137°29'00"E	Cell	5	16°47'00"S	137°29'00"E
16°47'00"S137°30'00"E	16°47'00"S137°30'00"E	Cell	5	16°47'00"S	137°30'00"E
16°47'00"S137°31'00"E	16°47'00"S137°31'00"E	Cell	5	16°47'00"S	137°31'00"E
16°47'00"S137°33'00"E	16°47'00"S137°33'00"E	Cell	4	16°47'00"S	137°33'00"E
16°48'00"S137°27'00"E	16°48'00"S137°27'00"E	Cell	5	16°48'00"S	137°27'00"E
16°48'00"S137°31'00"E	16°48'00"S137°31'00"E	Cell	5	16°48'00"S	137°31'00"E
16°48'00"S137°32'00"E	16°48'00"S137°32'00"E	Cell	5	16°48'00"S	137°32'00"E
16°48'00"S137°33'00"E	16°48'00"S137°33'00"E	Cell	4	16°48'00"S	137°33'00"E
16°49'00"S137°32'00"E	16°49'00"S137°32'00"E	Cell	5	16°49'00"S	137°32'00"E
16°49'00"S137°33'00"E	16°4900"S137°33'00"E	Cell	5	16°49'00"S	137°33'00"E
16°49'00"S137°34'00"E	16°4900"S137°34'00"E	Cell	5	16°49'00"S	137°34'00"E
16°52'00"S137°34'00"E	16°5200"S137°34'00"E	Cell	5	16°52'00"S	137°34'00"E
16°54'00"S137°36'00"E	16°5400"S137°36'00"E	Cell	5	16°54'00"S	137°36'00"E
16°55'00"S137°36'00"E	16°5500"S137°36'00"E	Cell	5	16°55'00"S	137°36'00"E
16°58'00"S137°38'00"E	16°5800"S137°38'00"E	Cell	5	16°58'00"S	137°38'00"E
16°59'00"S137°38'00"E	16°5900"S137°38'00"E	Cell	5	16°59'00"S	137°38'00"E
17°09'00"S137°39'00"E	17°0900"S137°39'00"E	Cell	4	17°09'00"S	137°39'00"E
PUBE01	Bella	2ha 20min, 500m Area	5	16°42'22"S	137°25'26"E
PUBO01	Bog Site 1	2ha 20min, 500m Area	5	16°38'08"S	137°25'13"E
PUCA01	Pungalina Caves	2ha 20min, 500m Area	5	16°38'35"S	137°25'53"E
PUCARIBL01	Calvert River Bluff	2ha 20min, 500m Area	5	16°40'03"S	137°24'28"E
PUCO01	Cobble Site 1	2ha 20min, 500m Area	5	16°36'41"S	137°27'43"E
PUCOSPRI01	Coconut Spring Riparian	2ha 20min, 500m Area	5	16°43'32"S	137°25'16"E
PUESSOCARI01	Escarpment South of Calvert River	2ha 20min, 500m Area	5	16°32'06"S	137°31'16"E
PUFESP01	Fern Springs	2ha 20min, 500m Area	5	16°40'41"S	137°34'46'E
PUFESPSW01	Fern Springs Swamp	500m Area, Acoustic	5	16°42'48"S	137°34'14'E
PUGRSW01	Green Swamp	500m Area	2	16°40'56"S	137°30'10"E
PUHEWO01	Heathy Woodland Site 1	2ha 20min, 500m Area	5	16°33'35"S	137°29'35"E
PUHO01	Pungalina Homestead	500m Area	5	16°43'16"S	137°24'52"E
PUIR01	Ironwood	2ha 20min, 500m Area	5	16°37'01"S	137°27'15"E
PUJALA01	Jabiru Lake	500m Area, Acoustic	5	16°45'27"S	137°32'33"E
PUKACA01	Karnes Creek Campsite	500m Area, Incidental	9	16°47'49"S	137°27'60"E
PUKACRBUSARI01	Karnes Creek Bubbling Sands Riparian	2ha 20min, 500m Area	4	16°46'53"S	137°27'10"E

Site ID	Site Name	Survey Type	Number of Surveyors	Latitude	Longitude
PUKACRESWO01	Karnes Creek Escarpment Woodland Site 1	2ha 20min, 500m Area	4	16°47'48"S	137°29'35"E
PUKACRRI01	Karnes Creek Riparian	2ha 20min, 500m Area, Acoustic	5	16°44'11"S	137°24'50"E
PUKACRRIGRSP01	Karnes Creek Riparian Green Spring	2ha 20min, 500m Area	5	16°48'04"S	137°29'16"E
PUKACRVIFO01	Karnes Creek Vine Forest	2ha 20min, 500m Area	5	16°48'34"S	137°27'15"E
PUKACRWO01	Karnes Creek Woodland 1	2ha 20min, 500m Area	5	16°45'30"S	137°26 50"E
PULACR01	Lake Crocodilus	500m Area, Incidental	5	16°43'42"S	137°31'48"E
PUMIWOROHI01	Mixed Woodland near Rocky Hill	2ha 20min, 500m Area	5	16°44'04"S	137°25'26"E
PUMYSHCR01	Mystery Shovel Creek	2ha 20min, 500m Area	5	16°35'08"S	137°29'19"E
PURIVEPL01	Rigels Vegetation Plot	2ha 20min, 500m Area	5	16°44'51"S	137°29'37"E
PURORDSW04	Rocky Road Swamp Site 4	2ha 20min, 500m Area	5	16°43'25"S	137°29'37"E
PURORDWO01	Rocky Road Woodland Site 1	2ha 20min, 500m Area, Acoustic	5	16°41'05"S	137°30'15"E
PURORDWO02	Rocky Road Woodland Site 2	2ha 20min, 500m Area	4	16°33'29"S	137°30'16"E
PURORDWO03	Rocky Road Woodland Site 3	2ha 20min, 500m Area	5	16°42'07"S	137°29'52"E
PUSA01	Sandplain 1	2ha 20min, 500m Area	5	16°43'45"S	137°31'28"E
PUSA02	Sandplain 2	500m Area	5	16°42'12"S	137°32'36"E
PUSACA01	Safari Camp	2ha 20min, 500m Area	5	16°43'59"S	137°26'13"E
PUSAFLROHI01	Sand Flat Rocky Hill	2ha 20min, 500m Area	4	16°43'50"S	137°30'05"E
PUSI01	Sinkhole	2ha 20min, 500m Area	5	16°45'10"S	137°28'31"E
PUSP01	Spinifex Site 1	2ha 20min, 500m Area	5	16°32'34"S	137°30'56"E
PUSP02	Spinifex Site 2	2ha 20min, 500m Area	5	16°48'11"S	137°31'18"E
PUSW01	Swamp Site 1	2ha 20min, 500m Area	5	16°48'35"S	137°31'55"E
PUSW03	Swamp Site 3	2ha 20min, 500m Area	4	16°47'29"S	137°33'49"E
PUTE01	Tetradonta Site 1	2ha 20min, 500m Area	5	16°41'29"S	137°25'22"E
Site ID	Site Name	Survey Type	Number of Surveyors	Latitude	Longitude
PUTOPOCA01	Totem Pole Cave	2ha 20min, 500m Area	5	16°46'39"S	137°28'14"E
PUWA01	Wattle Site 1	2ha 20min, 500m Area	5	16°39'43"S	137°25'18"E
PUWO01	Woodland Site 1	2ha 20min	5	16°39'32"S	137°24'49"E
PUWO02	Woodland Site 2	2ha 20min, 500m Area	5	16°43'09"S	137°26'56"E
PUWO03	Woodland Site 3	2ha 20min, 500m Area	4	16°46'15"S	137°32'13"E

Site ID	Site Name	Survey Type	Number of Surveyors	Latitude	Longitude
PUWO04	Woodland Site 4	2ha 20min, 500m Area	5	16°36'36"S	137°28'08"E
PUWO05	Woodland Site 5	2ha 20min, 500m Area	4	16°44'28"S	137°29'35"E
PUWO06	Woodland Site 6	2ha 20min, 500m Area	5	16°39'32"S	137°24'49"E
PUWO07	Woodland Site 7	2ha 20min, 500m Area	5	16°32'13"S	137°31'46"E
PUWOROHI01	Woodland with Rocky Hill	2ha 20min, 500m Area	5	16°43'57"S	137°28'34"E
SESBISTLA01	Big Stinking Lagoon	500m Area, Incidental	9	16°21'38"S	137°38'40"E
SESBOWO01	Bog Woodland Site 1	500m Area	5	16°22'34"S	137°35'27"E
SESCARICR01	Calvert River Crossing	2ha 20min, 500m Area	5	16°30'50"S	137°32'09"E
SESCARICRWO01	Calvert River Crossing Woodland Site 1	2ha 20min, 500m Area	5	16°31'08"S	137°30'55"E
SESCARIMOBORA01	Calvert River Mouth Boat Ramp	500m Area	9	16°17'22"S	137°44'24"E
SESCARIMOGR01	Calvert River Mouth Grassland	2ha 20min, 500m Area	5	16°16'36"S	137°44'25"E
SESCARIMOMA02	Calvert River Mouth Mangrove Site 2	2ha 20min, 500m Area, Acoustic	5	16°16'20"S	137°44'04"E
SESCARIMORIFO01	Calvert River Mouth Riparian Forest	500m Area	5	16°16'05"S	137°44'11"E
SESCARIMOSADU02	Calvert River Mouth Sand Dune Site 2	2ha 20min, 500m Area, Acoustic	4	16°16'29"S	137°43'44'E
SESCARIMOWO01	Calvert River Mouth Woodland Site 1	2ha 20min, 500m Area	5	16°17'31"S	137°44'22"E
SESCARIMOWO02	Calvert River Mouth Woodland Site 2	2ha 20min, 500m Area	4	16°16'55"S	137°44'23"E
SESCARIMOWO03	Calvert River Mouth Woodland Site 3	2ha 20min, 500m Area	4	16°18'39"S	137°43'46"E
SESCOPL01	Coastal Plain Site 1	2ha 20min, 500m Area	5	16°22'28"S	137°32'57"E
SESCOPLWO01	Coastal Plain Woodland Site 1	2ha 20min, 500m Area	4	16°22'39"S	137°36'45"E
SESCY01	Cypress Site 1	2ha 20min, 500m Area	5	16°29'53"S	137°32'45"E
SESCYCRCA01	Cycad Creek Campsite	500m Area	10	16°27'06"S	137°34'34"E
SESCYCRGR01	Cycad Creek Grassland Site 1	500m Area	4	16°27'17"S	137°34'17"E
SESCYCRNO_CE01	Cycad Creek North Central Escarpment	2ha 20min, 500m Area	5	16°26'25"S	137°33'25"E
SESCYCRNO_WEES01	Cycad Creek North-west Escarpment	2ha 20min, 500m Area	5	16°27'15"S	137°32'04"E
SESCYCRNO_WEES01	Cycad Creek North-west Escarpment	2ha 20min	5	16°27'15"S	137°32'04"E
SESCYCRSAOU01	Cycad Creek Sandstone Outlier	2ha 20min, 500m Area, Acoustic	5	16°27'21"S	137°33'06"E
SESCYCRSO_EAES01	Cycad Creek South-east Escarpment	2ha 20min, 500m Area, Acoustic	10	16°28'13"S	137°33'07"E
SESCYCRSP01	Cycad Creek Spinifex	2ha 20min, 500m Area	5	16°29'17"S	137°33'50"E
SESCYCRWO01	Cycad Creek Woodland Site 1	2ha 20min, 500m Area	10	16°26'44"S	137°35'40"E

Site ID	Site Name	Survey Type	Number of Surveyors	Latitude	Longitude
SESCYCRWO02	Cycad Creek Woodland Site 2	2ha 20min, 500m Area	5	16°28'05"S	137°34'13"E
SESCYCRWO03	Cycad Creek Woodland Site 3	2ha 20min, 500m Area	5	16°27'34"S	137°33'44"E
SESDITR01	Diamond Track Site 1	2ha 20min, 500m Area	9	16°22'43"S	137°28'37"E
SESEAOU01	East Outcrop	2ha 20min, 500m Area	5	16°30'31"S	137°32'26"E
SESLASW01	Large Swamp site 1	Incidental	4	16°20'27"S	137°39'16"E
SESOLPURDSW01	Old Pungalina Rd Swamp Site 1	500"m Area	5	16°30'12"S	137°29'41"E
SESOLPURDSWSAPL01	Old Pungalina Rd Swamp Sand Plain Site 1	2ha 20min, 500m Area	5	16°30'03"S	137°29'48"E
SESPL01	Plain Site 1	2ha 20min, 500m Area	4	16°20'45"S	137°38'33"E
SESRIRONO01	River Road North (Spotlight Survey)	Incidental	2	16°19'55"S	137°41'25"E
SESSKCR01	Skeleton Creek Site 1	2ha 20min, 500m Area	5	16°22'30"S	137°33'58"E
SESSKCR02	Skeleton Creek Site 2	2ha 20min, 500m Area	5	16°22'25"S	137°31'53"E
SESSKCR03	Skeleton Creek Site 3	2ha 20min, 500m Area	5	16°22'27"S	137°29'09"E
SESSKCRRI01	Skeleton Creek Riparian	2ha 20min, 500m Area	4	16°19'32"S	137°27'26"E
SESSW01	Swamp Site 1	2ha 20min, 500m Area	5	16°2012"S	137°25'46"E
SESSW02	Swamp Site 2	2ha 20min, 500m Area	4	16°22'59"S	137°38'40"E
SESSW03	Swamp Site 3	2ha 20min, 500m Area	4	16°24'09"S	137°38'23"E
SESWO07	Woodland Site 7	2ha 20min, 500m Area	5	16°22'16"S	137°37'50"E
SESWO08	Woodland Site 8	2ha 20min, 500m Area	5	16°30'40"S	137°29'11"E

Appendix 2. Species table

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Order Anseriformes					
Anatidae (Ducks, Geese & Swans)	Plumed Whistling-Duck	*Dendrocygna eytoni*	Least concern	Nomadic, Australian	Herbivorous
	Torresian Wandering Whistling-Duck	*Dendrocygna arcuata australis*	Least concern	Nomadic, Australian	Herbivorous
	Grey Teal	*Anas gracilis*	Least concern	Nomadic, Australian	Herbivorous
	Green Pygmy-goose	*Nettapus pulchellus*	Least concern	Sedentary, Australian	Herbivorous
	Pacific Black Duck	*Anas superciliosa*	Least concern	Nomadic, Australian	Herbivorous
	Pink-eared Duck	*Malacorhynchus membranaceus*	Least concern	Nomadic, Endemic	Insectivorous
	Hardhead	*Aythya australis*	Least concern	Nomadic, Australian	Insectivorous
Order Podicipediformes					
Podicipedidae (Grebes)	Australian Grebe	*Tachybaptus novaehollandiae novaehollandiae*	Least concern	Nomadic	Insectivorous
	Australian Great Crested Grebe	*Podiceps cristatus australis*	Least concern	Sedentary, Endemic	Carnivorous
Order Ciconiiformes					
Ardeidae (Herons, Egret, Bitterns)	White-faced Heron	*Egretta novaehollandiae*	Least concern	Nomadic, Australian	Carnivorous
	Eastern Cattle Egret	*Bubulcus ibis coromandus*	Least concern	Sedentary, Australian	Insectivorous
	Great-billed Heron	*Ardea sumatrana mathewsae*	Least concern	Sedentary, Australian	Carnivorous
	Australasian Little Egret	*Egretta garzetta nigripes*	Least concern	Sedentary, Australian	Carnivorous
	Eastern Intermediate Egret	*Ardea intermedia intermedia*	Least concern	Sedentary, Australian	Carnivorous
	Western Striated Heron	*Butorides striatus stagnatilis*	Least concern	Sedentary, Endemic	Carnivorous
	Eastern Great Egret	*Ardea alba modesta*	Least concern	Sedentary, Australian	Carnivorous
	Common Eastern Reef Egret	*Egretta sacra sacra*	Least concern	Sedentary, Australian	Carnivorous
	White-necked Heron	*Ardea pacifica*	Least concern	Nomadic, Endemic	Carnivorous
	Torresian Nankeen Night-Heron	*Nycticorax caledonicus hilli*	Least concern	Nomadic, Australian	Carnivorous
Threskiornithidae (Ibis & Spoonbills)	Glossy Ibis	*Plegadis falcinellus*	Least concern	Nomadic, Australian	Insectivorous
	Royal Spoonbill	*Platalea regia*	Least concern	Sedentary, Endemic	Insectivorous
	Australian White Ibis	*Threskiornis moluccus*	Least concern	Nomadic	Insectivorous
	Straw-necked Ibis	*Threskiornis spinicollis*	Least concern	Sedentary, Endemic	Insectivorous
Ciconiidae (Storks)	Torresian Black-necked Stork	*Ephippiorhynchus asiaticus australis*	Least concern	Sedentary, Australian	Carnivorous
Pelicanidae	Australian Pelican	*Pelecanus conspicillatus*	Least concern	Sedentary, Australian	Carnivorous

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Order Acciptriformes					
Accipitridae (Eagles, Kites, Goshawks, Ospreys)	Torresian Brahminy Kite	*Haliastur indus girrenera*	Least concern	Sedentary, Australian	Carnivorous
	Mainland Wedge-tailed Eagle	*Aquila audax audax*	Least concern	Sedentary, Australian	Carnivorous
	Torresian Black Kite	*Milvus migrans affinis*	Least concern	Nomadic, Endemic	Carnivorous
	White-bellied Sea-Eagle	*Haliaeetus leucogaster*	Least concern	Sedentary, Australian	Carnivorous
	Eastern Osprey	*Pandion haliaetus cristatus*	Least concern	Nomadic, Australian	Carnivorous
	Australian Pacific Baza	*Aviceda subcristata subcristata*	Least concern	Sedentary, Endemic	Carnivorous
	Australian Grey Goshawk	*Accipiter novaehollandiae novaehollandiae*	Least concern	Nomadic, Endemic	Carnivorous
	Northern Brown Goshawk	*Accipiter fasciatus didimus*	Least concern	Nomadic, Endemic	Carnivorous
	Australian Collared Sparrowhawk	*Accipiter cirrocephalus cirrocephalus*	Least concern	Sedentary, Endemic	Carnivorous
	Whistling Kite	*Haliastur sphenurus*	Least concern	Nomadic, Australian	Carnivorous
Order Falconiformes					
Falconidae (Falcons)	Australian Brown Falcon	*Falco berigora berigora*	Least concern	Nomadic, Endemic	Carnivorous
	Australasian Nankeen Kestrel	*Falco cenchroides cenchroides*	Least concern	Nomadic, Australian	Carnivorous
	Inland Australian Hobby	*Falco longipennis murchisonianus*	Least concern	Sedentary, Endemic	Carnivorous
Order Gruiformes					
Rallidae (Crakes, Rails, Swamphens)	Australasian Purple Swamphen	*Porphyrio porphyrio melanotus*	Least concern	Sedentary, Endemic	Herbivorous
	Australian Eurasian Coot	*Fulica atra australis*	Least concern	Vagrant, Endemic	Herbivorous
	Australian Dusky Moorhen	*Gallinula tenebrosa tenebrosa*	Least concern	Vagrant, Endemic	Herbivorous
Gruidae (Cranes)	Brolga	*Grus rubicunda*	Least concern	Nomadic, Australian	Carnivorous
Otididae (Bustards)	Australian Bustard	*Ardeotis australis*	Least concern	Sedentary, Australian	Carnivorous
Order Charadriiformes					
Burhinidae (Stone-Curlews)	Beach Stone-curlew	*Esacus giganteus*	Least concern	Sedentary, Australian	Carnivorous
	Bush Stone-curlew	*Burhinus grallarius*	Least concern	Sedentary, Australian	Insectivorous
Turnicidae (Button-quails)	Red-backed Button-quail	*Turnix maculosa pseutes*	Least concern	Sedentary, Endemic	Granivorous
	Red-chested Button-quail	*Turnix pyrrhothorax*	Least concern	Nomadic, Endemic	Granivorous
	Little Button-quail	*Turnix velox*	Least concern	Nomadic, Endemic	Granivorous
Recurvirostridae (Stilts & Avocets)	Black-winged Stilt	*Himantopus leucocephalus*	Least concern	Nomadic, Australian	Insectivorous

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Charadriidae (Plovers, Dotterels, Lapwings)	Northern Masked Lapwing	*Vanellus miles miles*	Least concern	Sedentary, Australian	Insectivorous
	Black-fronted Dotterel	*Elseyornis melanops*	Least concern	Nomadic, Endemic	Insectivorous
Jacanidae (Jacanas)	Australian Comb-crested Jacana	*Irediparra gallinacea novaehollandiae*	Least concern	Sedentary, Endemic	Herbivorous
Laridae (Gulls, Terns, Noddies)	Australian Silver Gull	*Chroicocephalus novaehollandiae novaehollandiae*	Least concern	Endemic	Carnivorous
	Caspian Tern	*Hydroprogne caspia*	Least concern	Sedentary, Australian	Carnivorous
Order Galliformes					
Phasianidae (Pheasnats and Quails)	Mainland Brown Quail	*Coturnix ypsilophora australis*	Least concern	Sedentary, Endemic	Granivorous
Order Columbiformes					
Columbidae (Pigeons, Doves)	Common Bronzewing	*Phaps chalcoptera*	Least concern	Nomadic, Endemic	Granivorous
	Western Rose-crowned Fruit-Dove	*Ptilinopus regina ewingii*	Least concern	Sedentary, Endemic	Frugivorous
	Diamond Dove	*Geopelia cuneata*	Least concern	Nomadic, Endemic	Granivorous
	Northern Bar-shouldered Dove	*Geopelia humeralis inexpecta*	Least concern	Sedentary, Endemic	Granivorous
	Eastern Peaceful Dove	*Geopelia striata placida*	Least concern	Sedentary, Endemic	Granivorous
	Eastern Spinifex Pigeon	*Geophaps plumifera leucogaster*	Least concern	Sedentary, Endemic	Granivorous
Order Psittaciformes					
Psittacidae (Parrots, Rosellas and Lorikeets)	Top End Northern Rosella	*Platycercus venustus venustus*	Least concern	Sedentary, Endemic	Granivorous
	Varied Lorikeet	*Psitteuteles versicolour*	Least concern	Nomadic, Endemic	Nectivorous
	Western Red-winged Parrot	*Aprosmictus erythropterus coccineopterus*	Least concern	Sedentary, Australian	Granivorous, Frugivorous
	Red-collared Rainbow Lorikeet	*Trichoglossus haematodus rubitorquis*	Least concern	Sedentary, Endemic	Nectivorous
	Budgerigar	*Melopsittacus undulates*	Least concern	Nomadic, Endemic	Granivorous
Cacatuidae (Cockatoos and Corellas)	Cockatiel	*Nymphicus hollandicus*	Least concern	Nomadic, Endemic	Granivorous
	Northern Sulphur-crested Cockatoo	*Cacatua galerita fitzroyi*	Least concern	Nomadic, Endemic	Granivorous
	North-western Red-tailed Black-Cockatoo	*Calyptorhynchus banksii macrorhynchus*	Least concern	Nomadic, Endemic	Granivorous
	Northern Galah	*Eolophus roseicapillus kuhli*	Least concern	Sedentary, Endemic	Granivorous
	Eastern Little Corella	*Cacatua sanguinea gymnopis*	Least concern	Nomadic, Endemic	Granivorous

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Order Cuculiformes					
Cuculidae (Cuckoos)	Australian Channel-billed Cuckoo	*Scythrops novaehollandiae novaehollandiae*	Least concern	Australian, Summer Migrant	Frugivorous
	Northern Pheasant Coucal	*Centropus phasianinus melanurus*	Least concern	Sedentary, Endemic	Carnivorous
	Western Little Bronze-Cuckoo	*Chalcites minutillus minutillus*	Least concern	Sedentary, Endemic	Insectivorous
	Horsfield's Bronze-Cuckoo	*Chalcites basalis*	Least concern	Australian, Winter Migrant	Insectivorous
	Pallid Cuckoo	*Cacomantis pallidus*	Least concern	Australian, Winter Migrant	Insectivorous
Order Caprimulgiformes					
Eurostopodidae (Eared-nightjars)	Spotted Nightjar	*Eurostopodus argus*	Least concern	Sedentary, Endemic	Insectivorous
Podargidae (Frogmouths)	Northern Tawny Frogmouth	*Podargus strigoides phalaenoides*	Least concern	Sedentary, Endemic	Insectivorous
Aegothelidae (Owlet-nightjars)	Mainland Australian Owlet-nightjar	*Aegotheles cristatus cristatus*	Least concern	Sedentary, Endemic	Insectivorous
Order Strigiformes					
Strigidae (Hawk-Owls)	Western Boobook	*Ninox novaeseelandiae ocellata*	Least concern	Sedentary, Endemic	Carnivorous
	Northern Barking Owl	*Ninox connivens peninsularis*	Least concern	Sedentary, Endemic	Carnivorous
Order Phalacrocoraci-formes	Australasian Little Pied Cormorant	*Microcarbo melanoleucos melanoleucos*	Least concern	Sedentary, Endemic	Carnivorous
Phalacrocoracidae (Cormorants and Shags)	Australian Pied Cormorant	*Phalacrocorax varius hypoleucos*	Least concern	Sedentary, Endemic	Carnivorous
	Australian Great Cormorant	*Phalacrocorax carbo carboides*	Least concern	Sedentary, Endemic	Carnivorous
	Little Black Cormorant	*Phalacrocorax sulcirostris*	Least concern	Sedentary, Endemic	Carnivorous
Anhingidae (Darter)	Australian Darter	*Anhinga melanogaster*	Least concern	Sedentary, Australian	Carnivorous
Order Coraciiformes					
Alcedinidae (Kingfishers)	Northern Azure Kingfisher	*Ceyx azureus ruficollaris*	Least concern	Sedentary, Endemic	Carnivorous
Halcyonidae (Tree Kingfishers)	Australian Sacred Kingfisher	*Todiramphus sanctus sanctus*	Least concern	Endemic, Winter Migrant	Insectivorous
	Top End Forest Kingfisher	*Todiramphus macleayii macleayii*	Least concern	Sedentary, Endemic	Insectivorous
	Northern Collared Kingfisher	*Todiramphus chloris sordidus*	Least concern	Sedentary, Australian	Carnivorous
	Northern Blue-winged Kookaburra	*Dacelo leachii leachii*	Least concern	Sedentary, Endemic	Carnivorous
	Red-backed Kingfisher	*Todiramphus pyrrhopygius*	Least concern	Nomadic, Endemic	Insectivorous
Meropidae (Bee-eaters)	Rainbow Bee-eater	*Merops ornatus*	Least concern	Australian, Winter Migrant	Insectivorous

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Order Passeriformes					
Maluridae (Fairy-wrens, Emu-wrens and Grass-wrens)	Northern Red-backed Fairy-wren	*Malurus melanocephalus cruentatus*	Least concern	Sedentary, Endemic	Insectivorous
	Eastern Purple-crowned Fairy-wren	*Malurus coronatus macgillivrayi*	Near-threatened	Sedentary, Endemic	Insectivorous
	Inland Variegated Fairy-wren	*Malurus lamberti assimilis*	Least concern	Sedentary, Endemic	Insectivorous
Meliphagidae (Honeyeaters, Chats)	Banded Honeyeater	*Cissomela pectoralis*	Least concern	Nomadic, Endemic	Nectivorous
	Bar-breasted Honeyeater	*Ramsayornis fasciatus*	Least concern	Nomadic, Endemic	Nectivorous
	Northern Blue-faced Honeyeater	*Entomyzon cyanotis albipennis*	Least concern	Sedentary, Endemic	Insectivorous
	Western Brown Honeyeater	*Lichmera indistincta indistincta*	Least concern	Nomadic, Endemic	Nectivorous
	Northern Grey-fronted Honeyeater	*Lichenostomus plumulus planasi*	Least concern	Sedentary, Endemic	Insectivorous
	Western Silver-crowned Friarbird	*Philemon argenticeps argenticeps*	Least concern	Sedentary, Endemic	Omnivorous
	Northern Yellow-throated Miner	*Manorina flavigula lutea*	Least concern	Sedentary, Endemic	Insectivorous
	Mainland Yellow-tinted Honeyeater	*Lichenostomus flavescens flavescens*	Least concern	Sedentary, Endemic	Insectivorous
	North-western Little Friarbird	*Philemon citreogularis sordidus*	Least concern	Sedentary, Endemic	Nectivorous
	Golden-backed Honeyeater	*Melithreptus gularis laetior*	Least concern	Nomadic, Endemic	Insectivorous
	Top End Singing Honeyeater	*Lichenostomus virescens copperi*	Least concern	Nomadic, Endemic	Omnivorous
	Rufous-throated Honeyeater	*Conopophila rufogularis*	Least concern	Nomadic, Endemic	Insectivorous
	Northern Red-headed Honeyeater	*Myzomela erythrocephala erythrocephala*	Least concern	Sedentary, Endemic	Omnivorous
	White-gaped Honeyeater	*Lichenostomus unicolor*	Least concern	Sedentary, Endemic	Omnivorous
	Northern White-throated Honeyeater	*Melithreptus albogularis albogularis*	Least concern	Sedentary, Endemic	Insectivorous
Pardalotidae (Pardalotes)	Inland Red-browed Pardalote	*Pardalotus rubricatus rubricatus*	Least concern	Sedentary, Endemic	Insectivorous
	Northern Striated Pardalote	*Pardalotus striatus uropygialis*	Least concern	Sedentary, Endemic	Insectivorous

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Acanthizidae (Gerygones and Thornbills)	North-western White-throated Gerygone	*Gerygone olivacea rogersi*	Least concern	Sedentary, Endemic	Insectivorous
	Desert Western Gerygone	*Gerygone fusca mungi*	Least concern	Sedentary, Endemic	Insectivorous
	Northern Weebill	*Smicrornis brevirostris flavescens*	Least concern	Nomadic	Insectivorous
Petroicidae (Australian Robins)	Northern Hooded Robin	*Melanodryas cucullata picata*	Least concern	Sedentary, Endemic	Insectivorous
	Northern Jacky Winter	*Microeca fascinans pallida*	Least concern	Sedentary, Endemic	Insectivorous
	North-central Lemon-bellied Flycatcher	*Microeca flavigaster flavigaster*	Least concern	Sedentary, Endemic	Insectivorous
	Buff-sided Robin	*Poecilodryas cerviniventris*	Least concern	Sedentary, Endemic	Insectivorous
Pomatostomidae (Australian Babblers)	Western Grey-crowned Babbler	*Pomatostomus temporalis rubeculus*	Least concern	Sedentary, Endemic	Insectivorous
Corvidae (Ravens and Crows)	Eastern Australian Raven	*Corvus coronoides coronoides*	Least concern	Sedentary, Endemic	Carnivorous
	Australian Torresian Crow	*Corvus orru cecilae*	Least concern	Sedentary, Endemic	Omnivorous
Artamidae (Woodswallows, Butcherbirds, Currawongs and magpies)	Northern Australian Magpie	*Cracticus tibicen eylandtensis*	Least concern	Sedentary, Endemic	Insectivorous
	Inland Black-faced Woodswallow	*Artamus cinereus melanops*	Least concern	Sedentary, Endemic	Insectivorous
	Torresian White-breasted Woodswallow	*Artamus leucorynchus leucopygialis*	Least concern	Sedentary, Australian	Insectivorous
	White-browed Woodswallow	*Artamus superciliosus*	Least concern	Nomadic, Endemic	Insectivorous
	Northern Little Woodswallow	*Artamus minor derbyi*	Least concern	Sedentary, Endemic	Insectivorous
	Masked Woodswallow	*Artamus personatus*	Least concern	Nomadic, Endemic	Insectivorous
	Western Pied Butcherbird	*Cracticus nigrogularis picatus*	Least concern	Sedentary, Endemic	Carnivorous
Cisticolidae (Cisticolas)	Normanton Zitting Cisticola	*Cisticola juncidis normani*	Least concern	Sedentary, Endemic	Insectivorous
	North-western Golden-headed Cisticola	*Cisticola exilis lineocapilla*	Least concern	Sedentary, Endemic	Insectivorous
Monarchidae (Flycatchers, Monarchs)	Paperbark Flycatcher	*Myiagra nana*	Least concern	Sedentary, Australian	Insectivorous
	North-western Leaden Flycatcher	*Myiagra rubecula concinna*	Least concern	Nomadic, Endemic	Insectivorous
	Northern Magpie-lark	*Grallina cyanoleuca neglecta*	Least concern	Sedentary, Australian	Insectivorous

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Pachycephalidae (Whistlers, Shrike-thrush and Allies)	North-western Grey Shrike-thrush	*Colluricincla harmonica brunnea*	Least concern	Endemic	Insectivorous
	Sandstone Shrike-thrush	*Colluricincla woodwardi*	Least concern	Endemic	Insectivorous
	Eastern Mangrove Golden Whistler	*Pachycephala melanura robusta*	Least concern	Endemic	Insectivorous
	North-western Rufous Whistler	*Pachycephala rufiventris falcate*	Least concern	Endemic	Insectivorous
Campephagidae (Cuckoo-shrikes and Trillers)	Mainland Black-faced Cuckoo-shrike	*Coracina novaehollandiae melanops*	Least concern	Nomadic, Australian	Insectivorous
	North-western White-bellied Cuckoo-shrike	*Coracina papuensis hypoleuca*	Least concern	Nomadic, Endemic	Insectivorous
	White-winged Triller	*Lalage tricolor*	Least concern	Australian, Autumn Migrant	Insectivorous
Neosittidae (Sittella)	Northern Varied Sittella	*Daphoenositta chrysoptera leucoptera*	Least concern	Endemic	Insectivorous
Rhipiduridae (Fantails)	Northern Willie Wagtail	*Rhipidura leucophrys picata*	Least concern	Endemic	Insectivorous
	Grey Fantail	*Rhipidura albiscapa alisteri*	Least concern	Endemic, Winter Migrant	Insectivorous
	Australian Northern Fantail	*Rhipidura rufiventris isura*	Least concern	Endemic	Insectivorous
	Mangrove Grey Fantail	*Rhipidura phasiana*	Least concern	Sedentary, Australian	Insectivorous
	Arafura Rufous Fantail	*Rhipidura dryas*	Least Concern	Endemic	Insectivorous
Hirundinidae (Swallows, Martins)	Fairy Martin	*Petrochelidon ariel*	Least concern	Nomadic, Australian	Insectivorous
	Mainland Tree Martin	*Petrochelidon nigricans neglecta*	Least concern	Australian, Autumn Migrant	Insectivorous
Megaluridae (Grassbirds)	Torresian Tawny Grassbird	*Megalurus timoriensis alisteri*	Least concern	Australian	Insectivorous
	Brown Songlark	*Cincloramphus cruralis*	Least concern	Endemic	Granivorous
	Rufous Songlark	*Cincloramphus mathewsi*	Least concern	Endemic, Winter Migrant	Granivorous, Insectivorous
Alaudidae (Larks)	Western Queensland Horsfield's Bushlark	*Mirafra javanica rufescens*	Least concern	Endemic	Granivorous
Nectariniidae (Sunbirds, Flowerpeckers)	Australian Mistletoebird	*Dicaeum hirundinaceum hirundinaceum*	Least concern	Endemic	Frugivorous
Motacillidae (Pipits)	Northern Australian Pipit	*Anthus novaeseelandiae rogersi*	Least concern	Endemic	Insectivorous

Order & Family	Common name	Species	Status	Population	Feeding habit
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)
Estrildidae (Weaver Finches)	Western Double-barred Finch	*Taeniopygia bichenovii annulosa*	Least concern	Endemic	Granivorous
	Gouldian Finch	*Erythrura gouldiae*	Near Threatened	Endemic	Granivorous
	Western Masked Finch	*Poephila personata personata*	Least concern	Endemic	Granivorous
	Eastern Long-tailed Finch	*Poephila acuticauda hecki*	Least concern	Endemic	Granivorous
	Black-bellied Crimson Finch	*Neochmia phaeton phaeton*	Least concern	Endemic	Granivorous
	Torresian Chestnut-breasted Mannikin	*Lonchura castaneothorax castaneothorax*	Least concern	Endemic	Granivorous
Oriolidae (Orioles and Figbirds)	North-western Olive-backed Oriole	*Oriolus sagittatus affinis*	Least concern	Endemic	Frugivorous
	Cape York Australasian Figbird	*Sphecotheres vieilloti flaviventris*	Least concern	Endemic	Frugivorous
Timaliidae (True Babblers)	Northern Yellow White-eye	*Zosterops luteus luteus*	Least concern	Nomadic	Insectivorous
Climacteridae (Treecreepers)	Northern Black-tailed Treecreeper	*Climacteris melanura melanura*	Least concern	Endemic	Insectivorous

Appendix 3. Sites photographs

Site Photo 1: Lake Crocodilus

Site Photo 2: *Avicennia* low closed forest *Ceriops* low open forest *Avicennia* low open shrubland

Site Photo 3: *Avicennia* low closed forest *Ceriops* low open forest *Avicennia* low open shrubland (Inside)

Site Photo 4: *Tecticornia* low sparse samphire shrubland

Site Photo 5: Karnes Creek Lagoon

Site Photo 6: Bubbling Springs

Site Photo 7: Karnes Creek Riparian

Site Photo 8: Fern Spring Swamp

Site Photo 9: *Pandanus* low sparse palmland *Chrysopogon* mid tussock grassland (Fern Spring)

Site Photo 10: East Outcrop

Site Photo 11: East Outcrop

Site Photo 12: Lake Jabiru

Site Photo 13: South-east Escarpment Karnes Creek

Site Photo 14: *Eucalyptus tetrodonta* mid woodland *Bossiaea* tall sparse shrubland *Eriachne* low sparse tussock grassland

Site Photo 15: *Corymbia dichromophloia* low open woodland *Acacia* tall open shrubland *Triodia* mid open hummock grassland

Site Photo 16: *Eucalyptus microtheca* low open woodland *Carissa* mid sparse shrubland *Chrysopogon* low tussock grassland

Appendix 4. Bird photographs

Photographs of species marked with an asterisk (*) were not taken on Pungalina-Seven Emu.

Photo 1: Fantail

Photo 2: Australian Grebe

Photo 3: Mainland Australian Owlet-nightjar

Photo 4: Eastern Australian Raven

Photo 5: Australian White Ibis

Photo 6: Northern Azure Kingfisher

Photo 7: Banded Honeyeater

Photo 8: Bar-Breasted Honeyeater

Photo 9: Northern Barking Owl

Photo 10: Bar-shouldered Dove

Photo 11: Torresian Black Kite

Photo 12: Australasian Nankeen Kestrel

Photo 13: Torresian Black Kite

Photo 14: Dusky Woodswallow

Photo 15: Black-fronted Dotterel

Photo 16: Top End Northern Rosella


Photo 17: Torresian Black-necked Stork

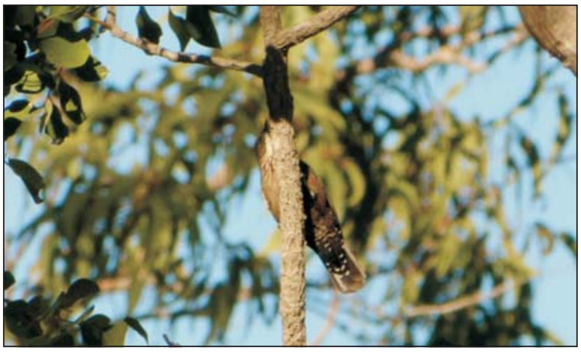


Photo 18: Northern Black-tailed Treecreeper


Photo 19: Northern Blue-winged Kookaburra


Photo 20: Torresian Brahminy Kite


Photo 21: North-western Leaden Flycatcher


Photo 22: Brolga


Photo 23: Australian Brown Falcon


Photo 24: Northern Brown Goshawk

Photo 25: Western Brown Honeyeater

Photo 26: Budgerigar

Photo 27: Buff-sided Robin

Photo 28: Australian Bustard

Photo 29: Australian Channel-billed Cuckoo* (Taken in Northern Territory 8th July while travelling, used for image descriptive)

Photo 30: Torresian Chestnut-breasted Mannikin

Photo 31: Northern Brown Goshawk


Photo 32: Australian Comb-crested Jacana


Photo 33: Common Bronzewing


Photo 34: Black-bellied Crimson Finch


Photo 35: Black-bellied Crimson Finch


Photo 36: Australian Darter


Photo 37: Diamond Dove


Photo 38: Eastern Double-barred Finch


Photo 39: Eastern Osprey

Photo 40 deliberately unused.

Photo 41: Common Eastern Reef Egret (Grey Phase)

Photo 42: Australian Sacred Kingfisher

Photo 43: Top End Forest Kingfisher

Photo 44: Northern Galah

Photo 45: Glossy Ibis

Photo 46: Golden-backed Honeyeater

Photo 47: North-western Golden-headed Cisticola

Photo 48: Gouldian Finch (Red Faced)


Photo 49: Gouldian Finch (Black Face)


Photo 50: Eastern Great Egret


Photo 51: Great-billed Heron


Photo 52: Green Pygmy-goose


Photo 53: Western Grey-crowned Babbler


Photo 54: Northern Hooded Robin* (Taken in Northern Territory 20th June


Photo 55: Northern Jacky Winter


Photo 56: North-central Lemon-bellied Flycatcher


Photo 57: Whistling Kite


Photo 58: Australasian Little Egret


Photo 59: North-western Little Friarbird


Photo 60: Australasian Little Pied Cormorant


Photo 61: Northern Little Woodswallow


Photo 62: Eastern Long-tailed Finch


Photo 63: Northern Magpie-lark (male)


Photo 64: Eastern Mangrove Golden Whistler (Immature)

Photo 65 deliberately unused.

Photo 66: Western Masked Finch

Photo 67: Northern Masked Lapwing

Photo 68: Masked Woodswallow

Photo 69: Torresian Nankeen Night-heron

Photo 70: Torresian Nankeen Night-heron (Juvenile)

Photo 71: Australian Northern Fantail

Photo 72: Top End Northern Rosella

Photo 73: North-western Olive-backed Oriole


Photo 74: Eastern Osprey


Photo 75: Pallid Cuckoo


Photo 76: Paperbark Flycatcher


Photo 77: Eastern Peaceful Dove


Photo 78: Northern Pheasant Coucal


Photo 79: Western Pied Butcherbird


Photo 80: Pink-eared Duck


Photo 81: Plumed Whistling-duck


Photo 82: Australian Mistletoebird


Photo 83: Eastern Purple-crowned Fairy-wren


Photo 84: Rainbow Bee-eater


Photo 85: Northern Red-backed Fairy-wren (Female)


Photo 86: Northern Red-backed Fairy-wren (Male) * (Taken in Northern Territory while travelling, used for image descriptive)


Photo 87: Red-backed Kingfisher


Photo 88: Red-collared Rainbow Lorikeet


Photo 89: Northern Red-headed Honeyeater


Photo 90: Red-necked Avocet


Photo 91: North-western Red-tailed Black-Cockatoo


Photo 92: Red-winged Parrot


Photo 93: Royal Spoonbill


Photo 94: North-western Rufous Whistler (Female)


Photo 95: North-western Rufous Whistler (Male)


Photo 96: Rufous-throated Honeyeater

Photo 97: Australian Sacred Kingfisher

Photo 98: Sandstone Shrike-thrush

Photo 99: Western Silver-crowned Friarbird

Photo 100: Straw-necked Ibis

Photo 101: Northern Striated Pardalote

Photo 102 & 103: Northern Sulphur-crested Cockatoo

Photo 104: Northern Tawny Frogmouth

Photo 105: Varied Lorikeet

Photo 106: Northern Varied Sittella (White-wing)

Photo 107: Torresian Wandering Whistling-Duck

Photo 108: Mainland Wedge-tailed Eagle

Photo 109: Whistling Kite

Photo 110: North-western White-bellied Cuckoo-shrike

Photo 111: White-bellied Sea-Eagle

Photo 112: Torresian White-breasted Woodswallow

Photo 113: White-browed Woodswallow

Photo 114: White-faced Heron

Photo 115: White-gaped Honeyeater

Photo 116: White-necked Heron

Photo 117: Northern White-throated Honeyeater

Photo 118: White-winged Triller (Female)

Photo 119: Northern Willie Wagtail

Photo 120: Northern Yellow White-eye

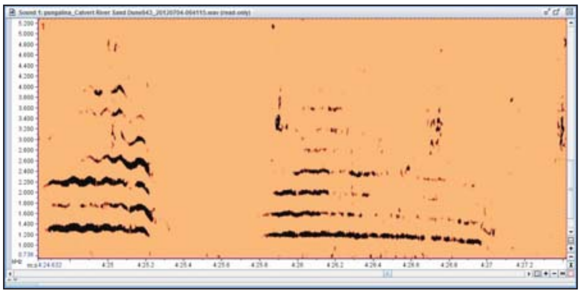
Photo 121: Northern Yellow-throated Miner

Photo 122: Mainland Yellow-tinted Honeyeater

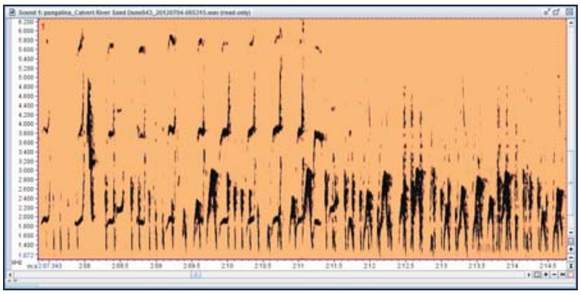
Photo 123: Australian Zebra Finch

Photo 124: Spotted Nightjar

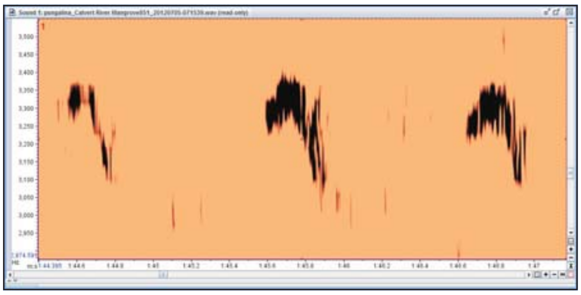
Appendix 5. Sonograms



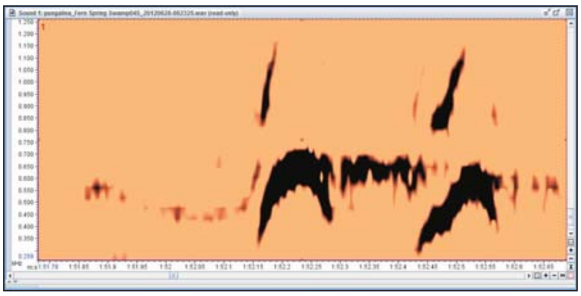
Sonogram 1: Eastern Australian Raven (Highest Energy 1300 Hz – Range 1100 to 4000 Hz)



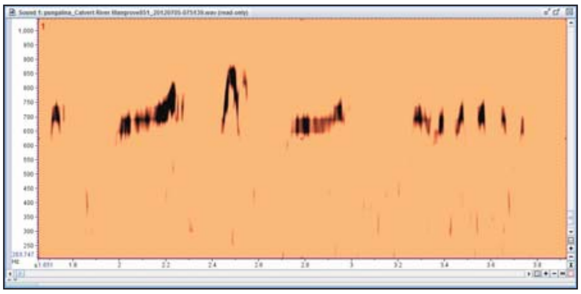
Sonogram 2: White-gaped Honeyeater (Highest Energy 3020 Hz – Range 1270 to 6000 Hz)



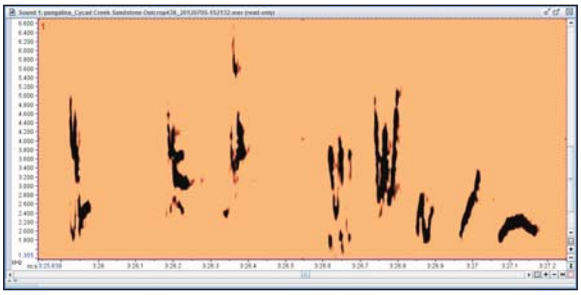
Sonogram 3: Northern Yellow White-eye (Highest energy 3350 Hz – Range 3050 to 3390 Hz)



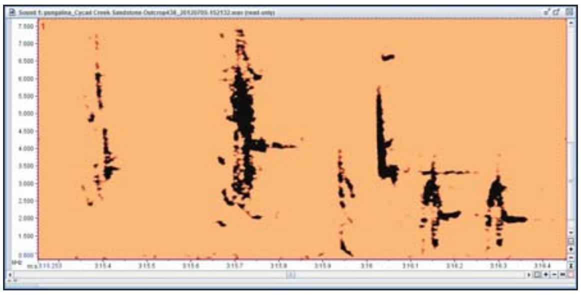
Song 4: Northern Barking Owl (Highest energy 650 Hz – Range 300 to 1150 Hz)



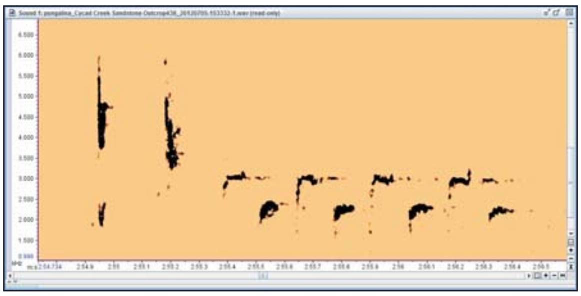
Song 5: Northern Bar-shouldered Dove (Highest Energy 800Hz – Range 640 to 870Hz)



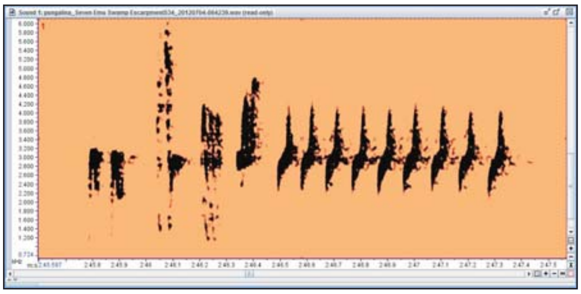
Song 6: Western Brown Honeyeater Song type 1 (Highest energy 4000Hz – Range 1460 to 5000Hz)



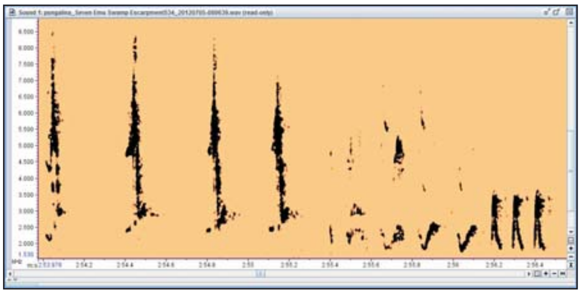
Song 7: Western Brown Honeyeater Song type 2 (Highest energy 3300Hz – Range 880 to 7400Hz)



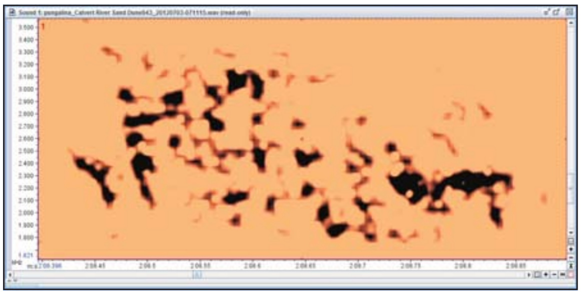
Song 8: Western Brown Honeyeater Song type 3 (Highest energy 2200Hz – Range 2000 to 6000Hz)



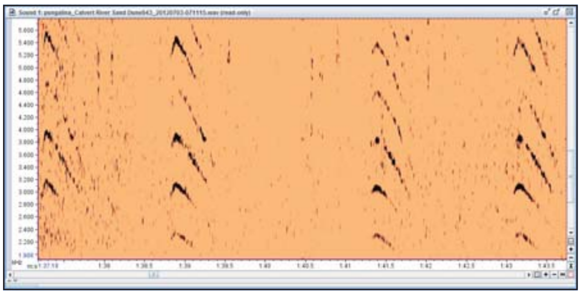
Song 9: Western Brown Honeyeater Song type 4 (Highest energy 3000Hz – Range 1200 to 6000Hz)



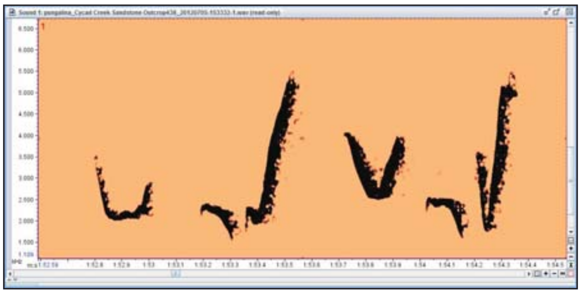
Song 10: Western Brown Honeyeater Song type 5 (Highest Energy 5500 Hz – Range 1800 to 8500Hz)



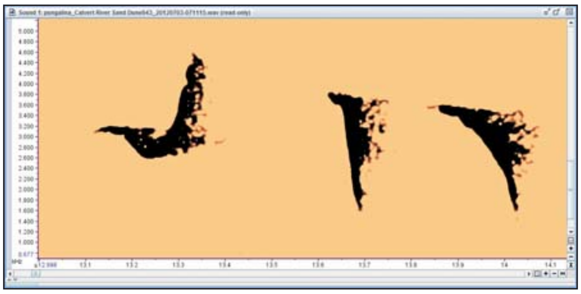
Song 11: Mainland Black-faced Cuckoo-shrike (Highest energy 2270Hz – Range 1730 to 3380Hz)



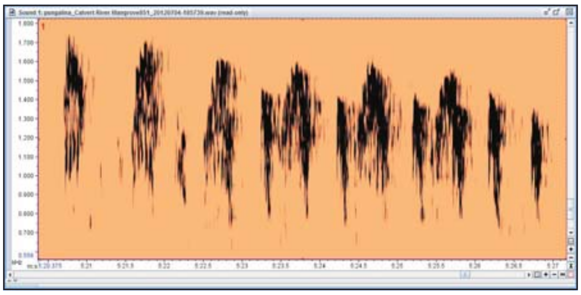
Song 12: Eastern Double-barred Finch (Highest Energy 3876Hz – Range 2026 to 5580Hz)



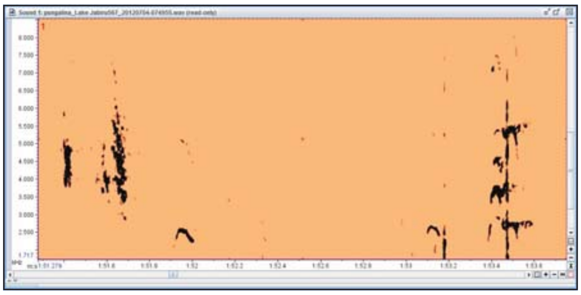
Song 13: North-western Rufous Whistler (Highest Energy 3600Hz – Range – 1360Hz to 5300Hz)



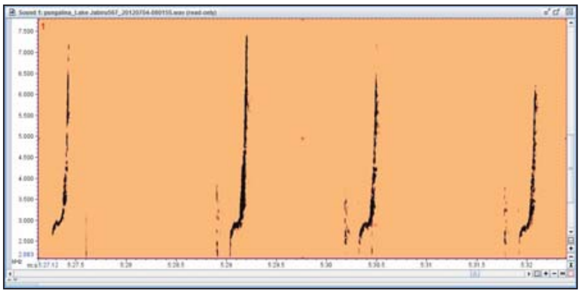
Song 14: Eastern Mangrove Golden Whistler (Highest Energy 2920Hz – Range 1330 to 4620Hz)



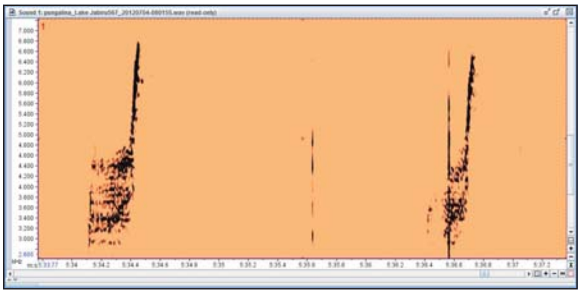
Song 15: Northern Blue-winged Kookaburra (Highest Energy 1290Hz – Range 720Hz to 1730Hz)



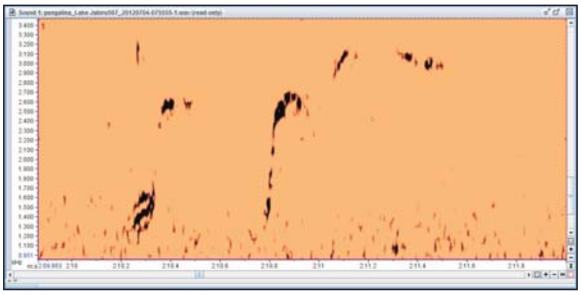
Song 16: Northern Galah (Highest Energy 4800Hz – Range 2180 to 7540Hz)



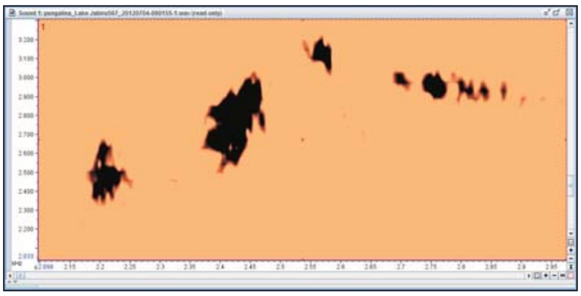
Song 17: Paperbark Flycatcher Song Type 1 (Highest Energy 3000Hz – Range 2100 to 7500Hz)



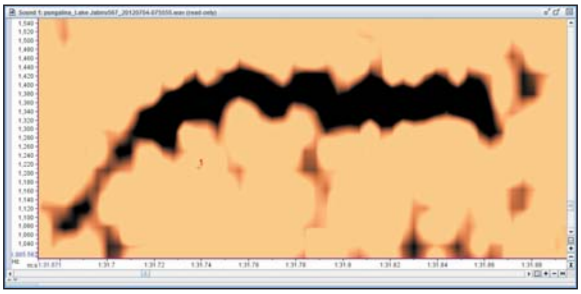
Song 18: Paperbark Flycatcher Song Type 2 (Highest Energy 3860Hz – Range 2630 to 6770Hz)



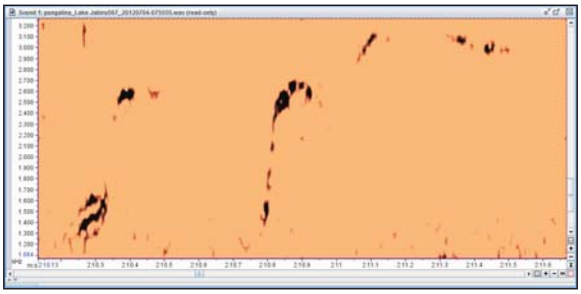
Song 19: Western Pied Butcherbird Song Type 1 (Highest Energy 3100Hz – Range 2050 to 3200Hz)



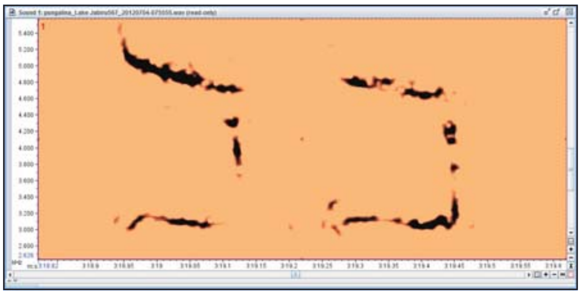
Song 20: Western Pied Butcherbird Song Type 2 (Highest Energy 2800Hz – Range 2350 to 3200Hz)



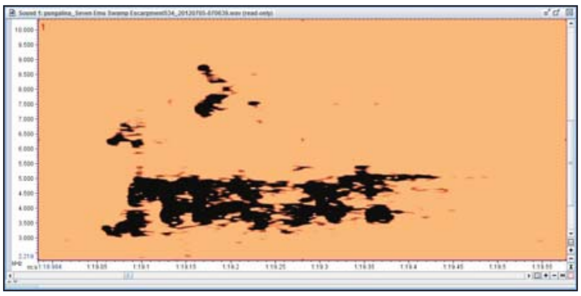
Song 21: Australian Torresian Crow (Highest Energy 1380Hz – Range 1058 to 1480Hz)



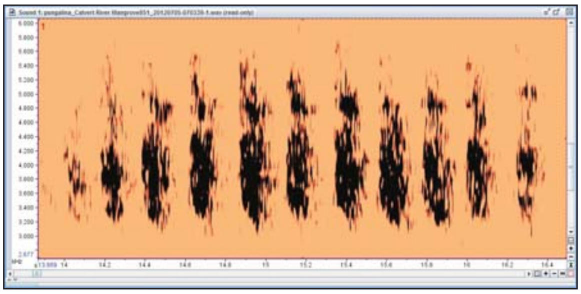
Song 22: Northern Magpie-lark Song Type 1 (Highest Energy 3057Hz – Range 2850 to 5500Hz)



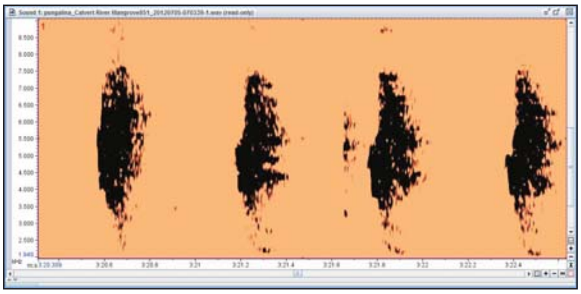
Song 23: Northern Magpie-lark Song Type 2 (Highest Energy 4830Hz – Range 2970 to 5350Hz)



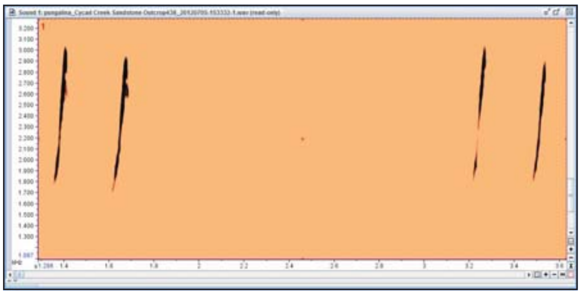
Song 24: Red-collared Rainbow Lorikeet (Highest Energy 4500Hz – Range 3000 to 9000Hz)



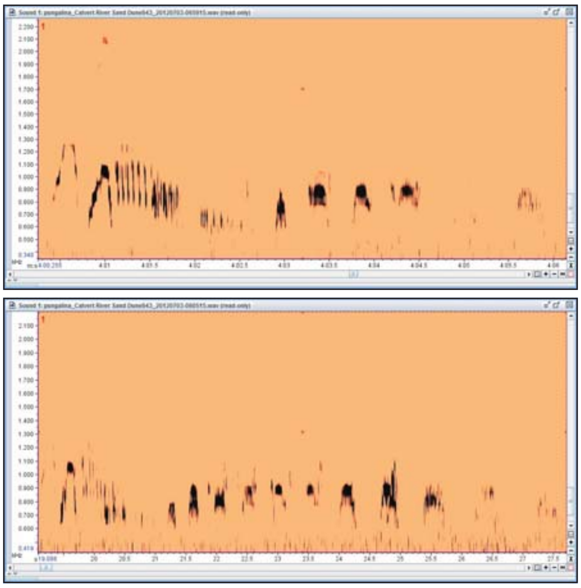
Song 25: Northern Red-headed Honeyeater (Highest Energy 3700Hz – Range 3550 to 5150Hz)



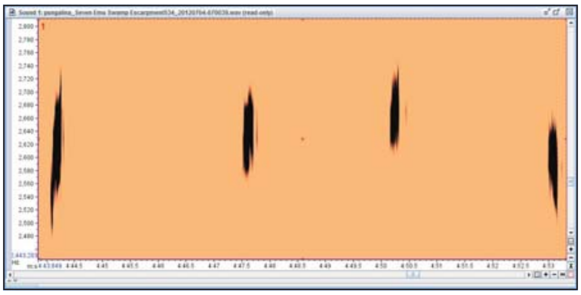
Song 26: Northern Red-headed Honeyeater (Highest Energy 4500Hz – Range 2300 to 7700Hz)



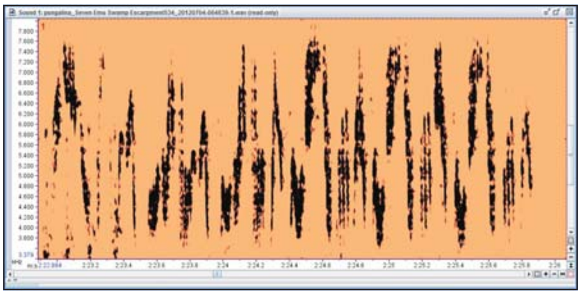
Song 27: Northern Striated Pardalote (Highest Energy 2700Hz – Range 1700 to 3050Hz)



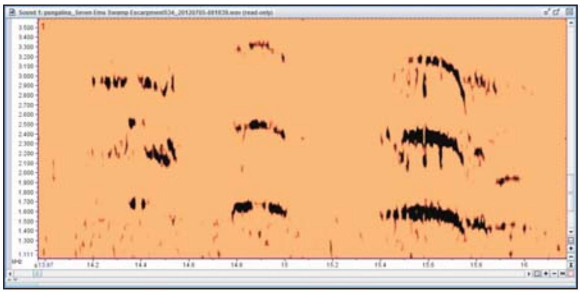
Song 28 & 29: Brolga (Highest Energy 900Hz – Range 600 to 1300Hz)



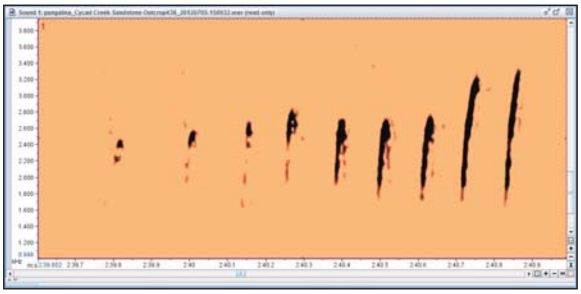
Song 30: Top End Northern Rosella (Highest Energy 2640Hz – Range 2400 to 2740Hz)



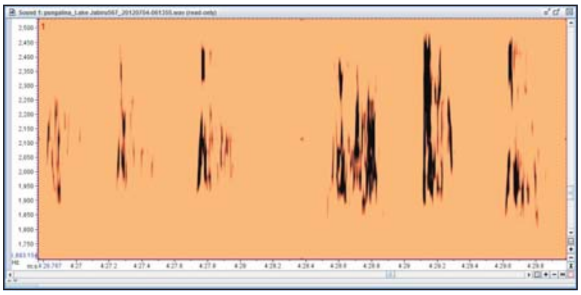
Song 31: Northern Red-backed Fairy-wren (Highest Energy 6400Hz – Range 3800 to 7600Hz)



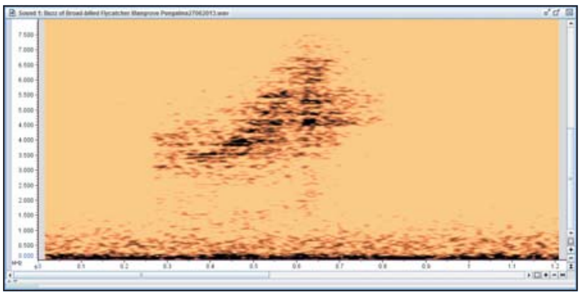
Song 32: North-western Red-tailed Black-Cockatoo (Highest Energy 1600Hz – Range 1300 to 3400Hz)



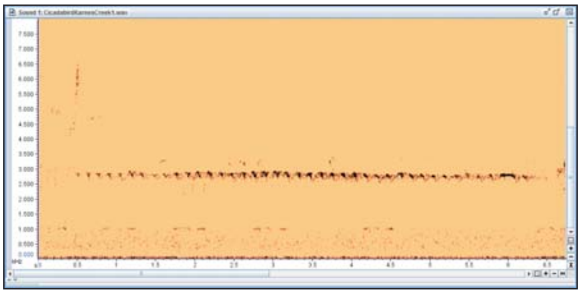
Song 33: Northern Jacky Winter (Highest Energy 2580Hz – Range 1630 to 3345Hz)



Song 34: Australasian Purple Swamphen (Highest Energy 2023Hz – Range 1800 to 2490Hz)



Song 35: Torresian Broad-billed Flycatcher (unverified, Highest Energy 4528Hz – Range 2500 to 6700Hz)

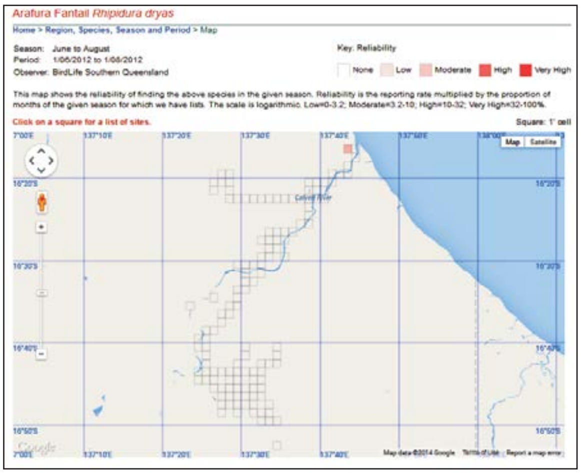


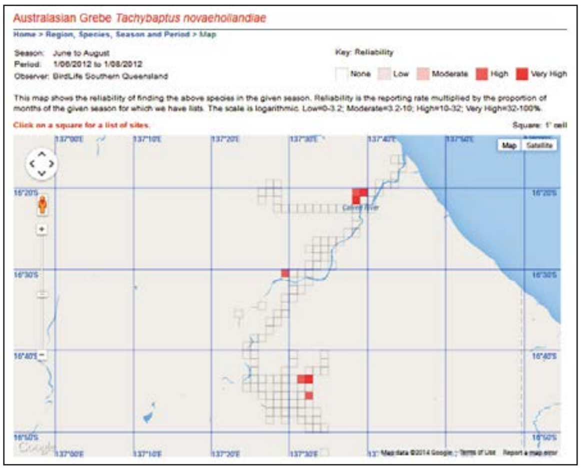
Song 36: Northern Cicadabird (unverified, Highest Energy 2784Hz – Range 2560 to 2950Hz)

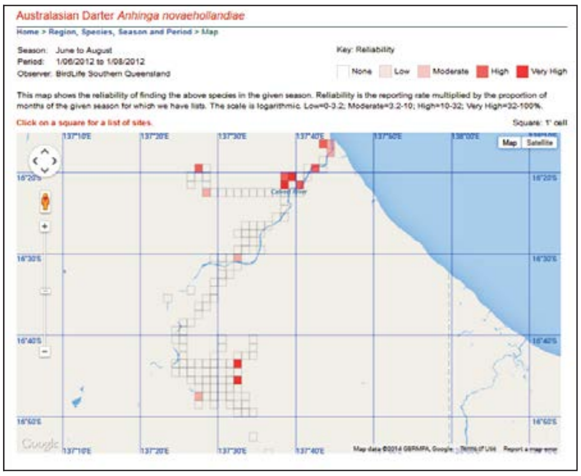
Appendix 6. Unverified bird species tentatively recorded on Pungalina–Seven Emu Wildlife Sanctuary (awaiting approval from BirdLife Australia Rarities Committee). (These may be affirmed or not affirmed by the committee based on evidence.)

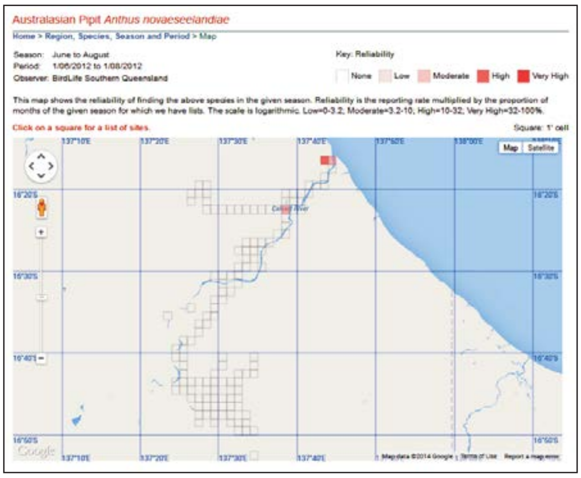
Order & Family	**Common name**	**Species**	**Status**	**Population**	**Feeding habit**	**URRF Case for Verifica-tion**
as per BirdLife Australia's Working list v1.1 (2013)		as per Clements checklist 6.7	as per IUCN Red List 2013.1	as per Pizzey & Knight (9th ed, 2012)	as per Reader's Digest (2010)	
Podicipedidae (Grebes)	Hoary-headed Grebe	*Poliocephalus poliocephalus*	Least concern	Nomadic, Endemic	Insectivorous	Notes
Accipitridae (Eagles, Kites, Goshawks, Ospreys)	Black-shouldered Kite	*Elanus axillaris*	Least concern	Nomadic, Endemic	Carnivorous	Notes
Rallidae (Crakes, Rails, Swamphens)	Torresian Baillon's Crake	*Porzana pusilla palustris*	Least concern	Winter Migrant, Australian	Insectivorous	Notes
Recurvirostridae	Red-necked Avocet	*Recurvirostra novaehollandiae*	Least concern	Nomadic, Endemic, (Rare NT Coastal)	Insectivorous	Photo-graphic
Glareolidae (Pratincoles)	Australasian Crested Tern	*Thalasseus bergii cristata*	Least concern	Sedentary, Australian	Carnivorous	Notes
Barnardius (Ringnecks)	Channel Country Ringneck	*Barnardius zonarius macgillivrayi*	Least concern	Vagrant (NT), Endemic	Granivorous	Notes
Strigidae (Hawk-Owls)	Australian Barn Owl	*Tyto alba delicatula*	Least concern	Sedentary, Endemic	Carnivorous	Notes
Meliphagidae (Honeyeaters, Chats)	Grey-headed Honeyeater	*Lichenostomus keartlandi*	Least concern	Sedentary, Endemic	Insectivorous	Notes
	Top End White-lined Honeyeater	*Meliphaga albilineata albilineata*	Least concern	Sedentary, Endemic	Insectivorous	Notes
	Rufous-banded Honeyeater	*Conopophila albogularis*	Least concern	Nomadic, Australian	Insectivorous	Notes
Monarchidae (Flycatchers, Monarchs)	Torresian Broad-billed Flycatcher	*Myiagra ruficollis mimikae*	Least concern	Sedentary, Australian	Insectivorous	Acoustic
	North-western Shining Flycatcher	*Myiagra alecto melvillensis*	Least concern	Sedentary, Endemic	Insectivorous	Notes
Campephagidae (Cuckoo-shrikes and Trillers)	Northern Cicadabird	*Edolisoma tenuirostre melvillense*	Least concern	Summer Migrant, Australian	Insectivorous	Acoustic
Estrildidae (Weaver Finches)	Australian Zebra Finch	*Taeniopygia guttata castanotis*	Least concern	Sedentary, Endemic	Granivorous	Photo-graphic

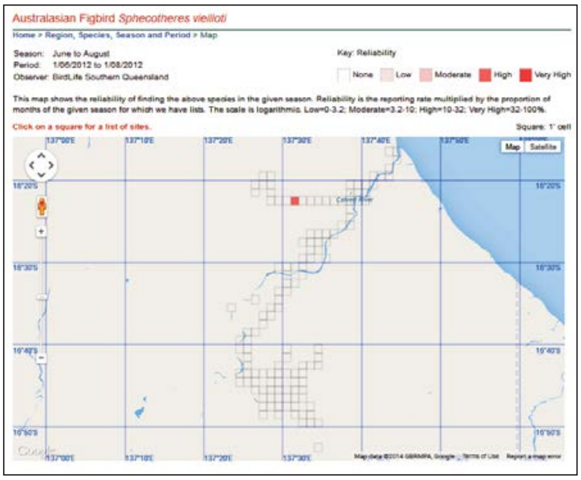
Appendix 7. Distribution maps

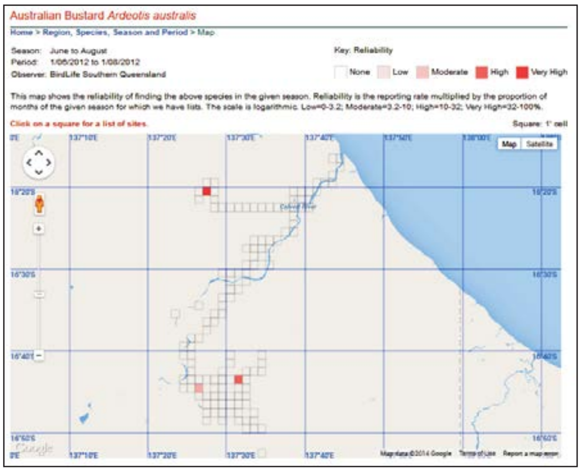


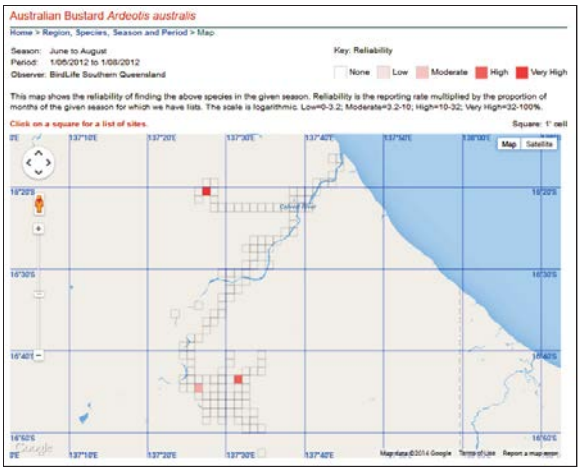


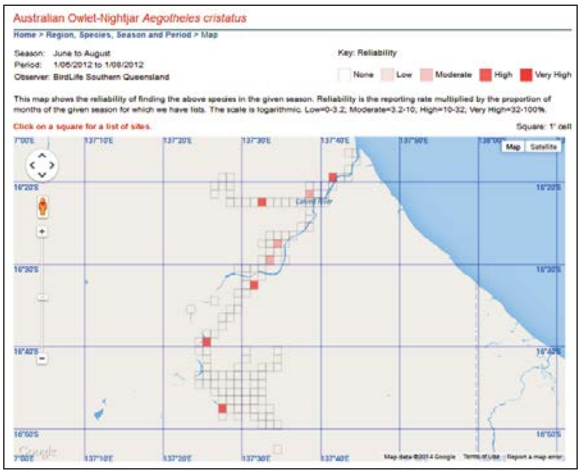


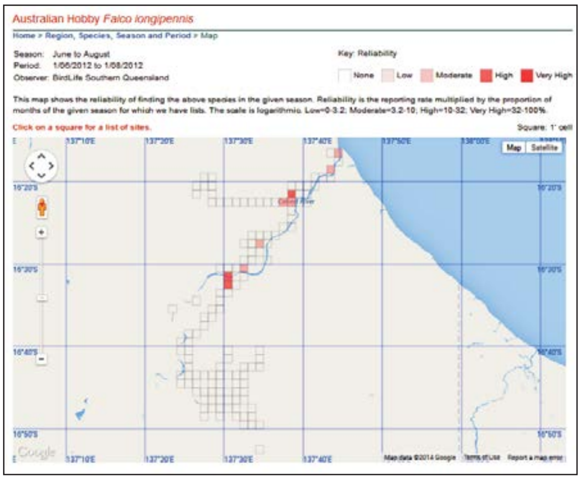


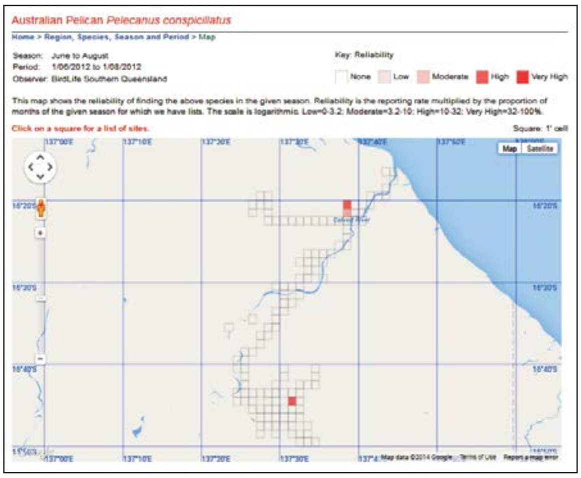


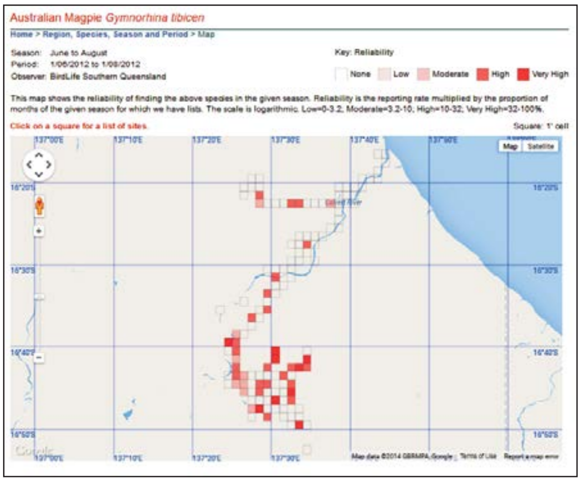


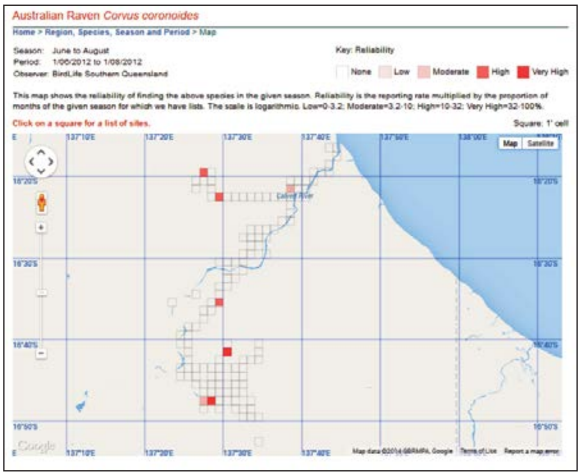

Australian Bustard Ardeotis australis
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

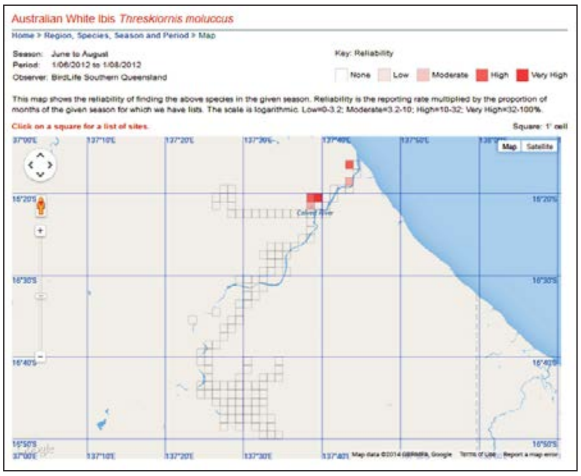

Australian Owlet-Nightjar Aegotheles cristatus
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

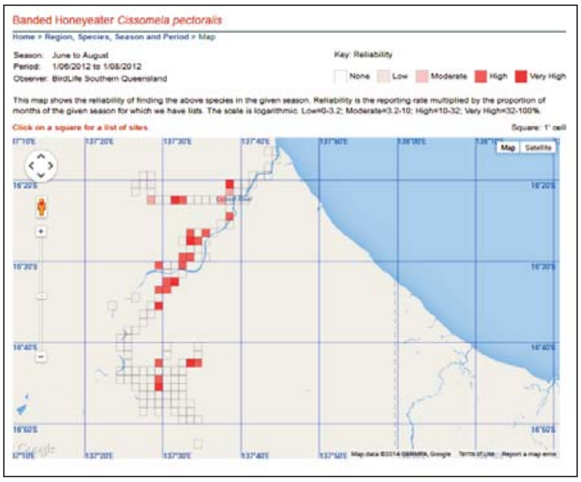

Australian Hobby Falco longipennis
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

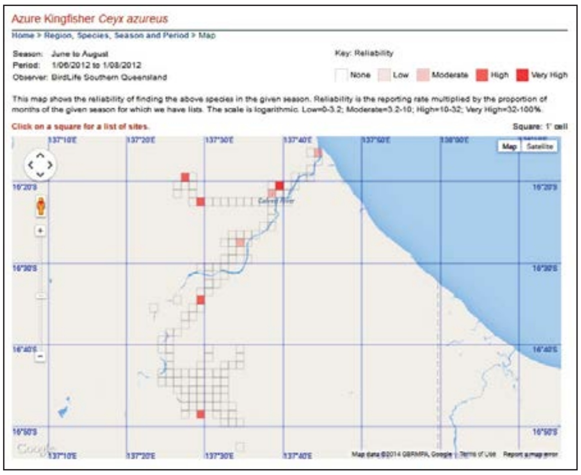

Australian Pelican Pelecanus conspicillatus
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

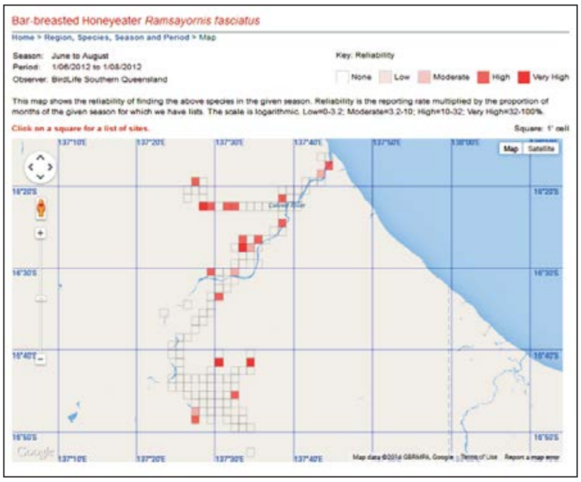

Australian Magpie Gymnorhina tibicen
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

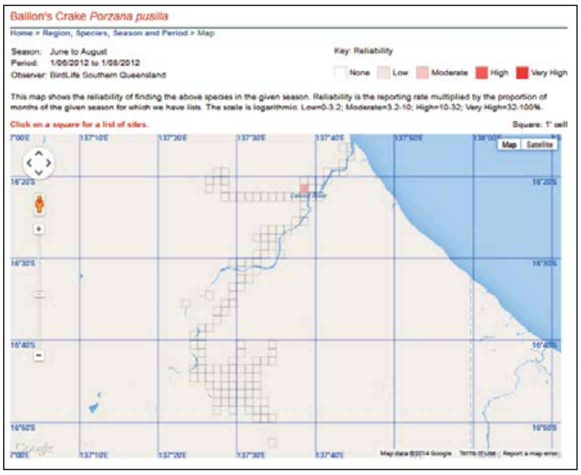

Australian Raven Corvus coronoides
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

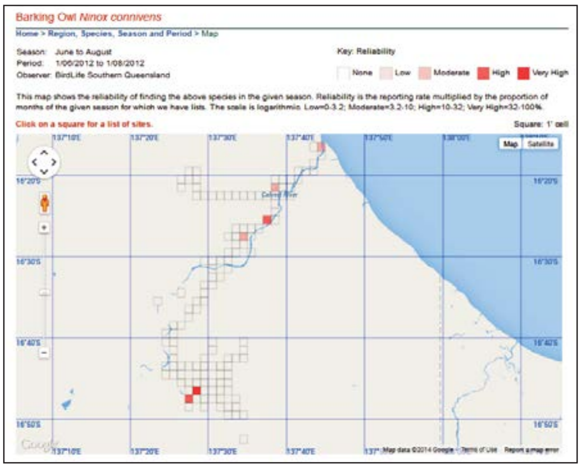

Australian White Ibis *Threskiornis moluccus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

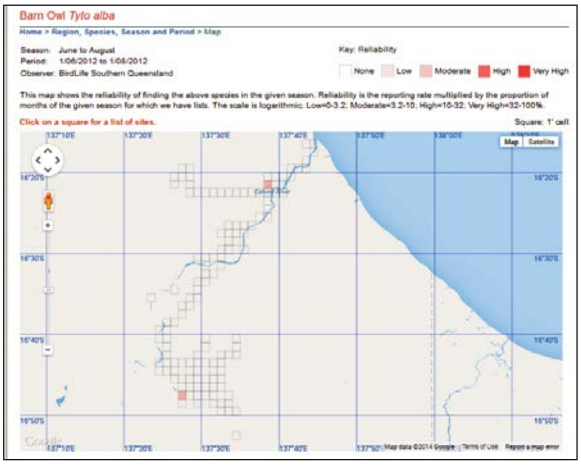

Banded Honeyeater *Cissomela pectoralis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

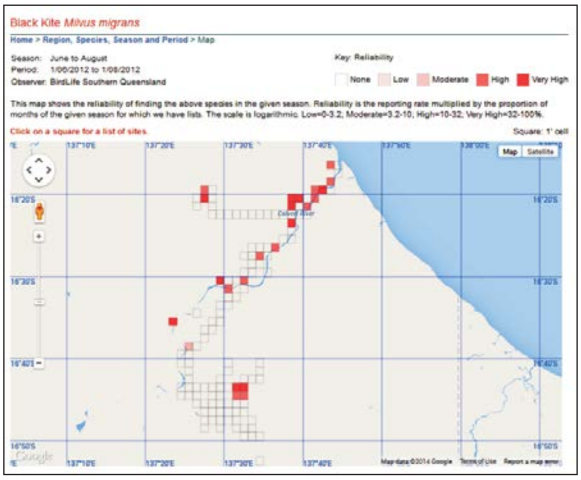

Azure Kingfisher *Ceyx azureus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

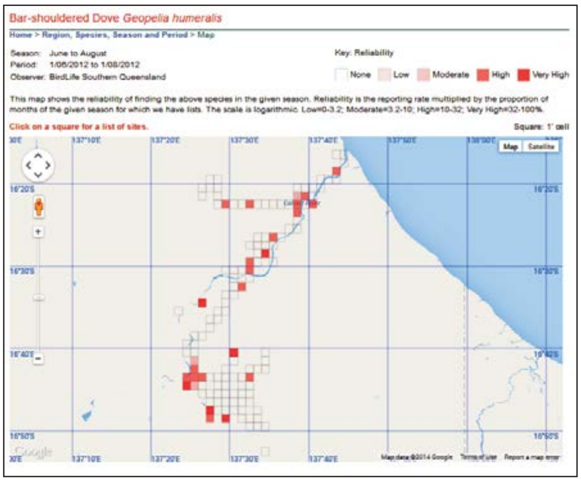

Bar-breasted Honeyeater *Ramsayornis fasciatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

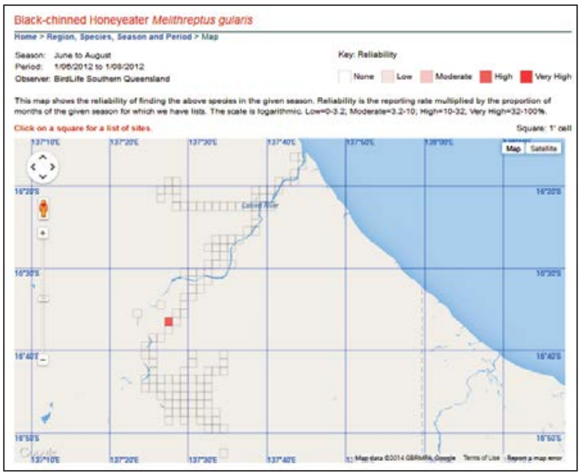

Baillon's Crake *Porzana pusilla*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

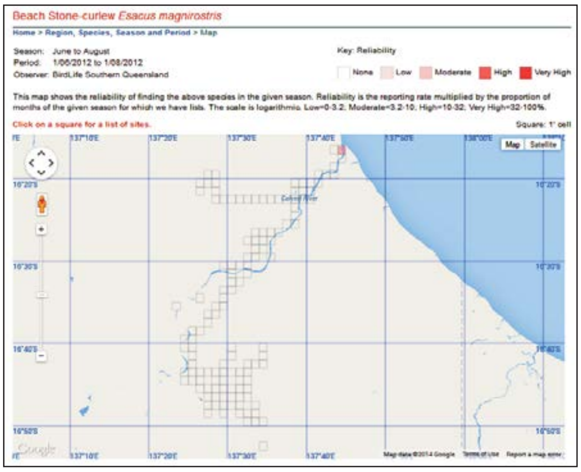

Barking Owl *Ninox connivens*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

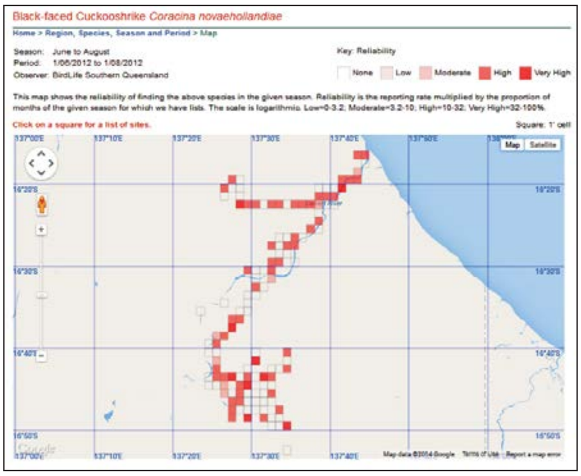

Barn Owl *Tyto alba*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

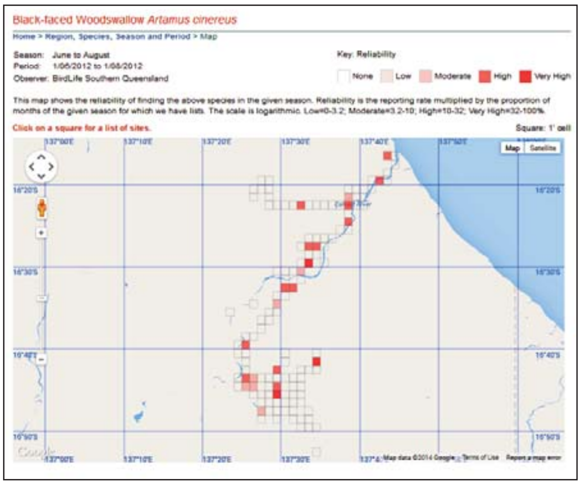

Black Kite *Milvus migrans*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

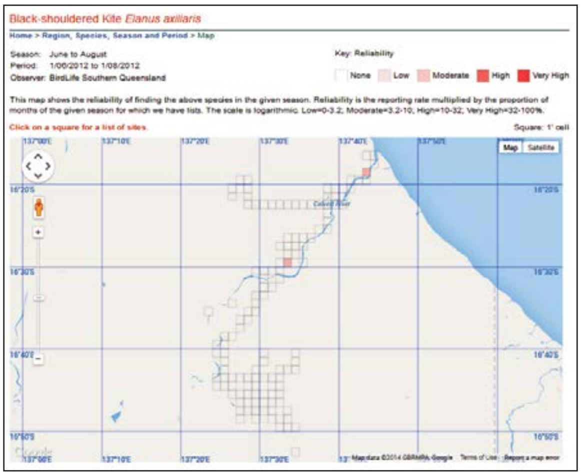

Bar-shouldered Dove *Geopelia humeralis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

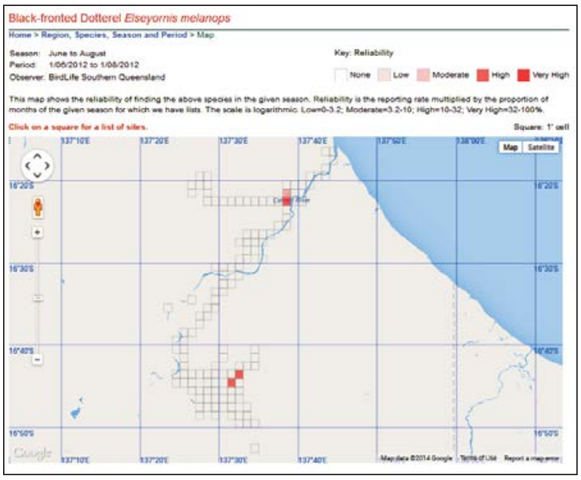

Black-chinned Honeyeater *Melithreptus gularis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

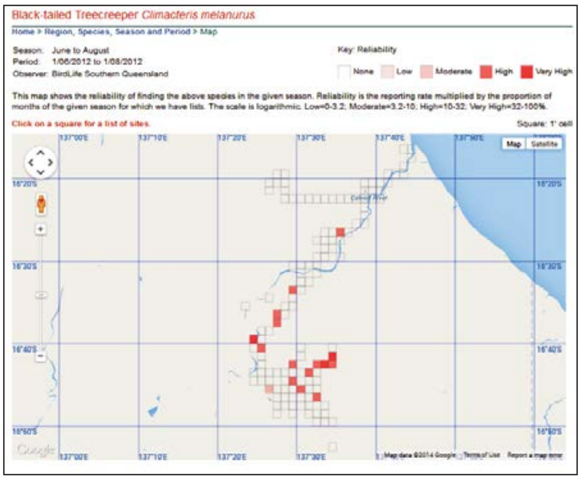

Beach Stone-curlew *Esacus magnirostris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

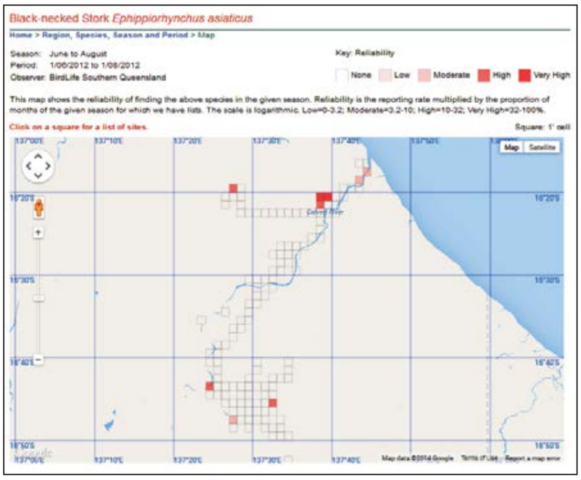

Black-faced Cuckooshrike *Coracina novaehollandiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

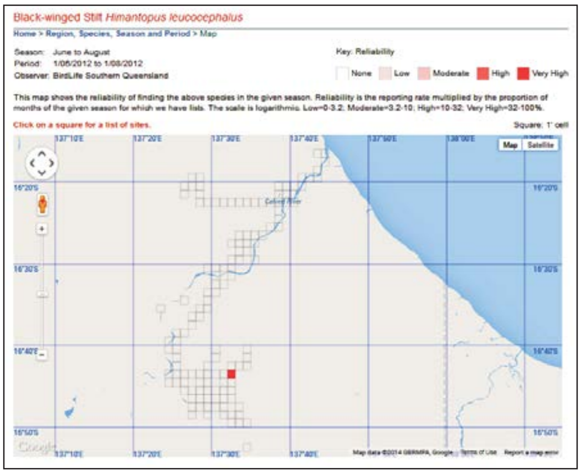

Black-faced Woodswallow *Artamus cinereus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

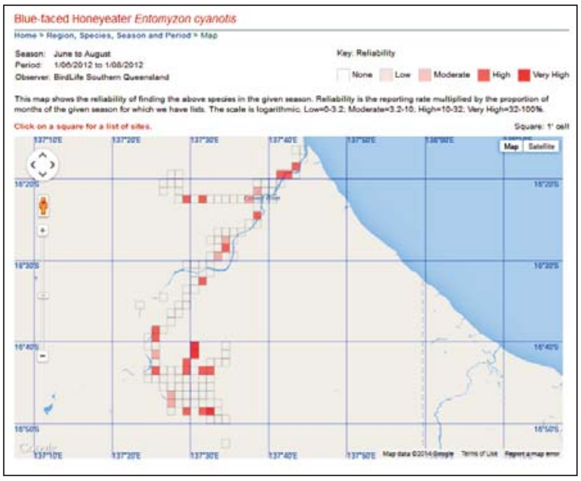

Black-shouldered Kite *Elanus axillaris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

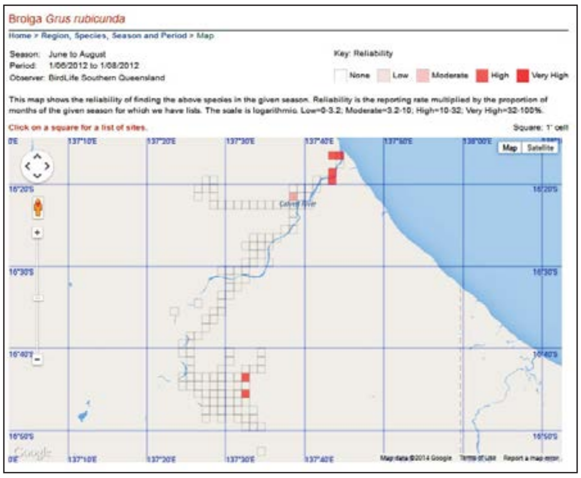

Black-fronted Dotterel *Elseyornis melanops*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

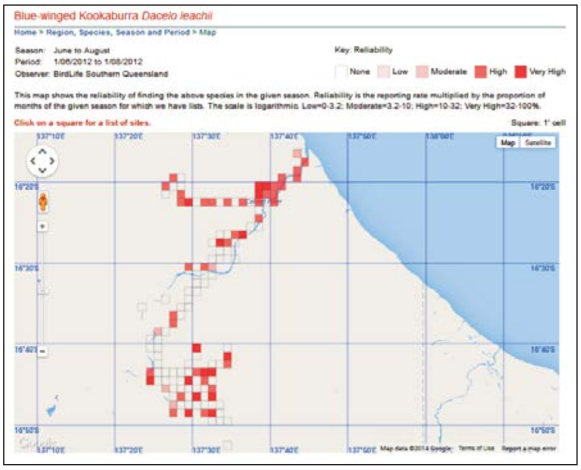

Black-tailed Treecreeper *Climacteris melanurus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

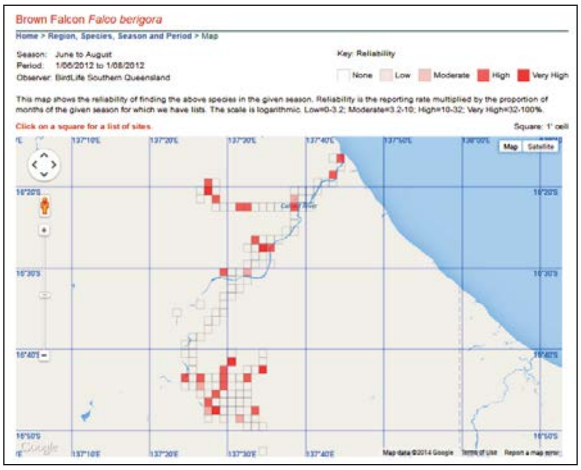

Black-necked Stork *Ephippiorhynchus asiaticus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

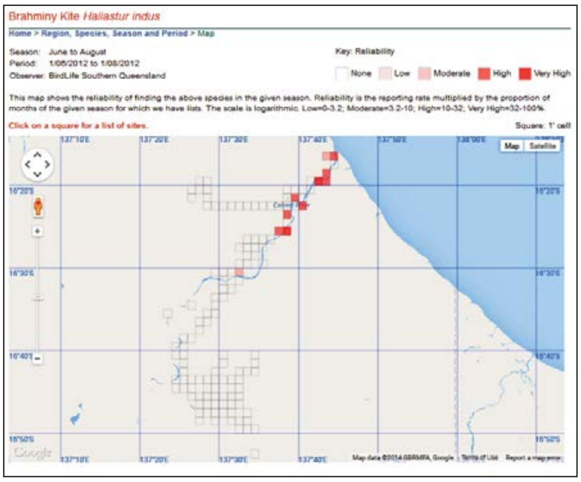

Black-winged Stilt *Himantopus leucocephalus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

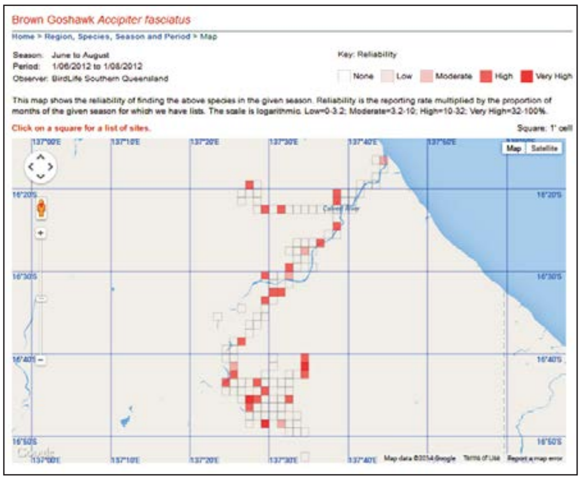

Blue-faced Honeyeater Entomyzon cyanotis
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

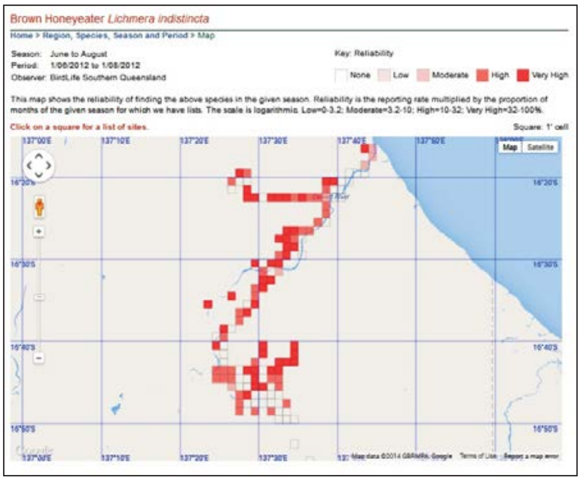

Brolga Grus rubicunda
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

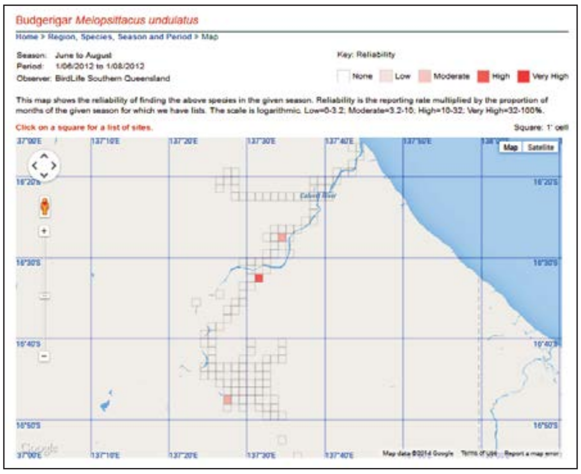

Blue-winged Kookaburra Dacelo leachii
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

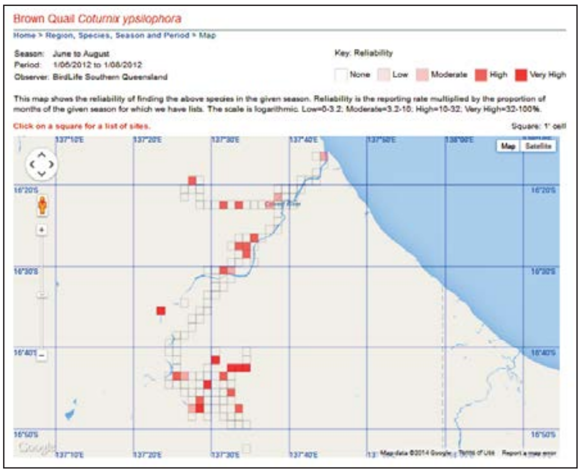

Brown Falcon Falco berigora
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

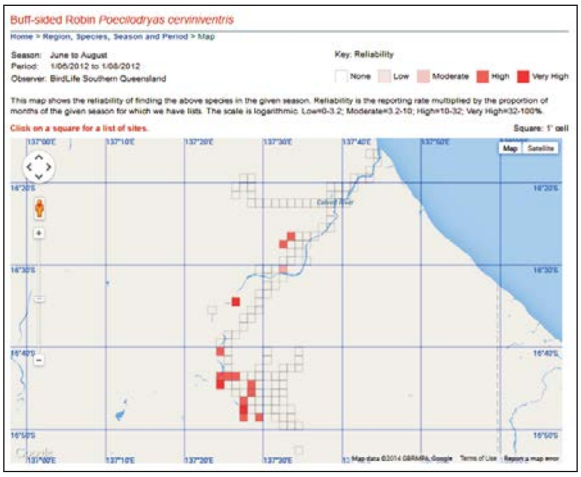

Brahminy Kite Haliastur indus
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

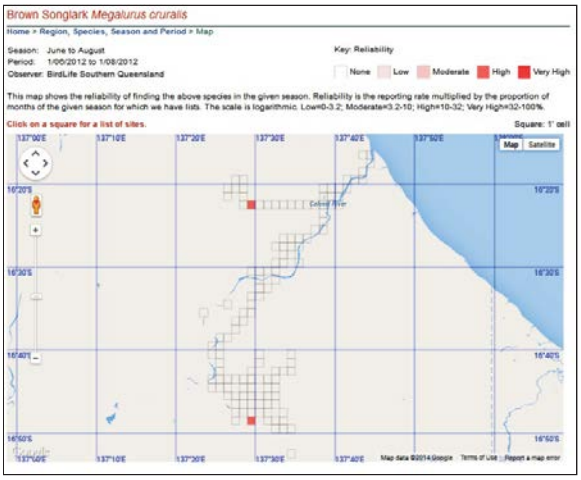

Brown Goshawk Accipiter fasciatus
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

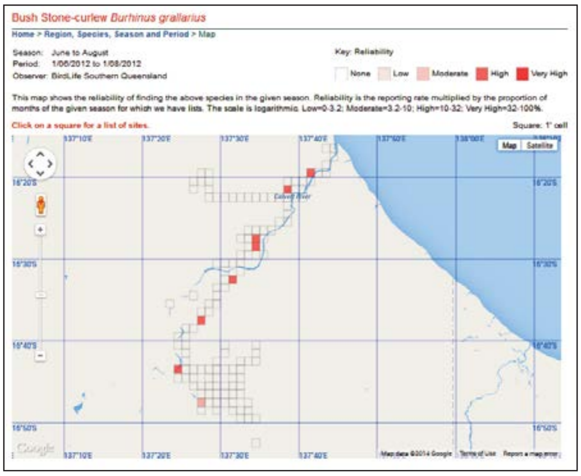

Brown Honeyeater *Lichmera indistincta*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

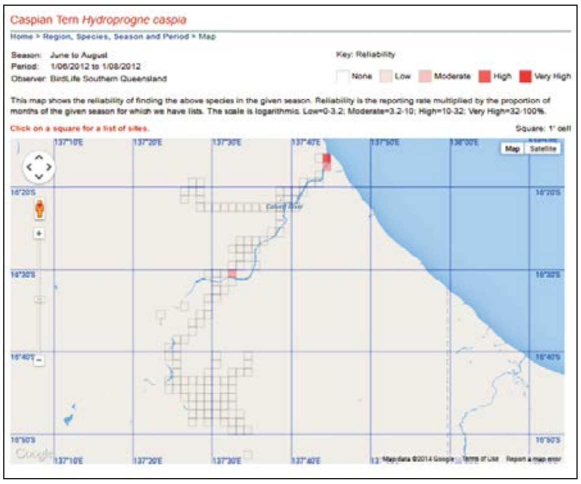

Budgerigar *Melopsittacus undulatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

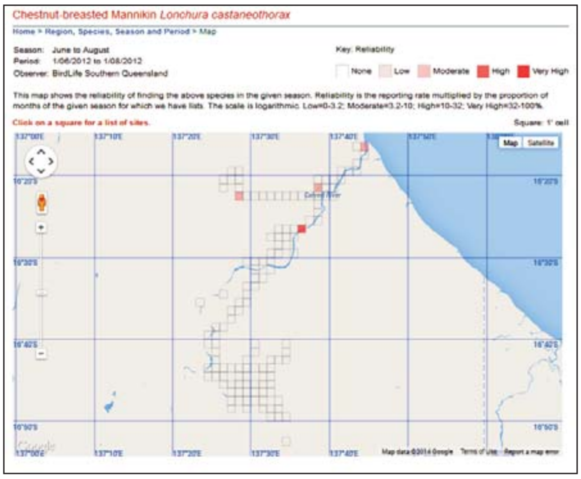

Brown Quail *Coturnix ypsilophora*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

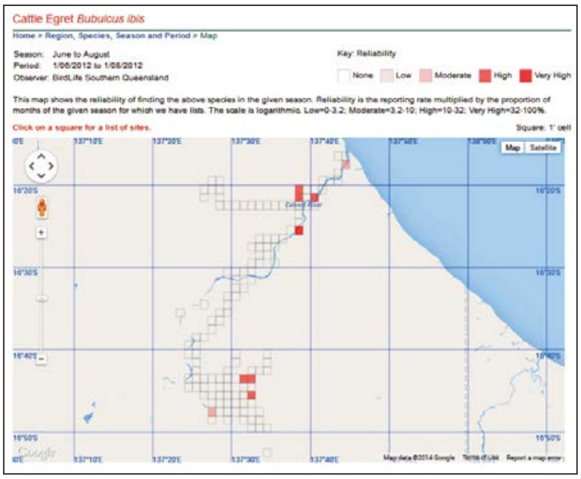

Buff-sided Robin *Poecilodryas cerviniventris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

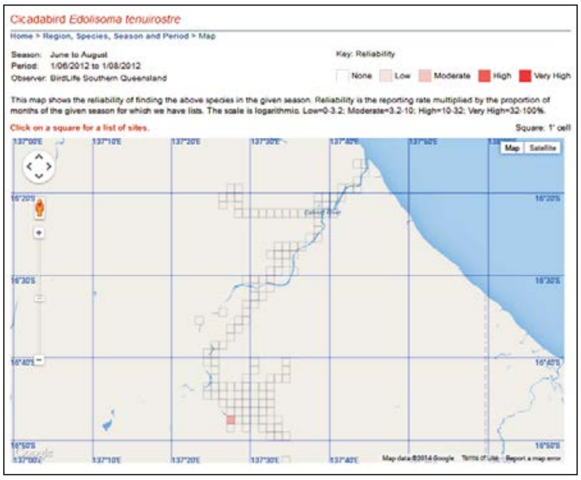

Brown Songlark *Megalurus cruralis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

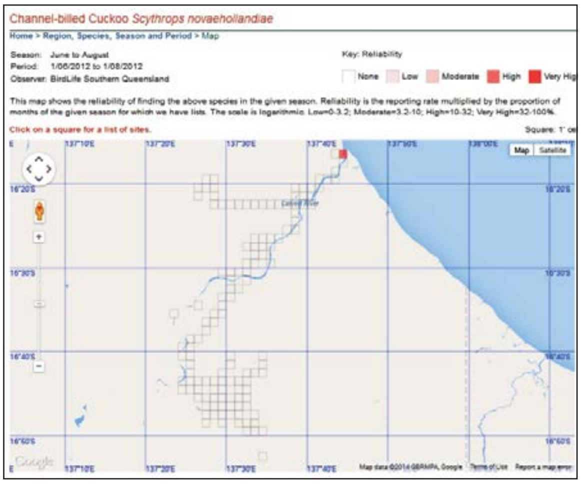

Bush Stone-curlew *Burhinus grallarius*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

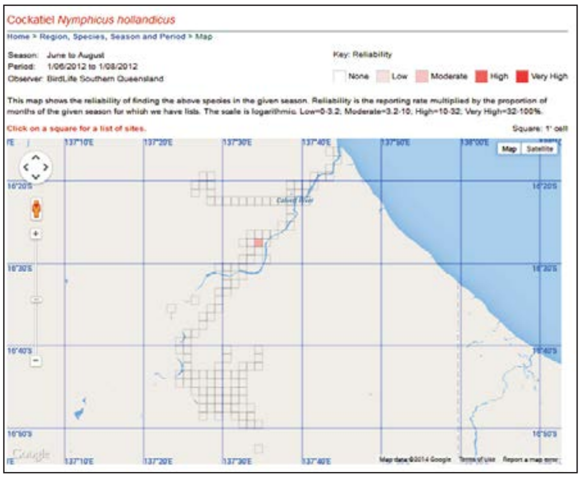

Caspian Tern *Hydroprogne caspia*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

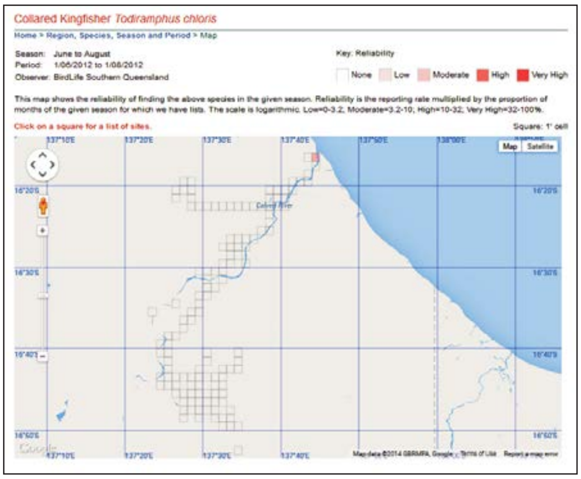

Chestnut-breasted Mannikin *Lonchura castaneothorax*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

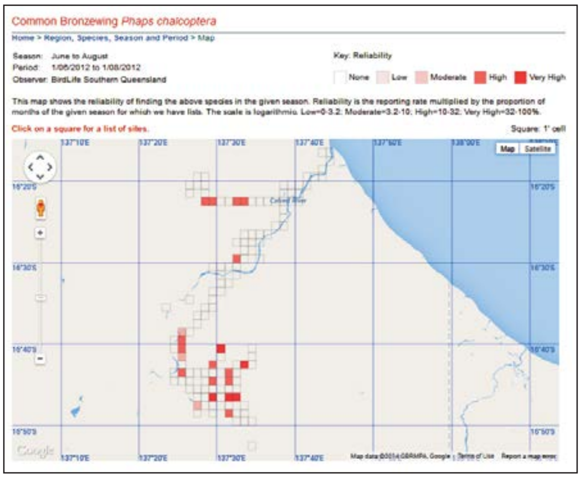

Cattle Egret *Bubulcus ibis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

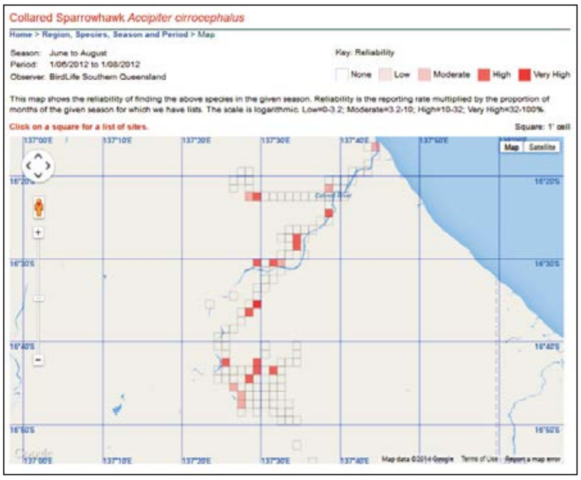

Cicadabird *Edolisoma tenuirostre*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

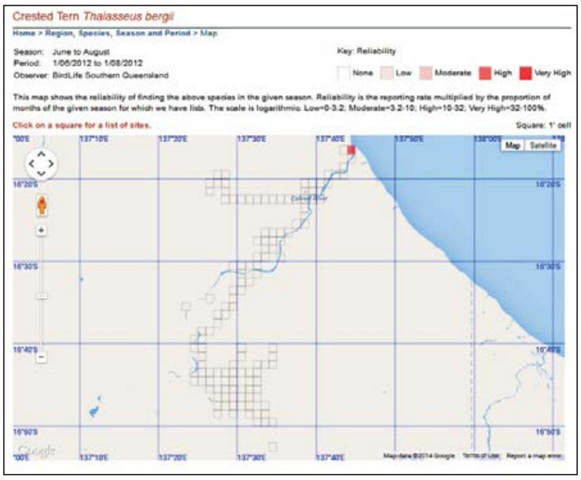

Channel-billed Cuckoo *Scythrops novaehollandiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very Hig
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' ce
Map Satellite

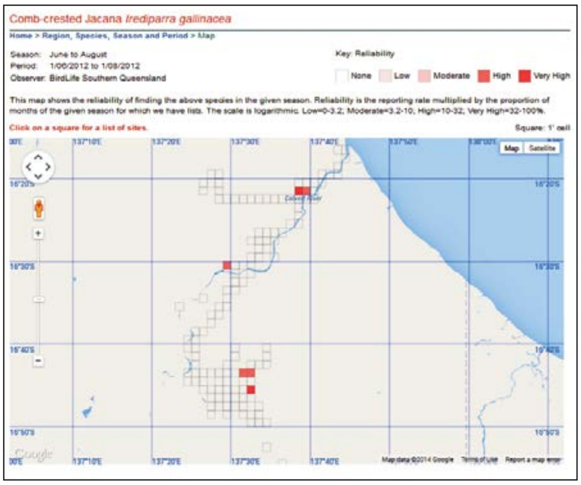

Cockatiel *Nymphicus hollandicus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

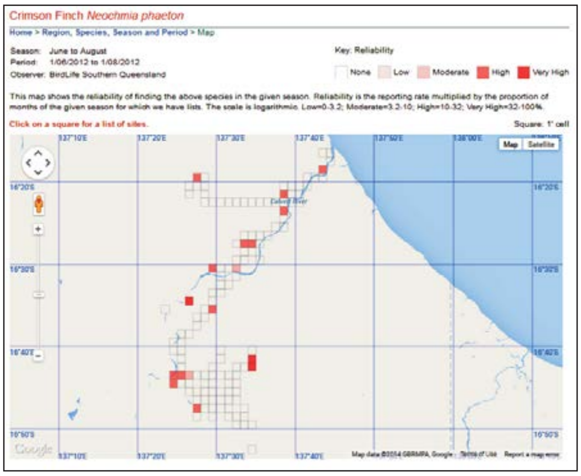

Collared Kingfisher *Todiramphus chloris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

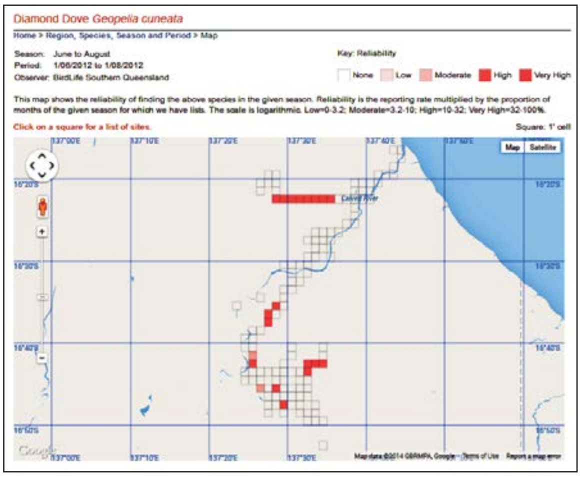

Common Bronzewing *Phaps chalcoptera*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

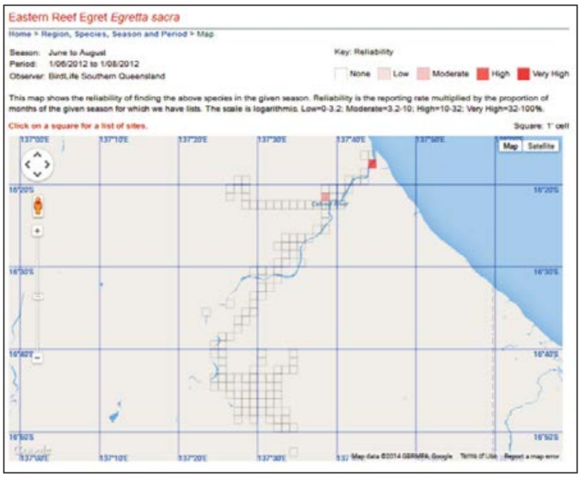

Collared Sparrowhawk *Accipiter cirrocephalus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

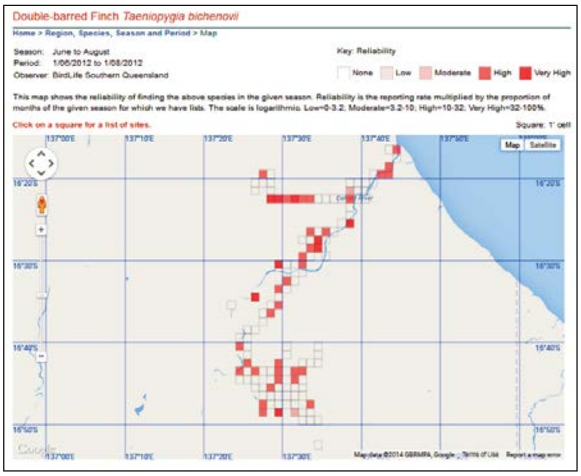

Crested Tern *Thalasseus bergii*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

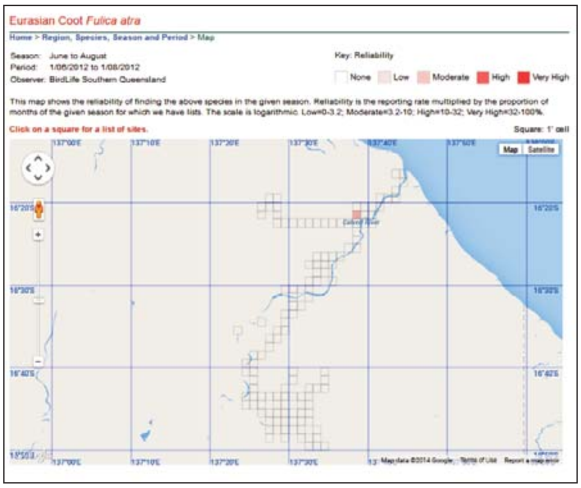

Comb-crested Jacana *Irediparra gallinacea*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

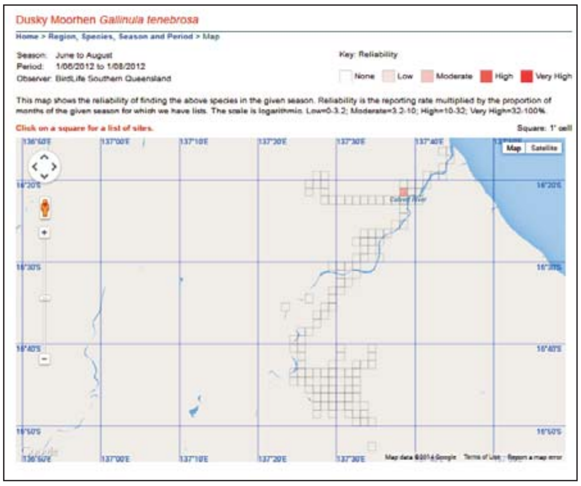

Crimson Finch *Neochmia phaeton*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

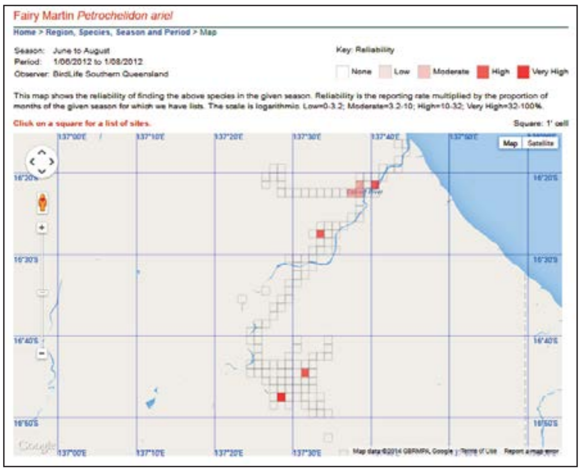

Diamond Dove *Geopelia cuneata*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

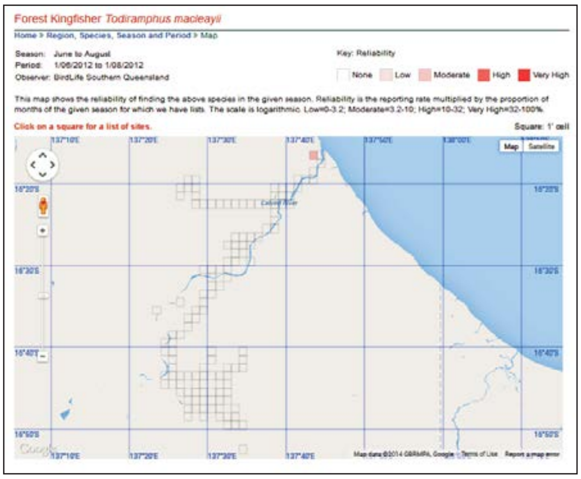

Eastern Reef Egret *Egretta sacra*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

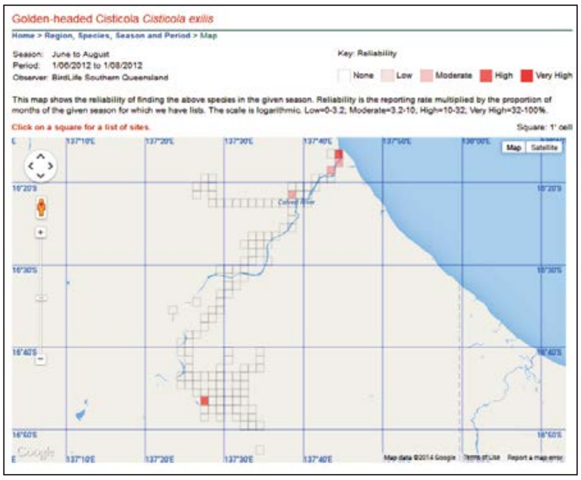

Double-barred Finch *Taeniopygia bichenovii*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

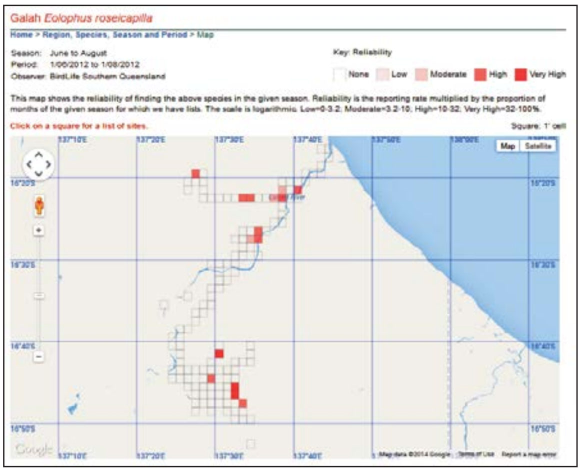

Eurasian Coot *Fulica atra*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

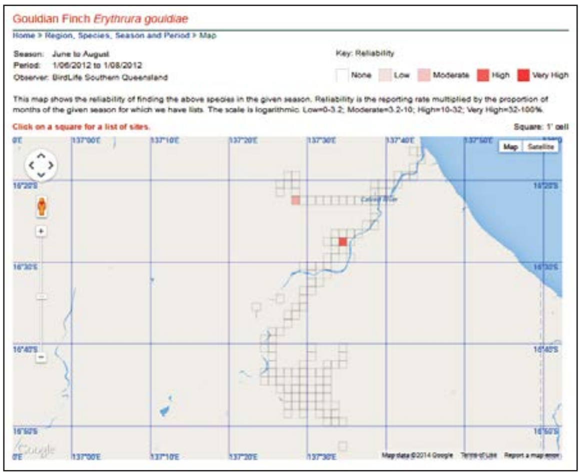

Dusky Moorhen *Gallinula tenebrosa*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

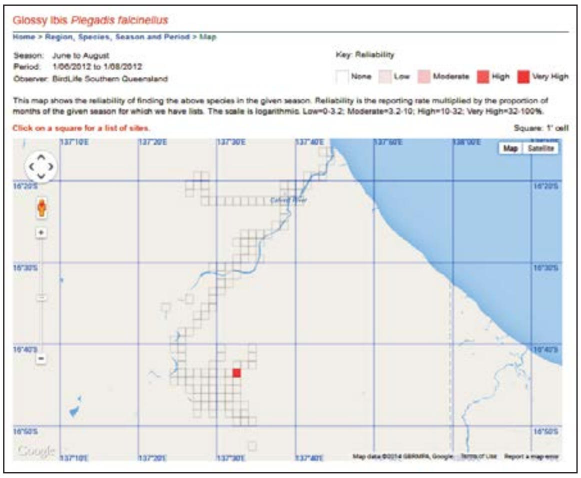

Fairy Martin *Petrochelidon ariel*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

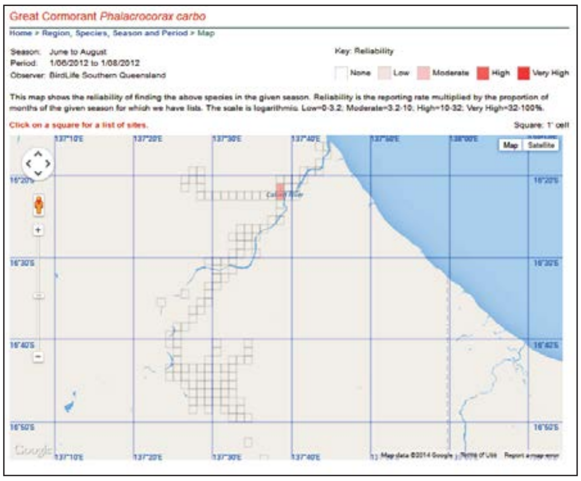

Forest Kingfisher *Todiramphus macleayii*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

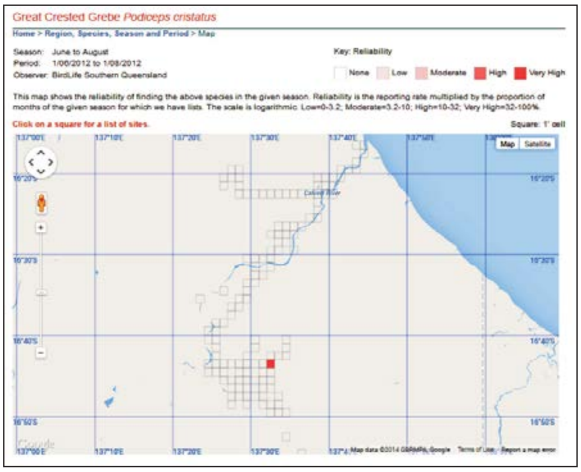

Golden-headed Cisticola *Cisticola exilis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

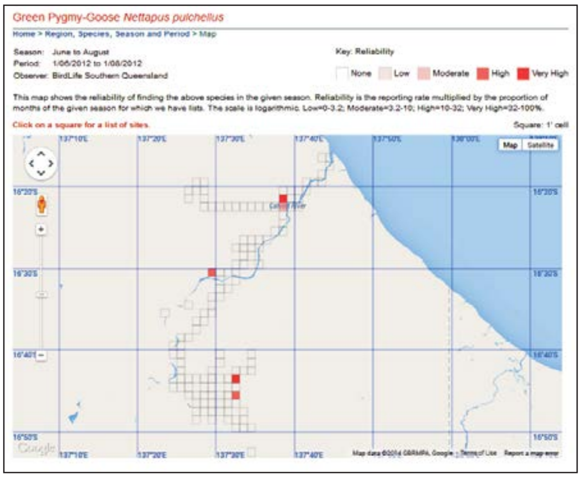

Galah *Eolophus roseicapilla*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

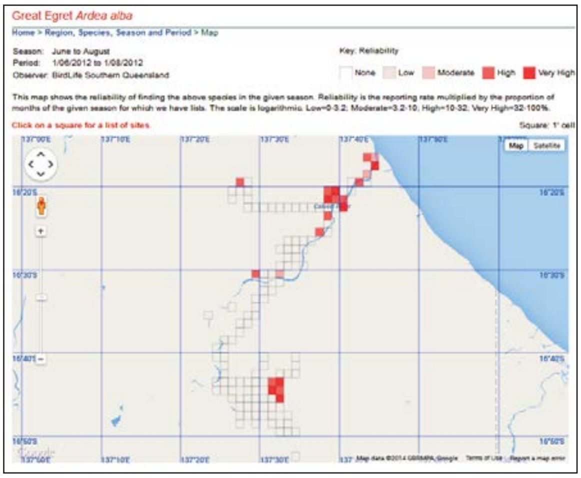

Gouldian Finch *Erythrura gouldiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

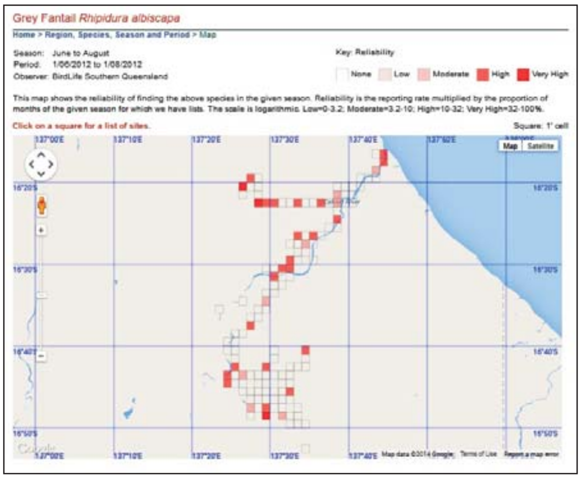

Glossy Ibis *Plegadis falcinellus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

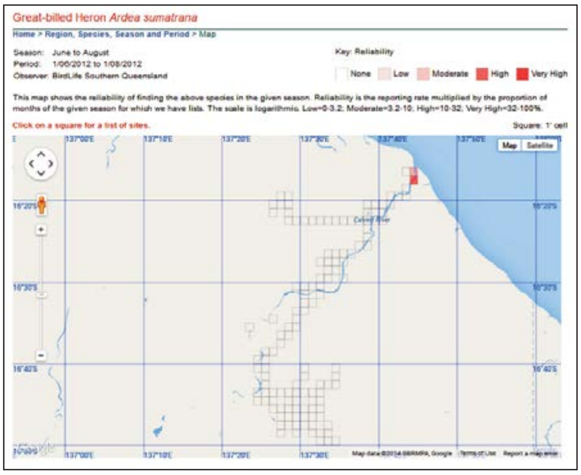

Great Cormorant *Phalacrocorax carbo*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

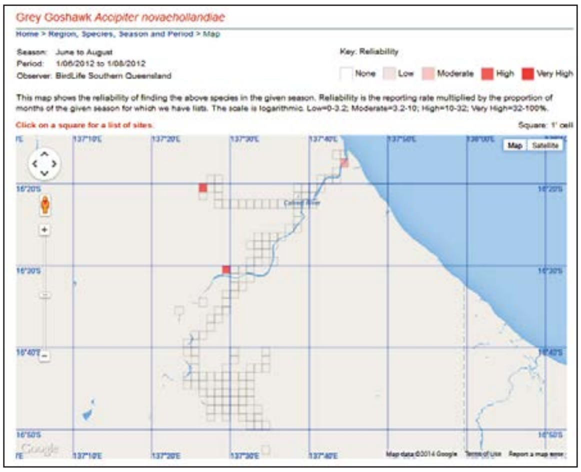

Great Crested Grebe *Podiceps cristatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

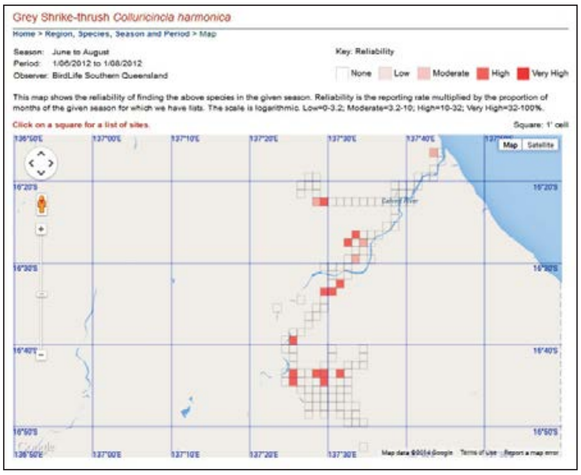

Green Pygmy-Goose *Nettapus pulchellus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

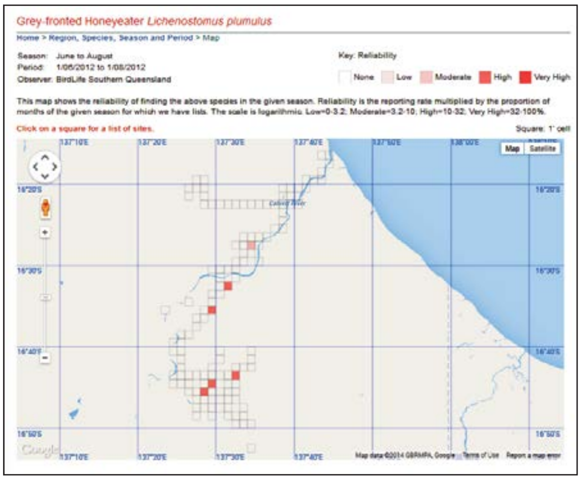

Great Egret *Ardea alba*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

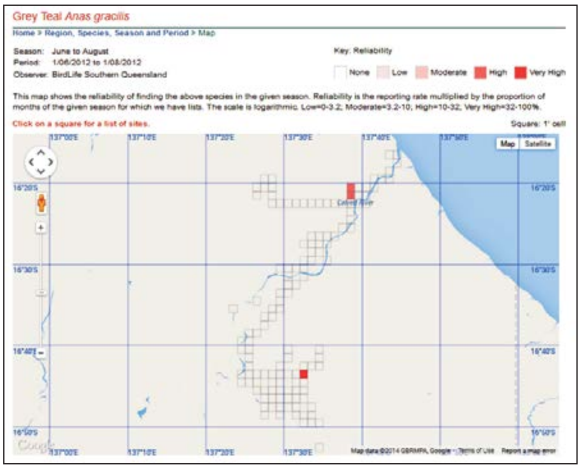

Grey Fantail *Rhipidura albiscapa*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

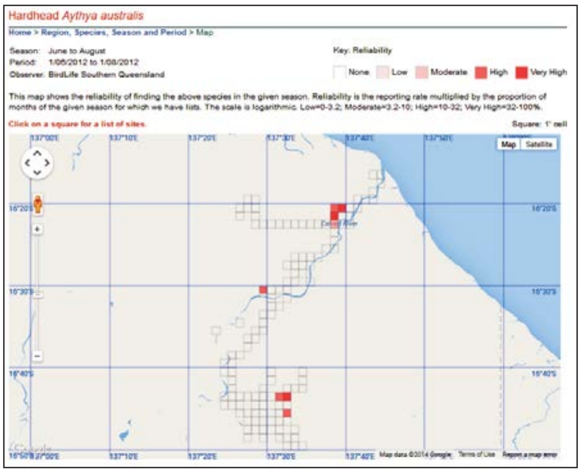

Great-billed Heron *Ardea sumatrana*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

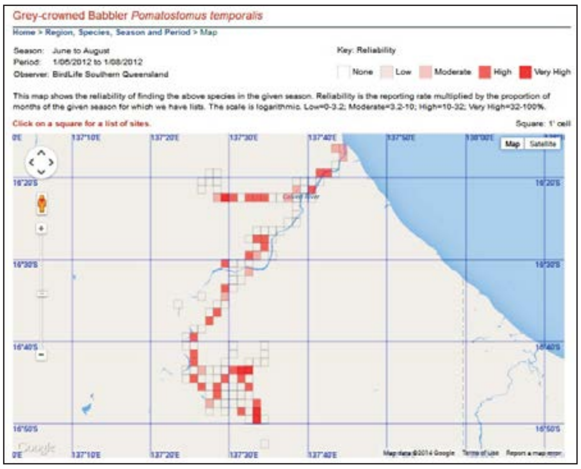

Grey Goshawk *Accipter novaehollandiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

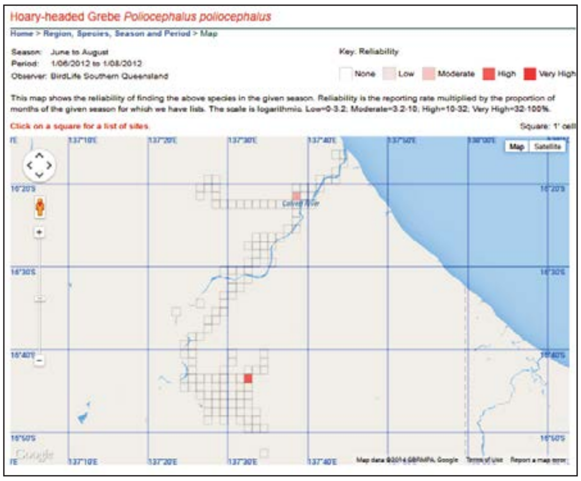

Grey Shrike-thrush *Colluricincla harmonica*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

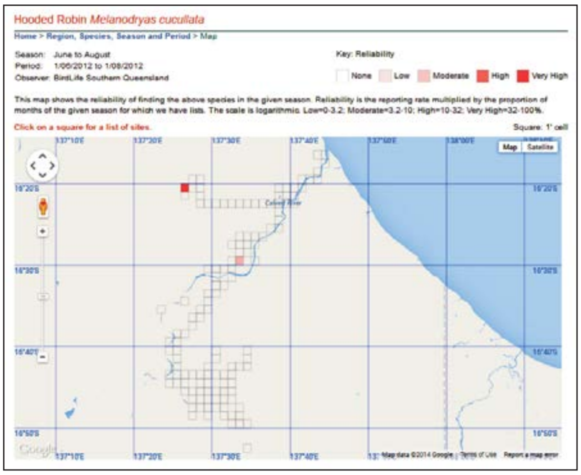

Grey-fronted Honeyeater *Lichenostomus plumulus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

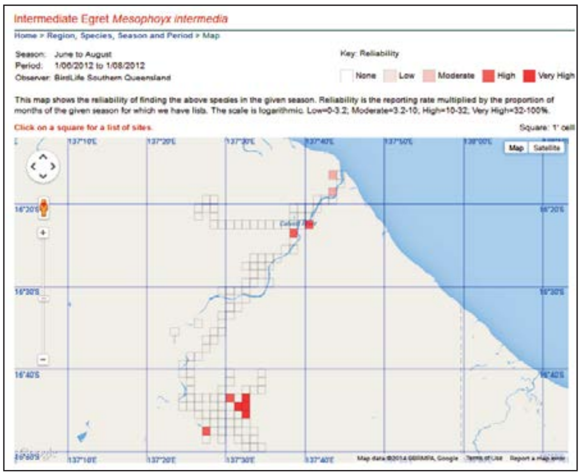

Grey Teal *Anas gracilis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

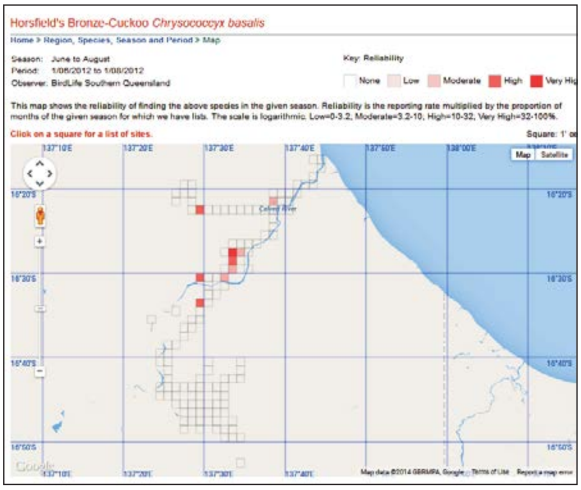

Hardhead *Aythya australis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

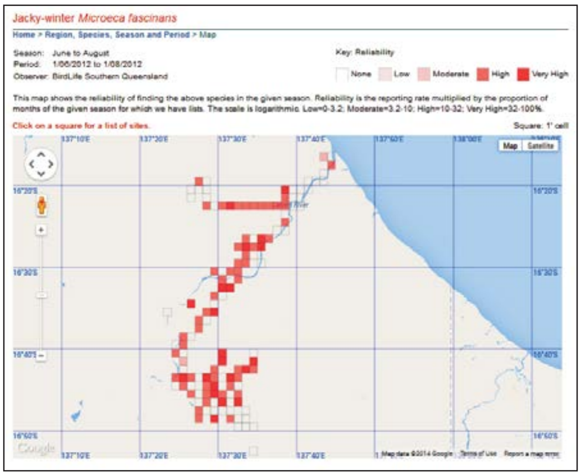

Grey-crowned Babbler *Pomatostomus temporalis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

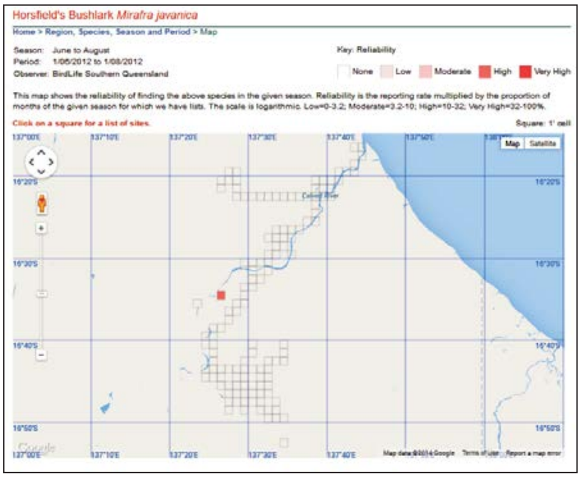

Hoary-headed Grebe *Poliocephalus poliocephalus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

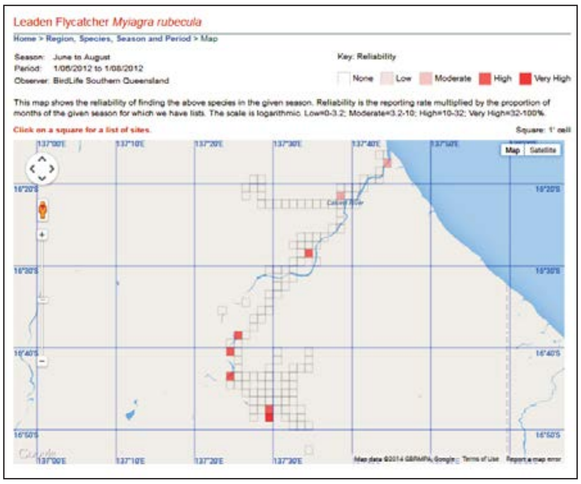

Hooded Robin Melanodryas cucullata
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

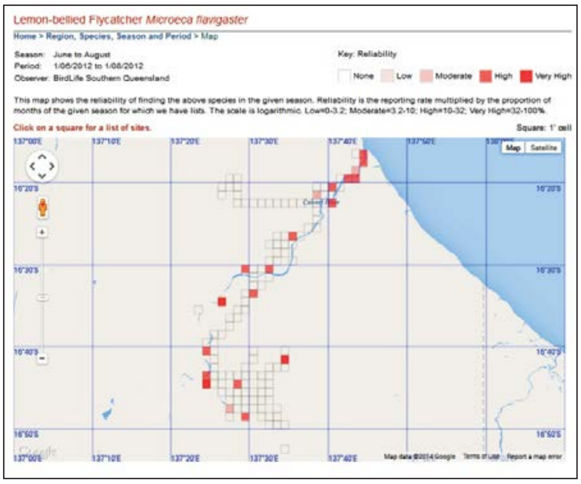

Intermediate Egret Mesophoyx intermedia
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

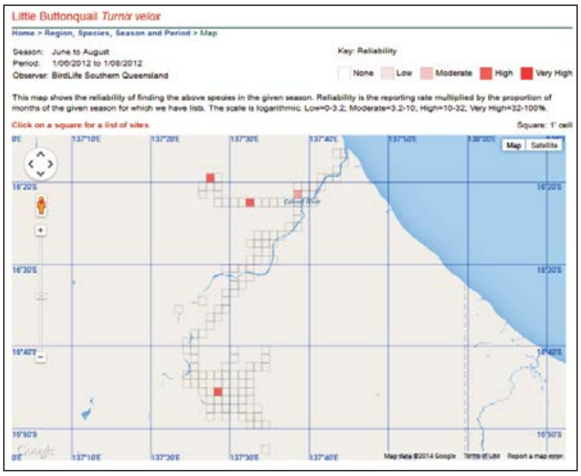

Horsfield's Bronze-Cuckoo Chrysococcyx basalis
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very Hig
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Map Satellite

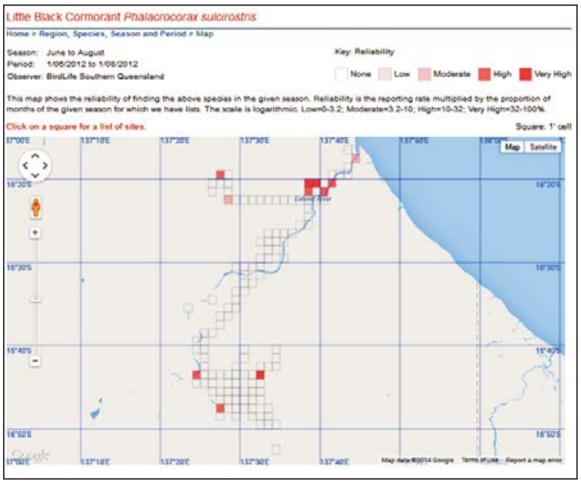

Jacky-winter Microeca fascinans
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

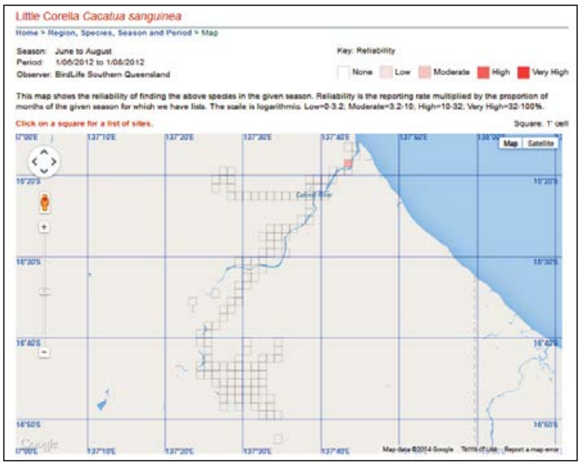

Horsfield's Bushlark Mirafra javanica
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

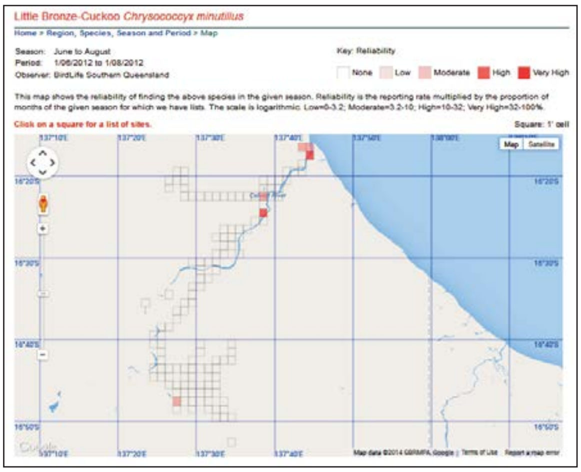

Leaden Flycatcher Myiagra rubecula
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

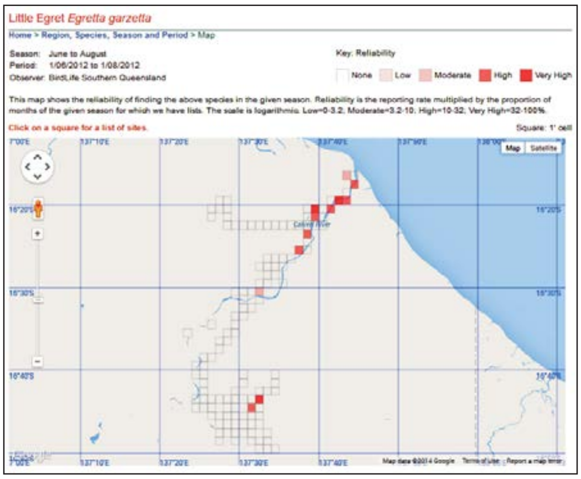

Lemon-bellied Flycatcher *Microeca flavigaster*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

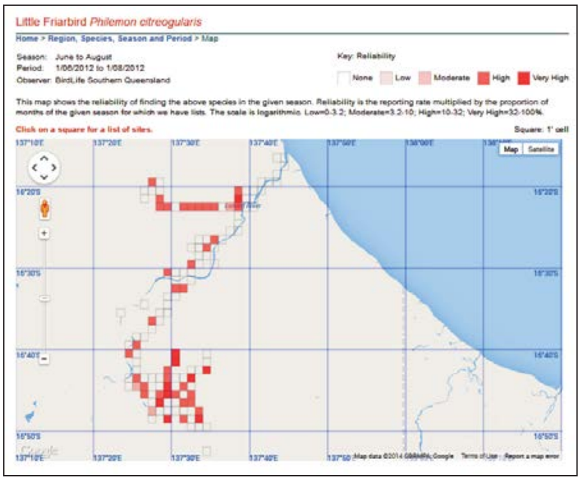

Little Buttonquail *Turnix velox*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

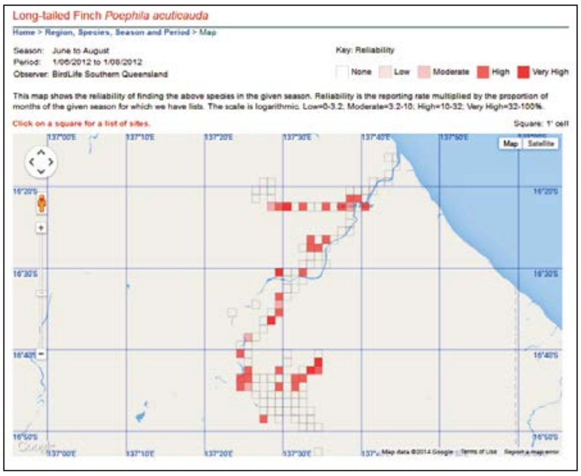

Little Black Cormorant *Phalacrocorax sulcirostris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

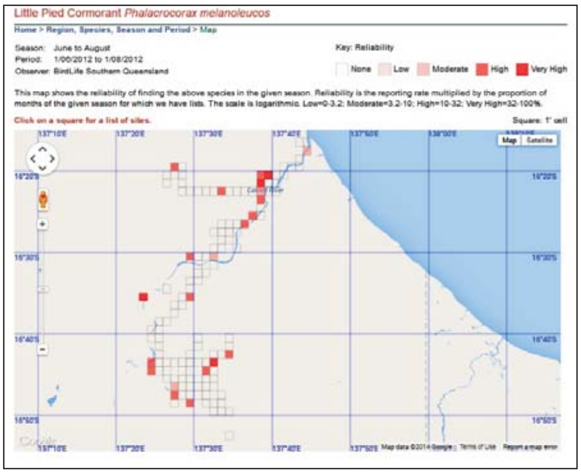

Little Corella *Cacatua sanguinea*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

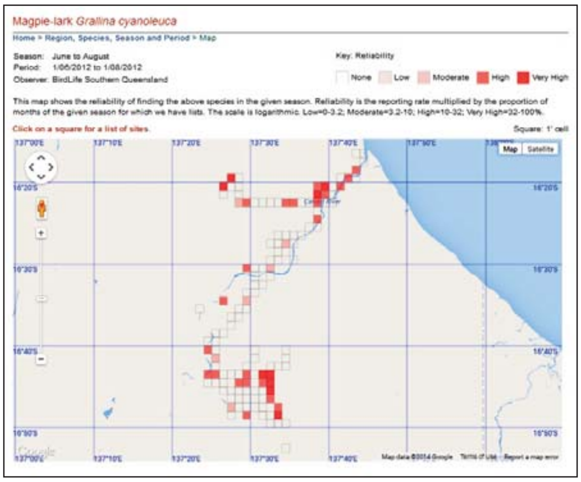

Little Bronze-Cuckoo *Chrysococcyx minutillus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

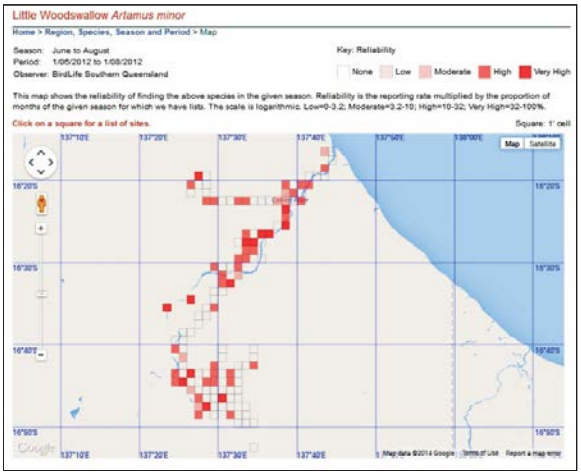

Little Egret *Egretta garzetta*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

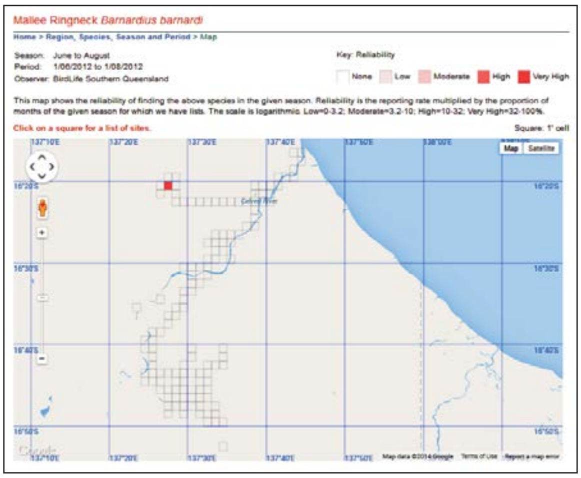

Little Friarbird *Philemon citreogularis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

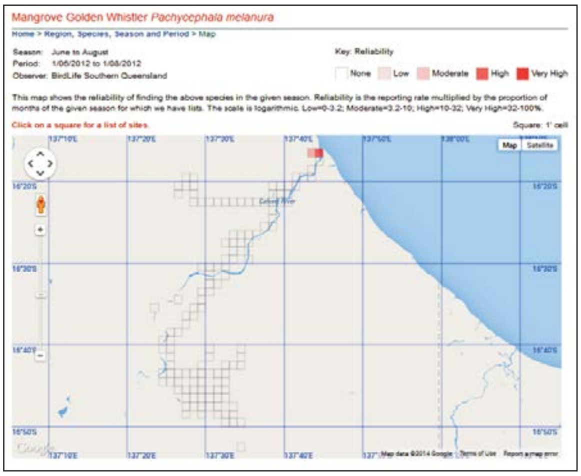

Long-tailed Finch *Poephila acuticauda*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

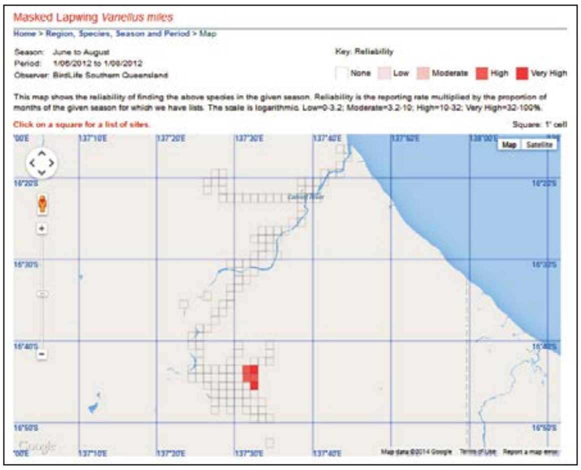

Little Pied Cormorant *Phalacrocorax melanoleucos*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

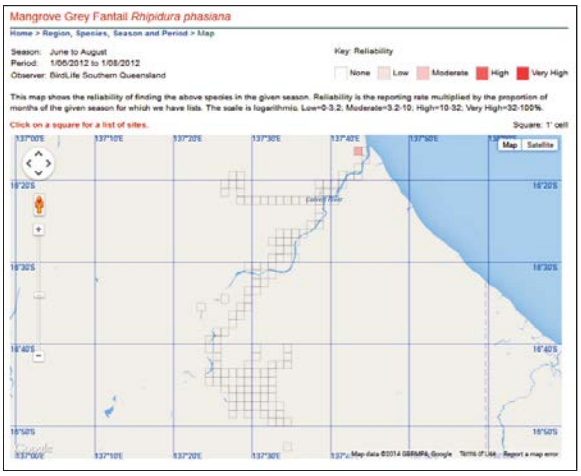

Magpie-lark *Grallina cyanoleuca*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

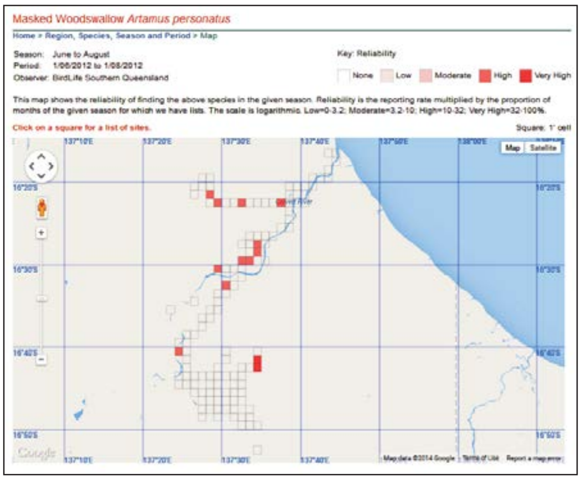

Little Woodswallow *Artamus minor*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

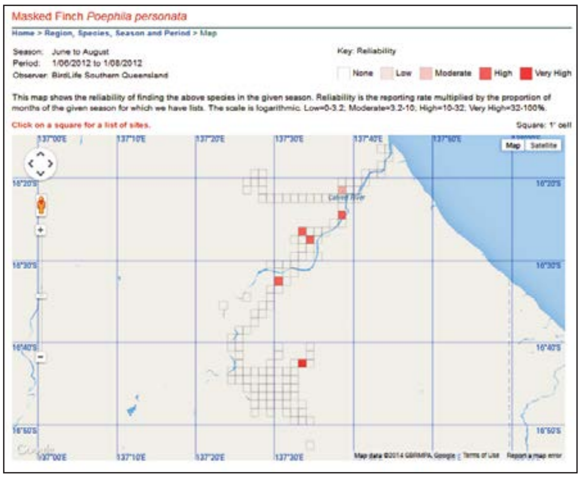

Mallee Ringneck *Barnardius barnardi*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

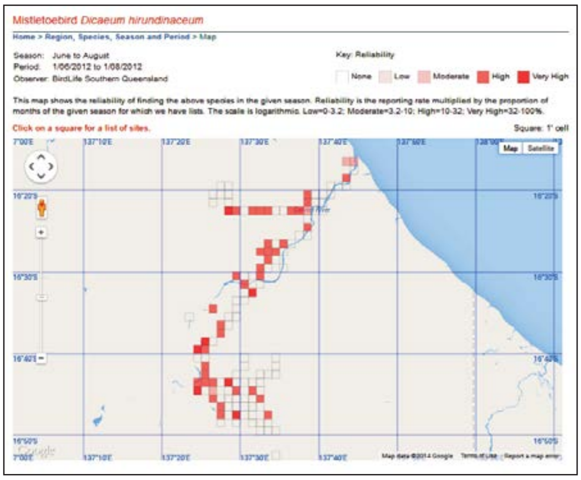

Mangrove Golden Whistler *Pachycephala melanura*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

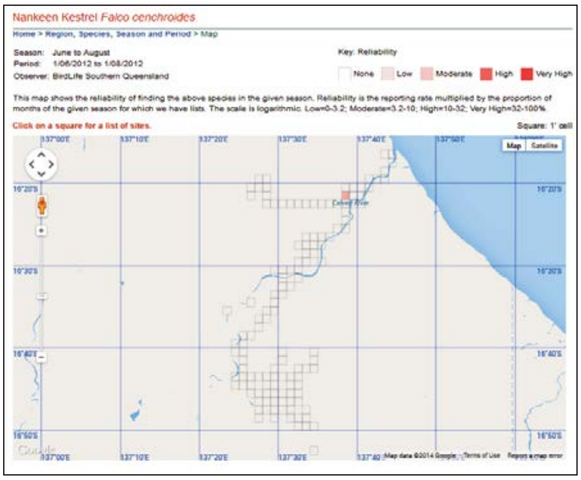

Masked Lapwing *Vanellus miles*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

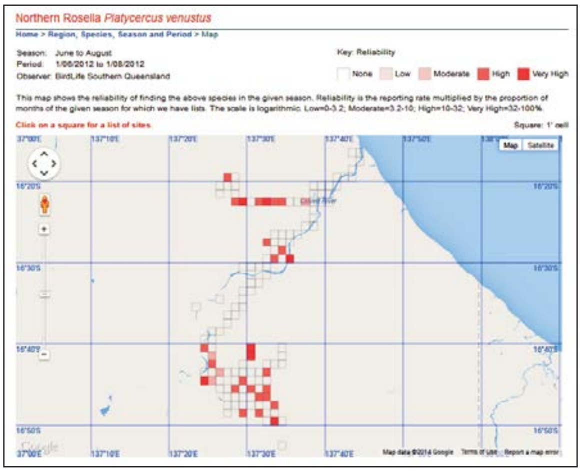

Mangrove Grey Fantail *Rhipidura phasiana*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

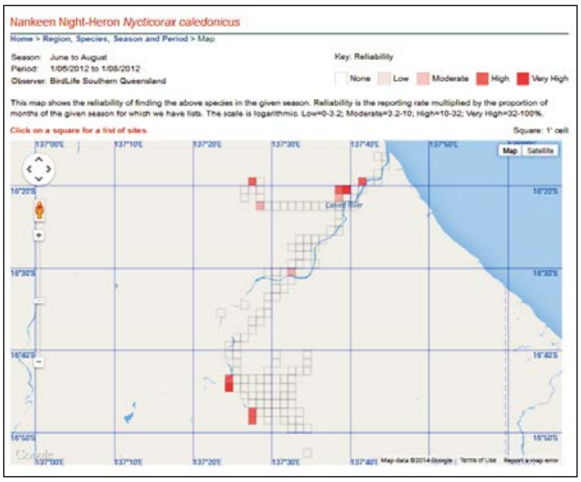

Masked Woodswallow *Artamus personatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

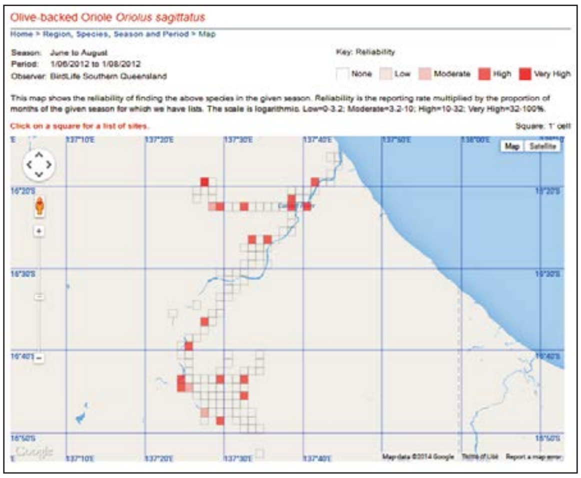

Masked Finch *Poephila personata*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

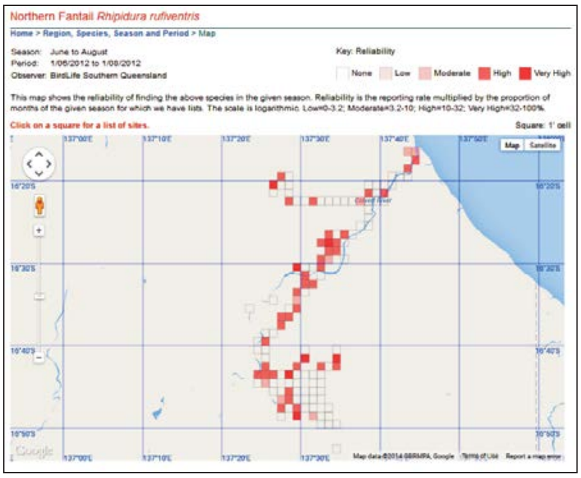

Mistletoebird *Dicaeum hirundinaceum*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

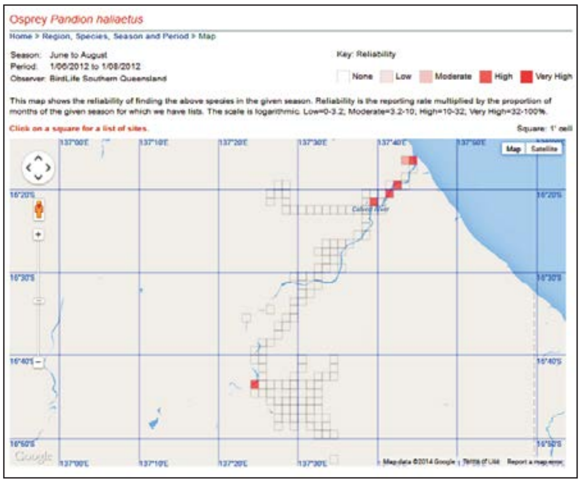

Nankeen Kestrel *Falco cenchroides*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

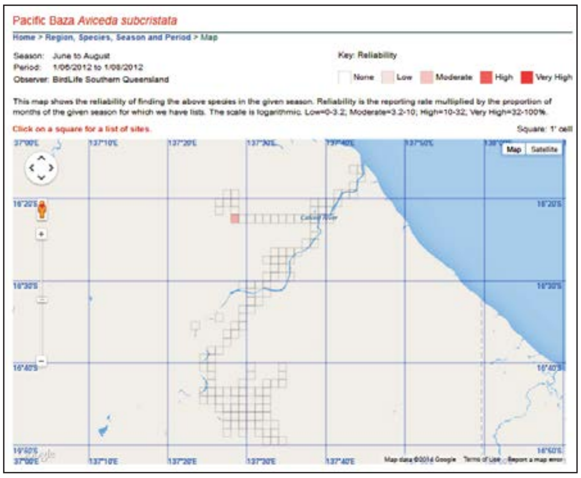

Northern Rosella *Platycercus venustus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

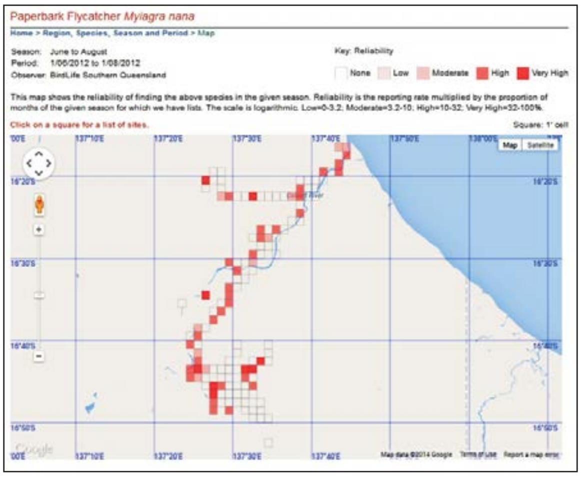

Nankeen Night-Heron *Nycticorax caledonicus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

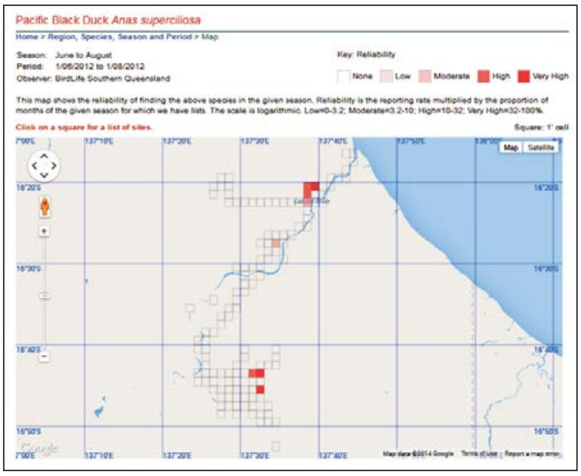

Olive-backed Oriole *Oriolus sagittatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

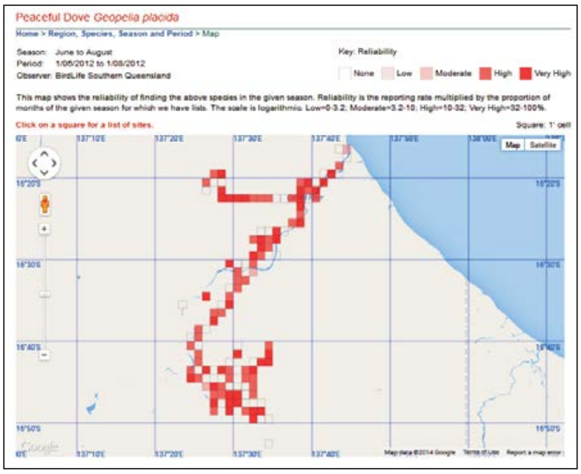

Northern Fantail *Rhipidura rufiventris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

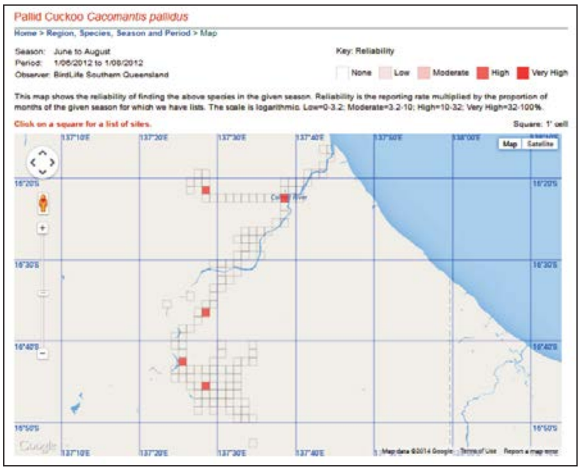

Osprey *Pandion haliaetus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

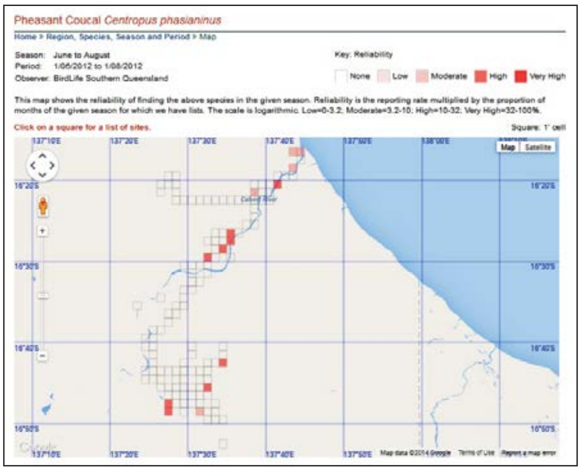

Pacific Baza *Aviceda subcristata*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

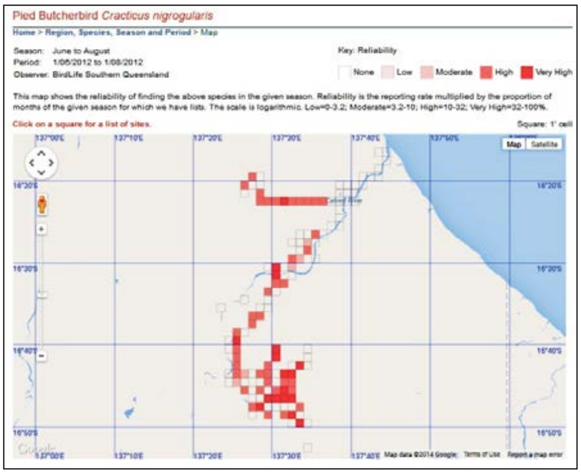

Paperbark Flycatcher *Myiagra nana*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

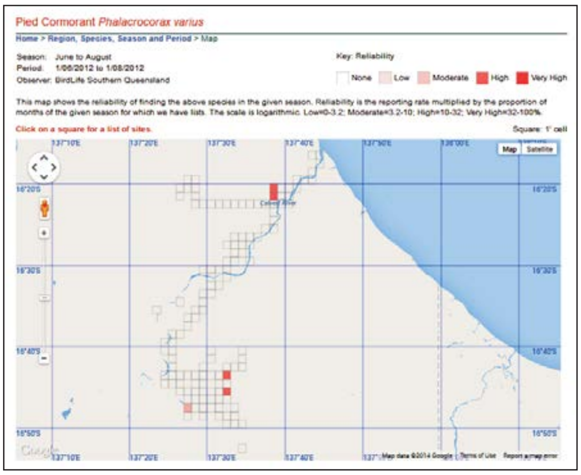

Pacific Black Duck *Anas superciliosa*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

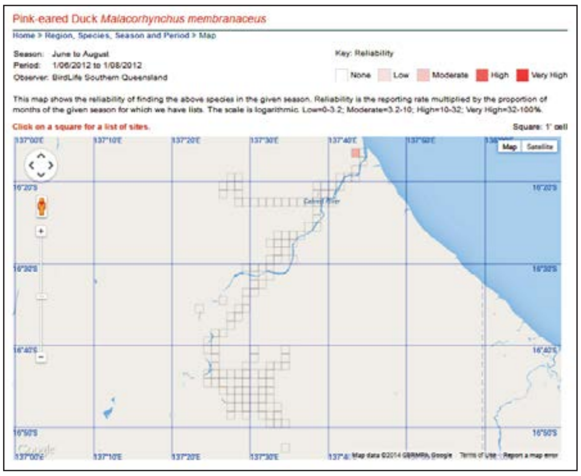

Peaceful Dove *Geopelia placida*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

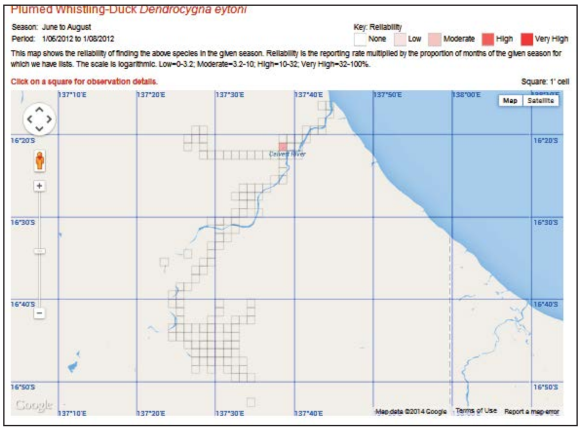

Pallid Cuckoo *Cacomantis pallidus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

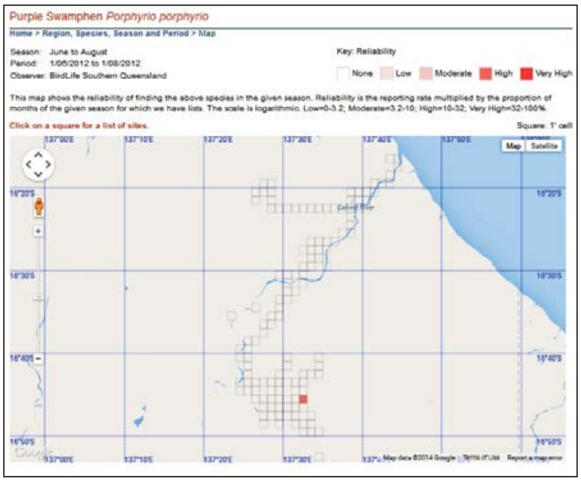

Pheasant Coucal *Centropus phasianinus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

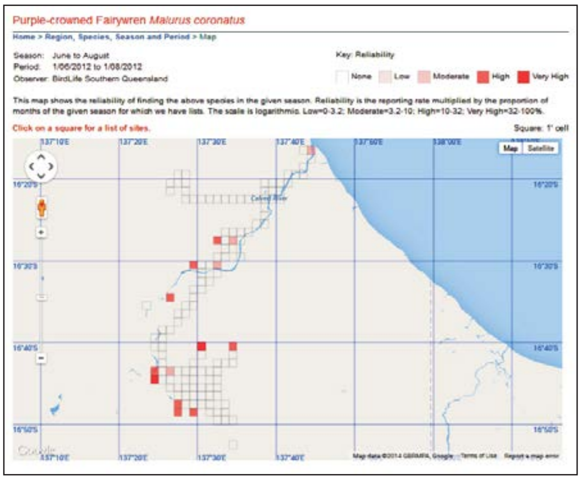

Pied Butcherbird *Cracticus nigrogularis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite
Map data ©2014 Google Terms of Use Report a map error

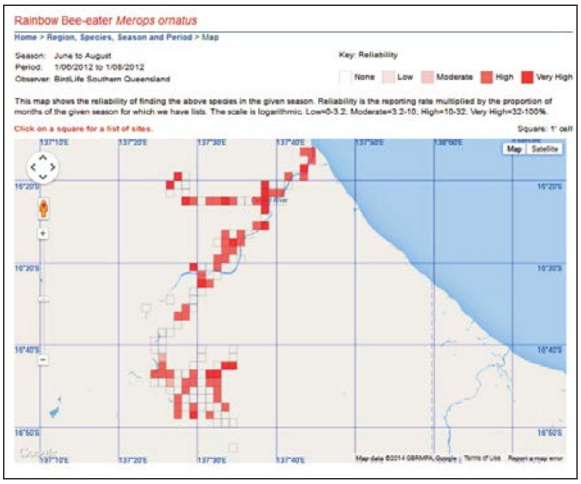

Pied Cormorant *Phalacrocorax varius*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite
Map data ©2014 Google Terms of Use Report a map error

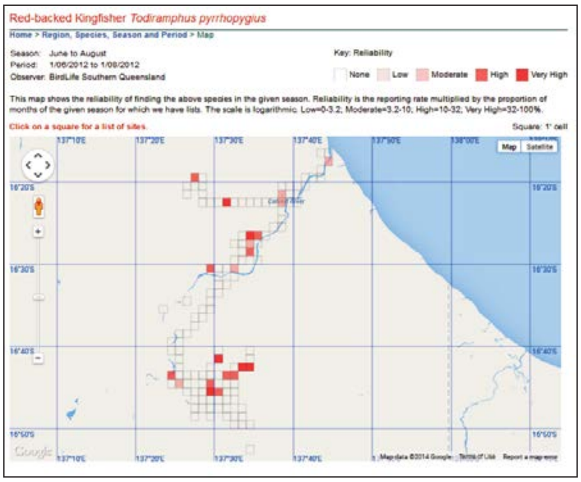

Pink-eared Duck *Malacorhynchus membranaceus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite
Map data ©2014 GBRMPA, Google Terms of Use Report a map error

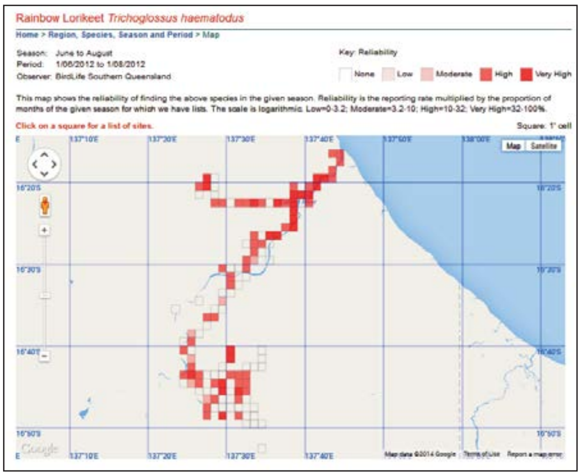

Plumed Whistling-Duck *Dendrocygna eytoni*
Season: June to August
Period: 1/06/2012 to 1/08/2012
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for observation details.
Square: 1' cell
Map Satellite
Map data ©2014 Google Terms of Use Report a map error

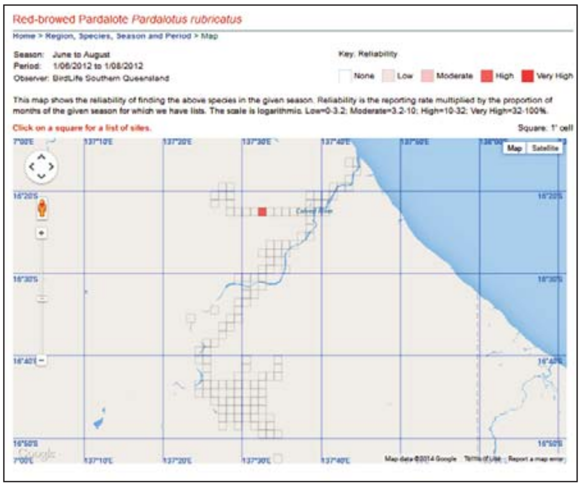

Purple Swamphen *Porphyrio porphyrio*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite
Map data ©2014 Google Terms of Use Report a map error

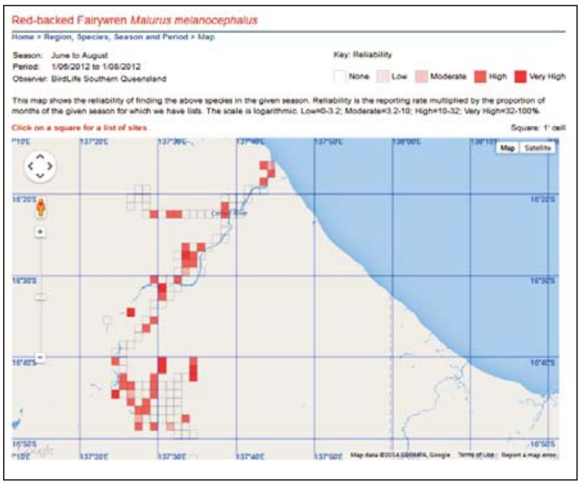

Purple-crowned Fairywren *Malurus coronatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite
Map data ©2014 GBRMPA, Google Terms of Use Report a map error

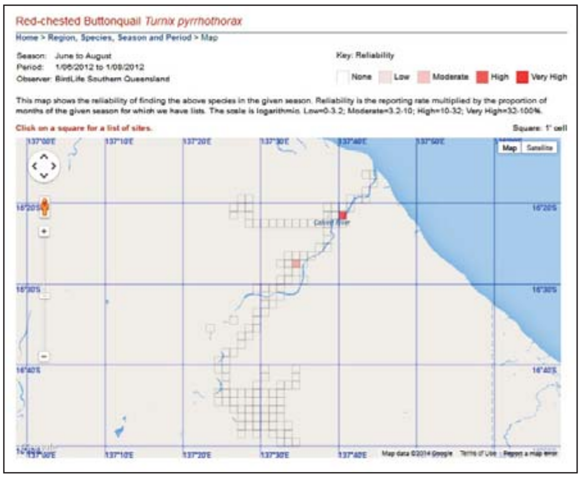

Rainbow Bee-eater *Merops ornatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

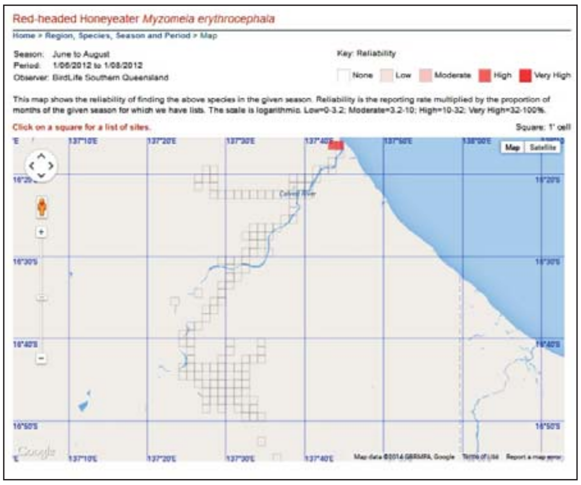

Red-backed Kingfisher *Todiramphus pyrrhopygius*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

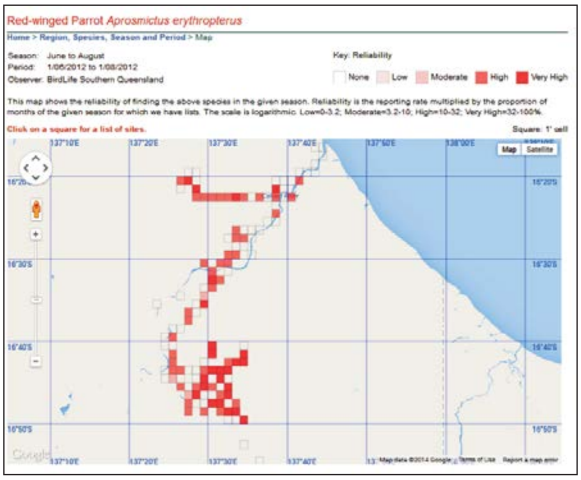

Rainbow Lorikeet *Trichoglossus haematodus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

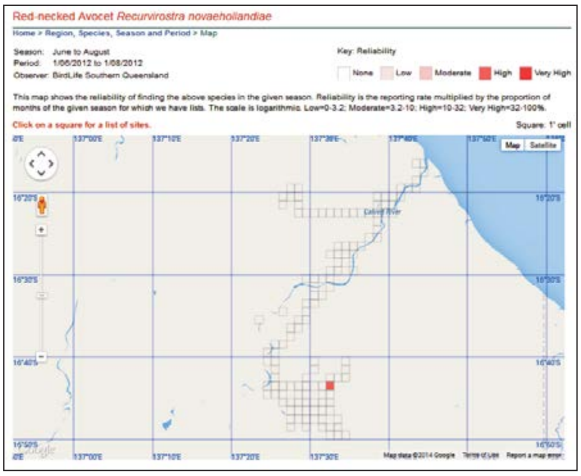

Red-browed Pardalote *Pardalotus rubricatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

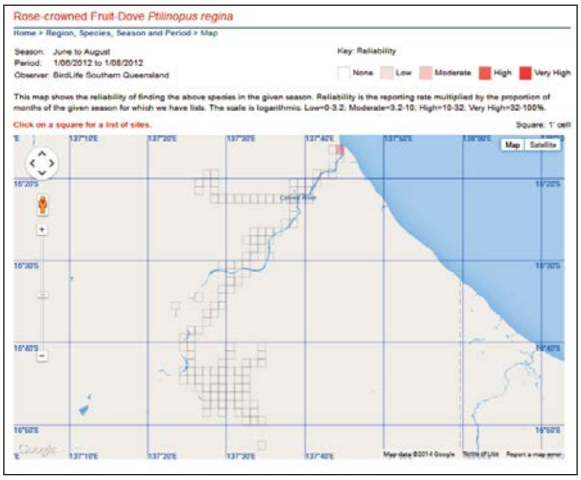

Red-backed Fairywren *Malurus melanocephalus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

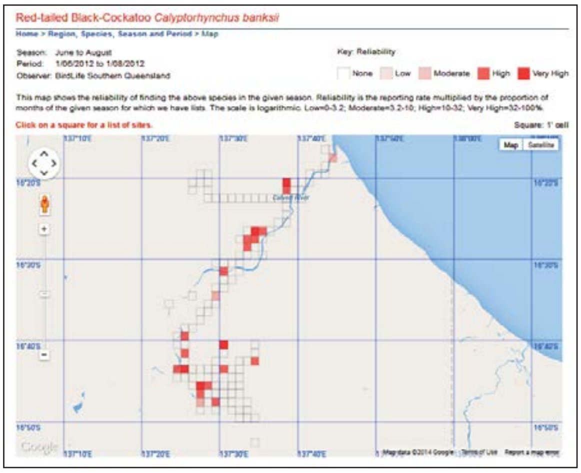

Red-chested Buttonquail *Turnix pyrrhothorax*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

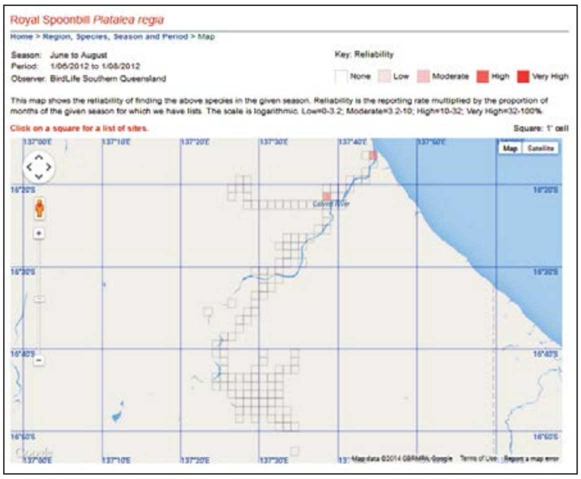

Red-headed Honeyeater *Myzomela erythrocephala*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

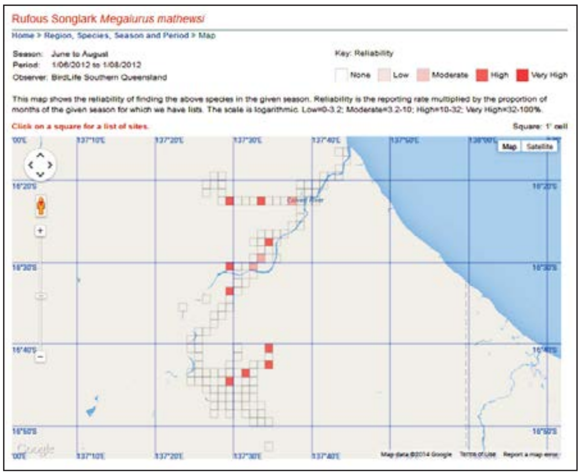

Red-winged Parrot *Aprosmictus erythropterus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

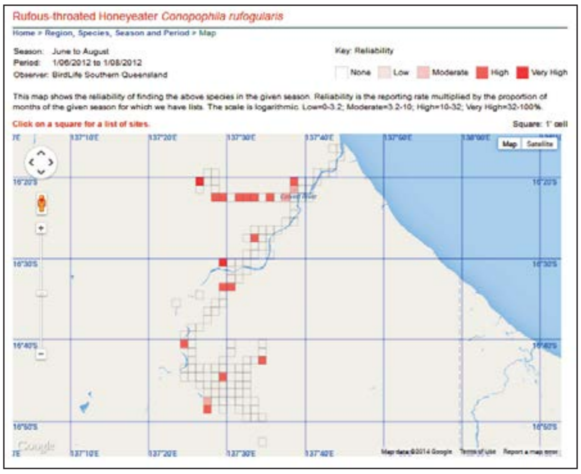

Red-necked Avocet *Recurvirostra novaehollandiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

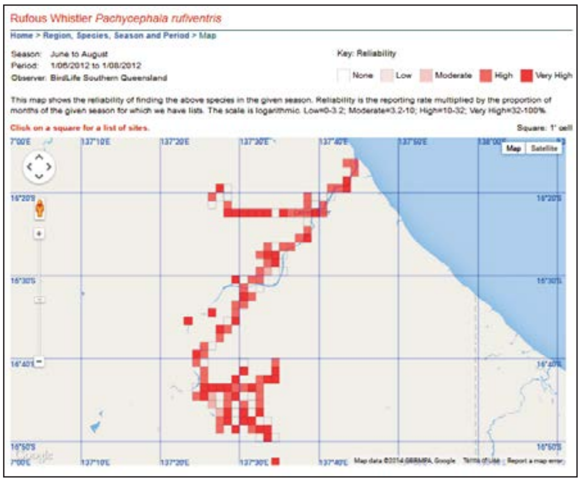

Rose-crowned Fruit-Dove *Ptilinopus regina*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

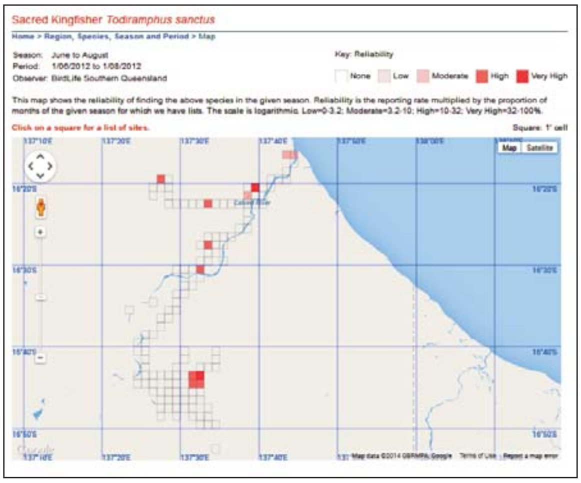

Red-tailed Black-Cockatoo *Calyptorhynchus banksii*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

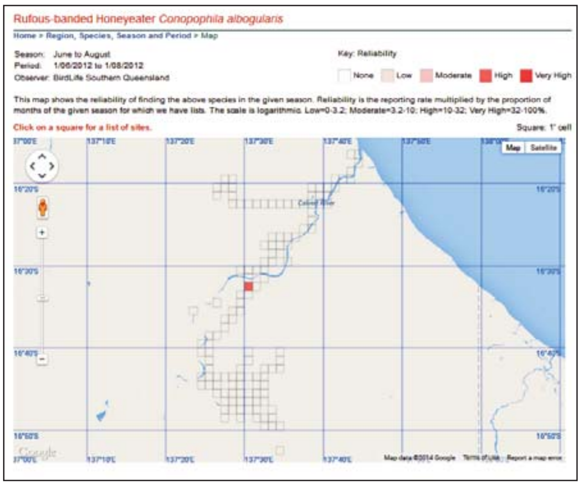

Royal Spoonbill *Platalea regia*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

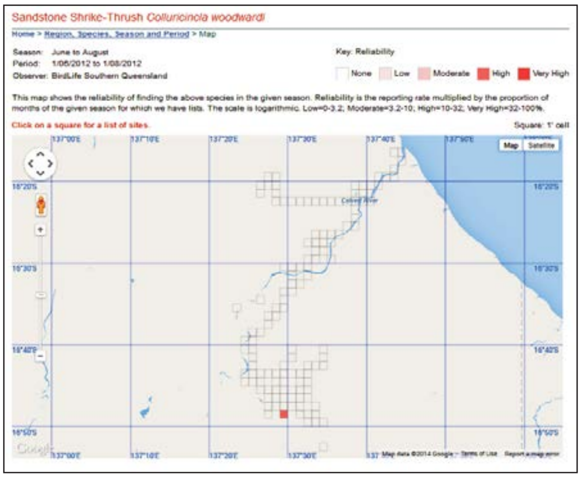

Rufous Songlark *Megalurus mathewsi*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

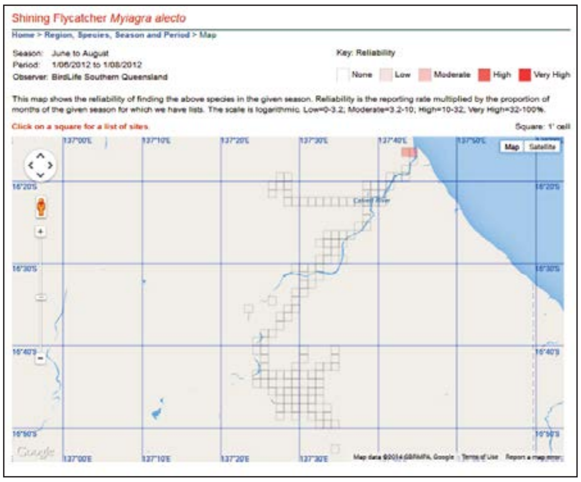

Rufous-throated Honeyeater *Conopophila rufogularis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

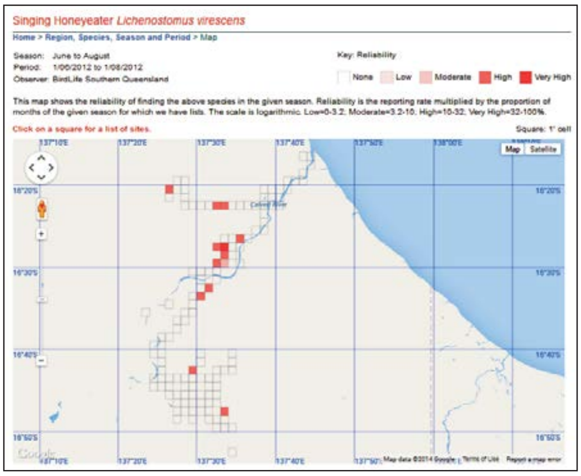

Rufous Whistler *Pachycephala rufiventris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

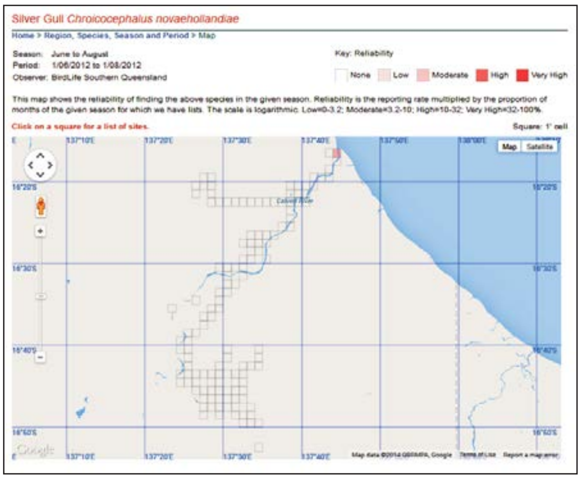

Sacred Kingfisher *Todiramphus sanctus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

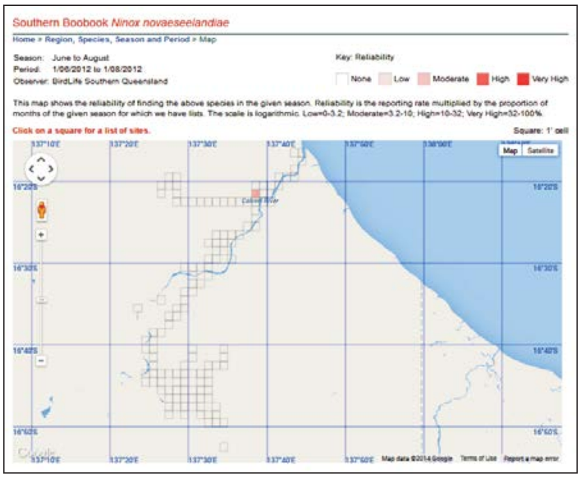

Rufous-banded Honeyeater *Conopophila albogularis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

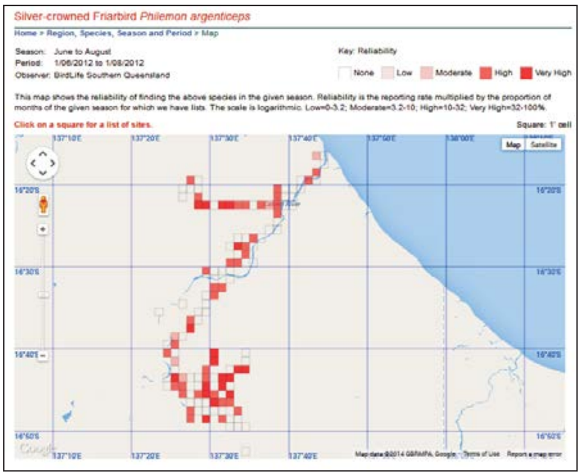

Sandstone Shrike-Thrush *Colluricincla woodwardi*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell

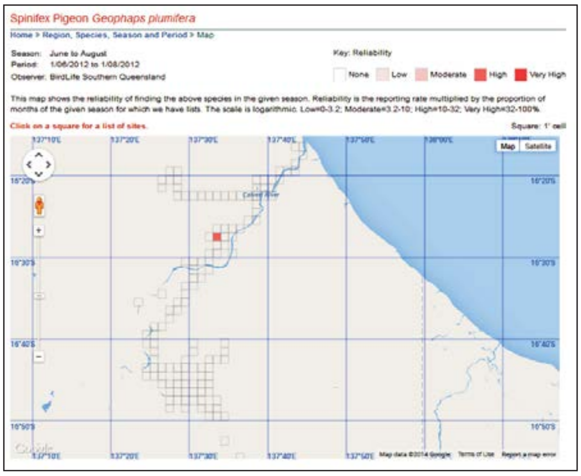

Shining Flycatcher *Myiagra alecto*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

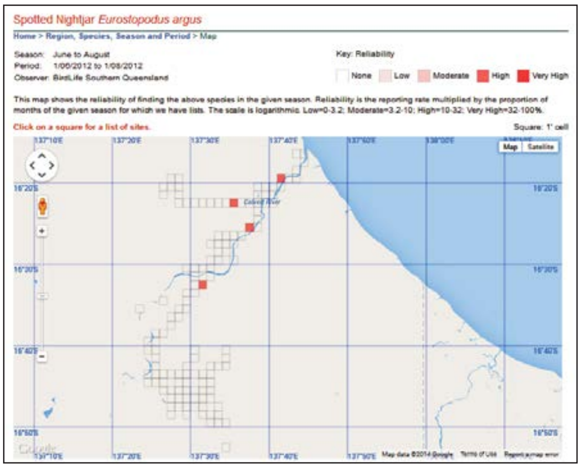

Singing Honeyeater *Lichenostomus virescens*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

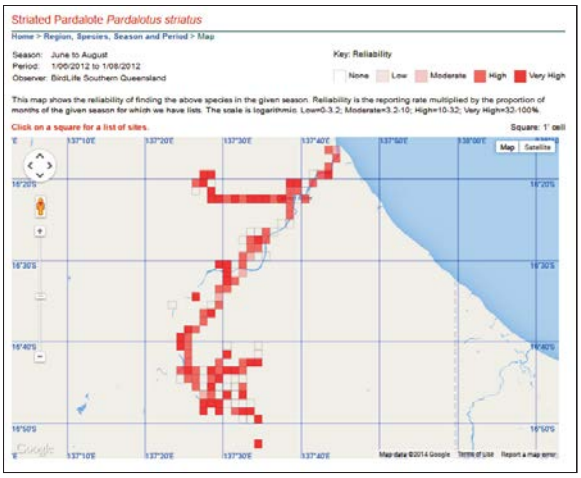

Silver Gull *Chroicocephalus novaehollandiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

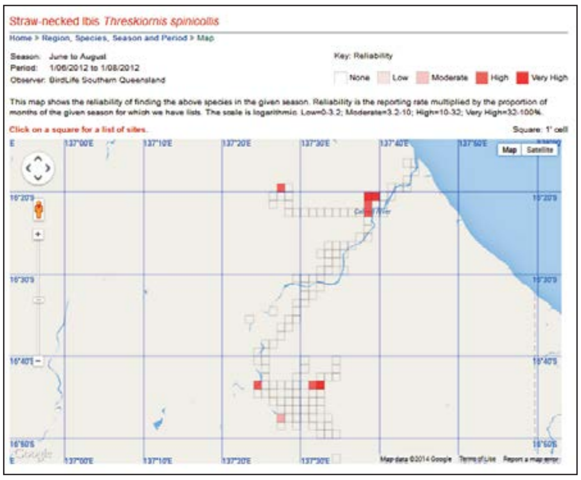

Southern Boobook *Ninox novaeseelandiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

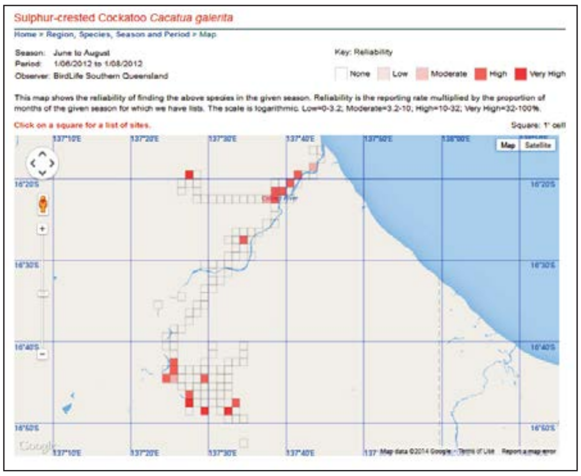

Silver-crowned Friarbird *Philemon argenticeps*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

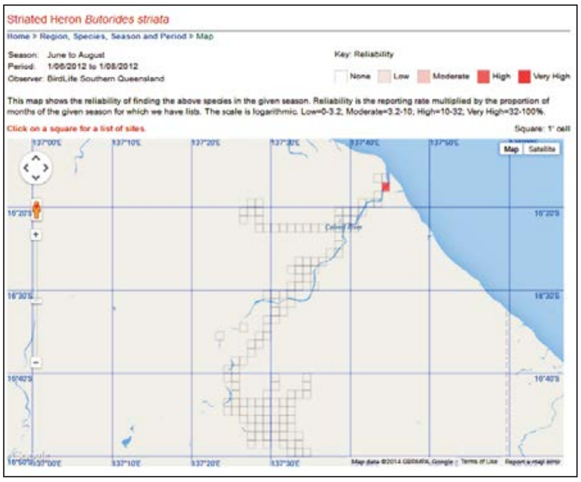

Spinifex Pigeon *Geophaps plumifera*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

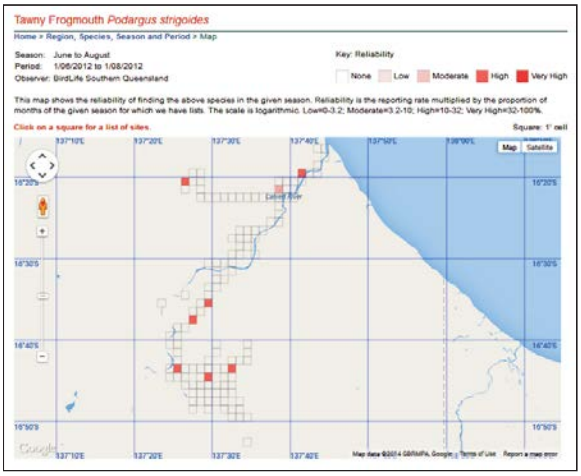

Spotted Nightjar *Eurostopodus argus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

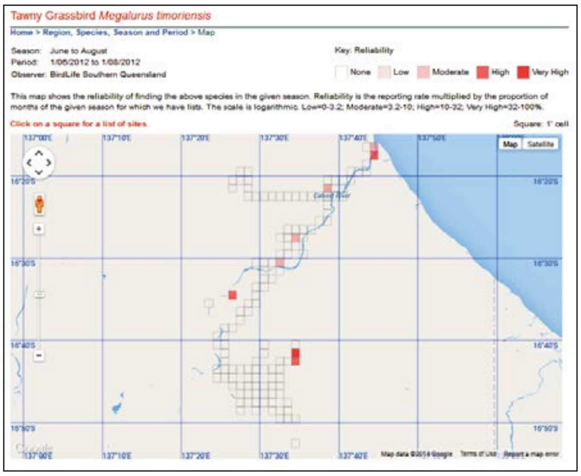

Striated Pardalote *Pardalotus striatus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

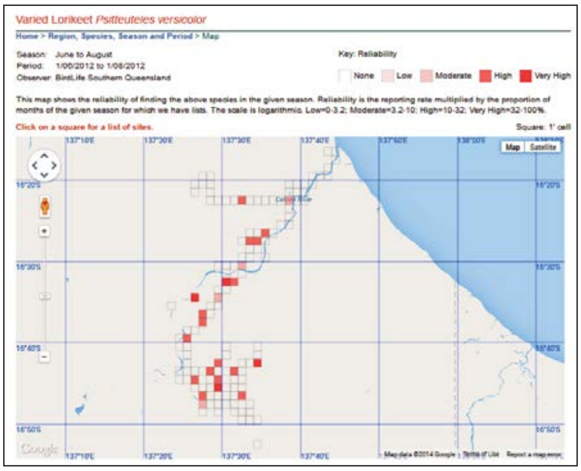

Straw-necked Ibis *Threskiornis spinicollis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite


Sulphur-crested Cockatoo *Cacatua galerita*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

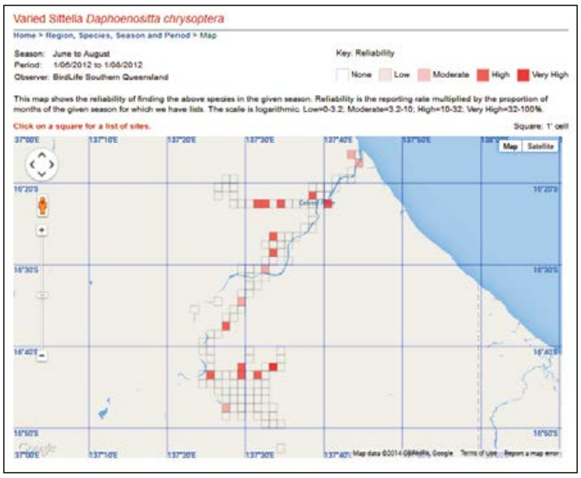

Striated Heron *Butorides striata*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

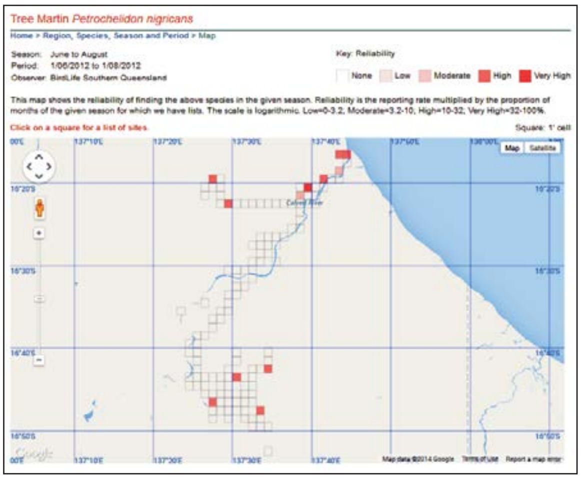

Tawny Frogmouth *Podargus strigoides*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

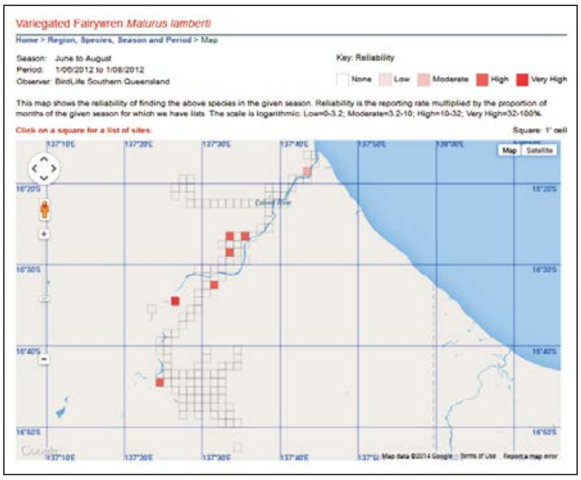

Tawny Grassbird *Megalurus timoriensis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

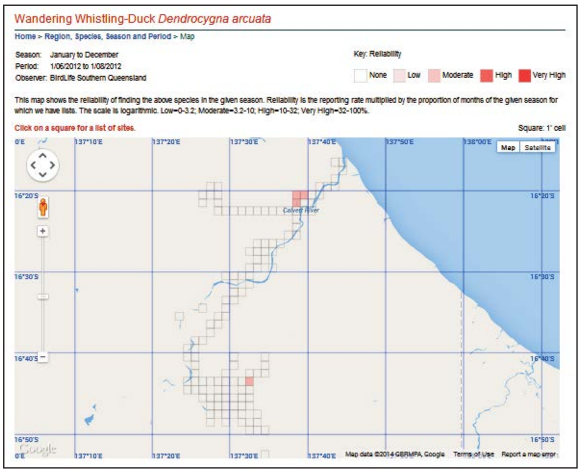

Varied Lorikeet *Psitteuteles versicolor*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

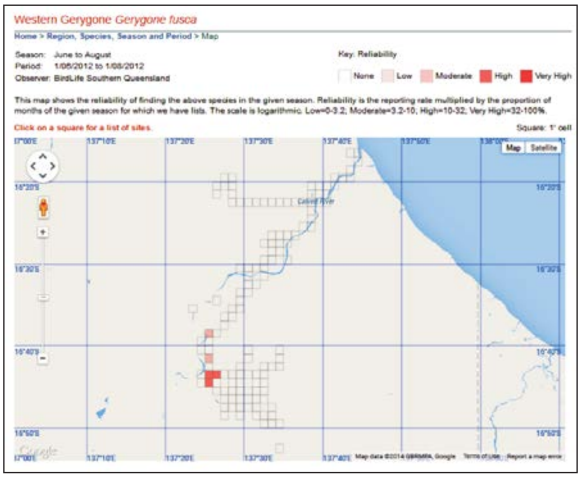

Torresian Crow *Corvus orru*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

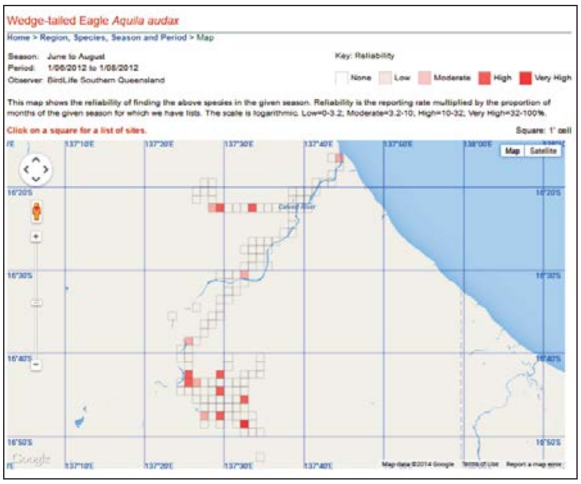

Varied Sittella *Daphoenositta chrysoptera*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

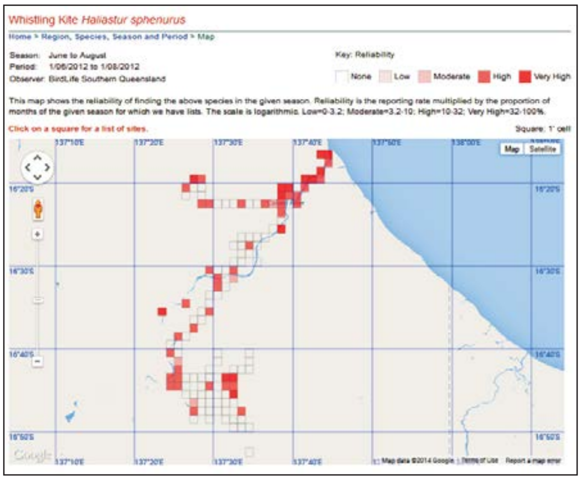

Tree Martin *Petrochelidon nigricans*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

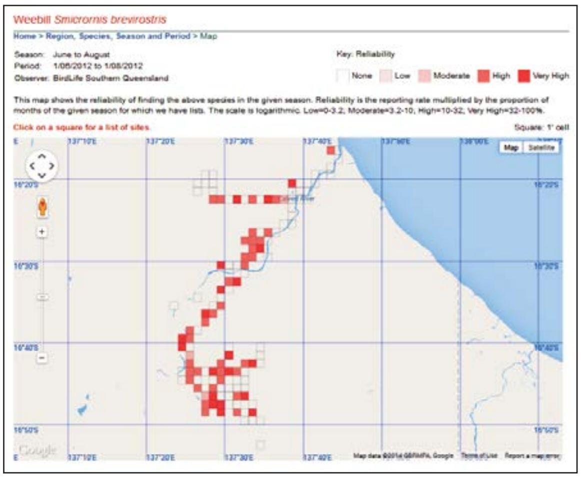

Variegated Fairywren *Malurus lamberti*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

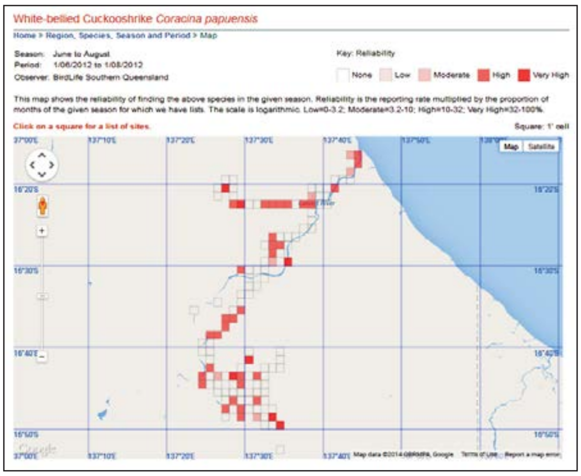

Wandering Whistling-Duck *Dendrocygna arcuata*
Home > Region, Species, Season and Period > Map
Season: January to December
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite
Calvert River

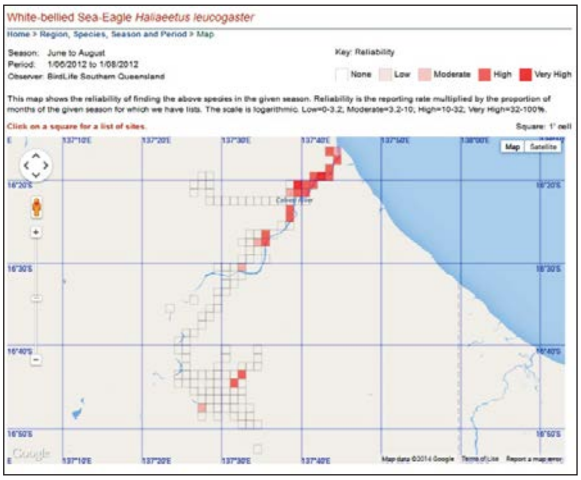

Western Gerygone *Gerygone fusca*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

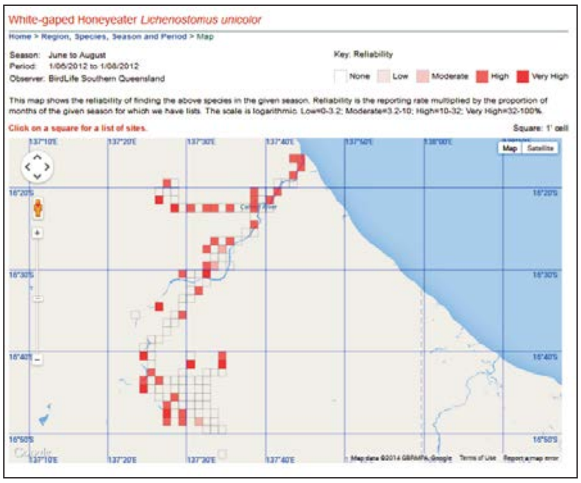

Wedge-tailed Eagle *Aquila audax*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

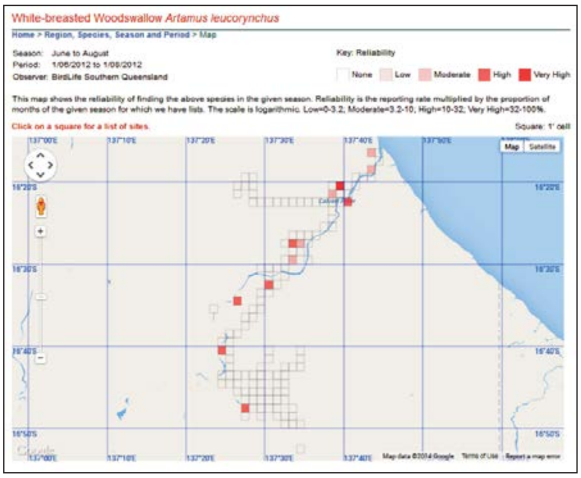

Whistling Kite *Haliastur sphenurus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

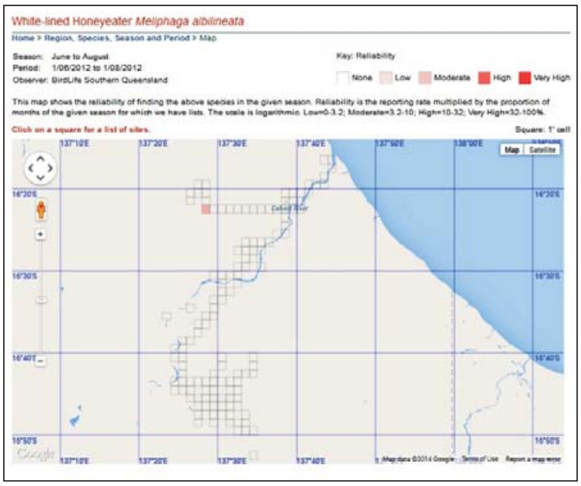

Weebill *Smicrornis brevirostris*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

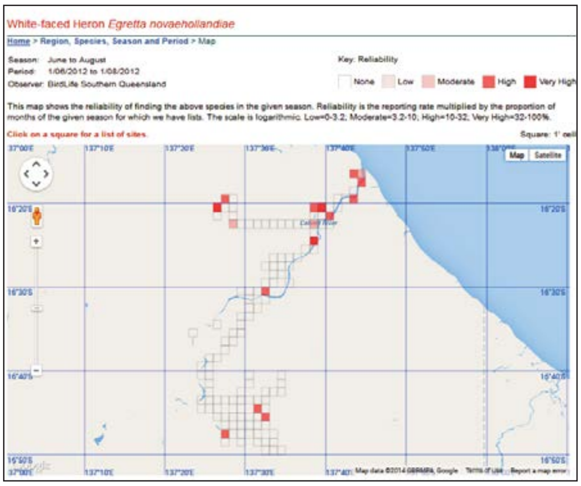

White-bellied Cuckooshrike *Coracina papuensis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

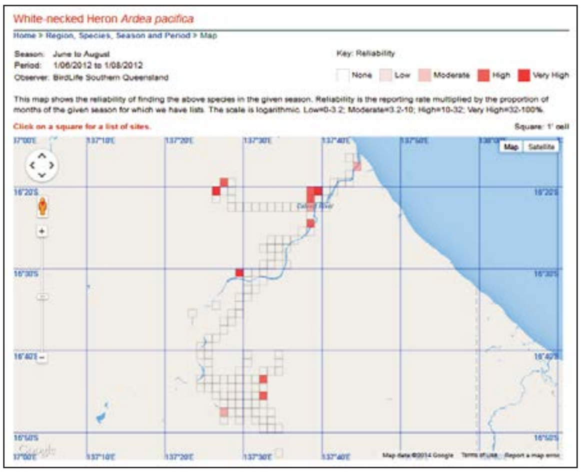

White-bellied Sea-Eagle *Haliaeetus leucogaster*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

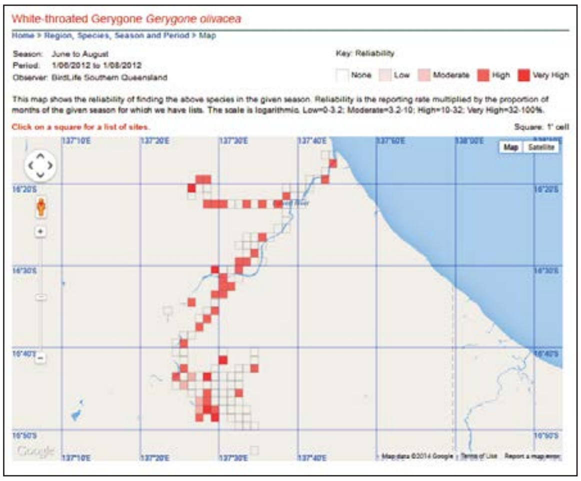

White-gaped Honeyeater *Lichenostomus unicolor*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

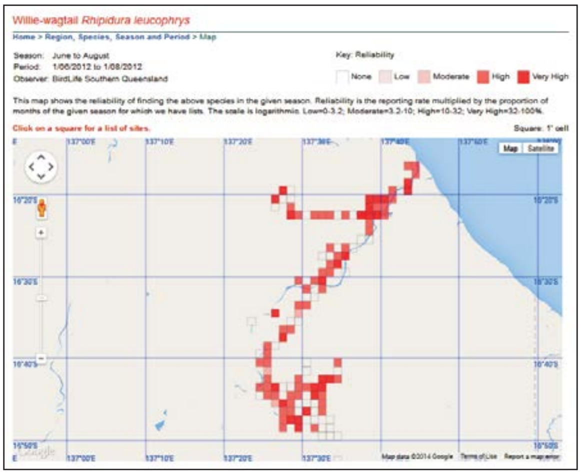

White-breasted Woodswallow *Artamus leucorynchus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

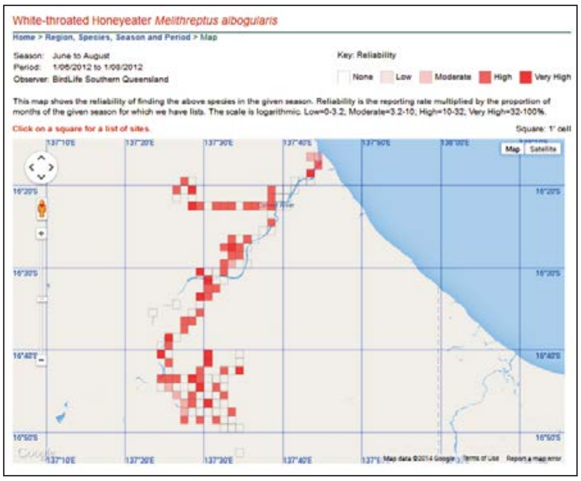

White-lined Honeyeater *Meliphaga albilineata*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

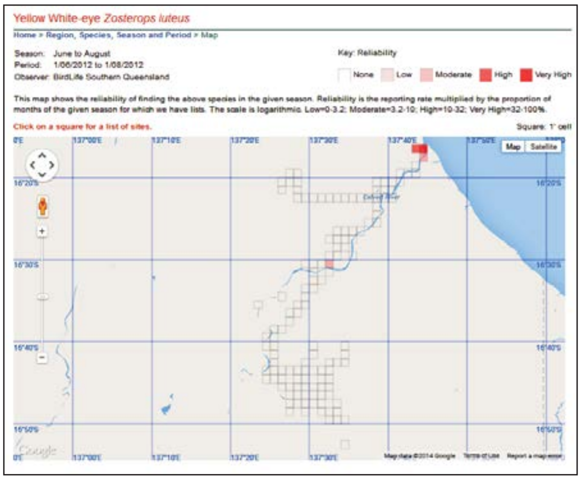

White-faced Heron *Egretta novaehollandiae*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

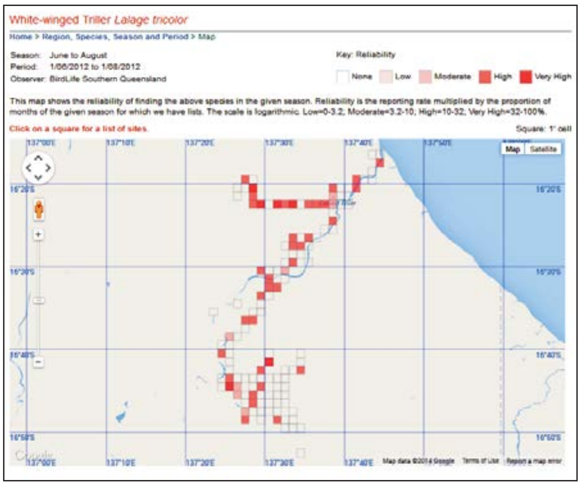

White-necked Heron *Ardea pacifica*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

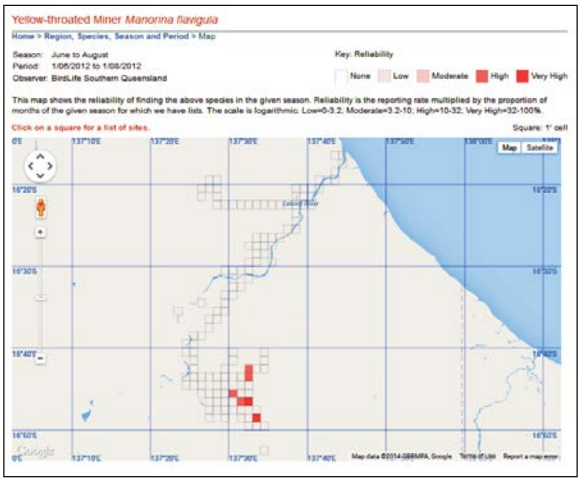

White-throated Gerygone *Gerygone olivacea*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

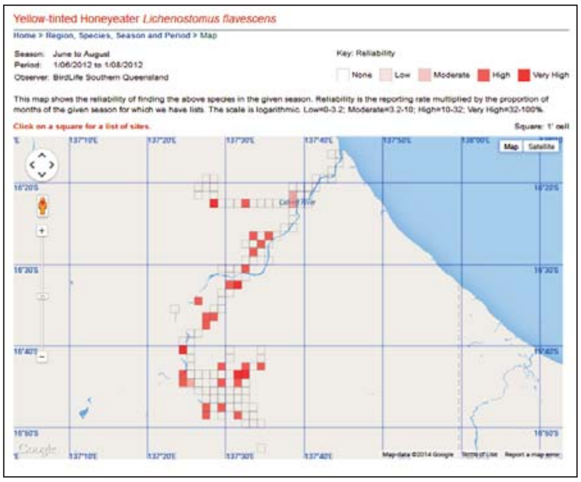

Willie-wagtail *Rhipidura leucophrys*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

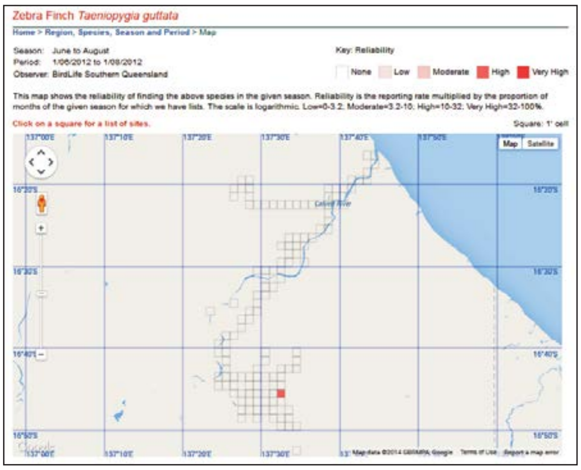

White-throated Honeyeater *Melithreptus albogularis*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite

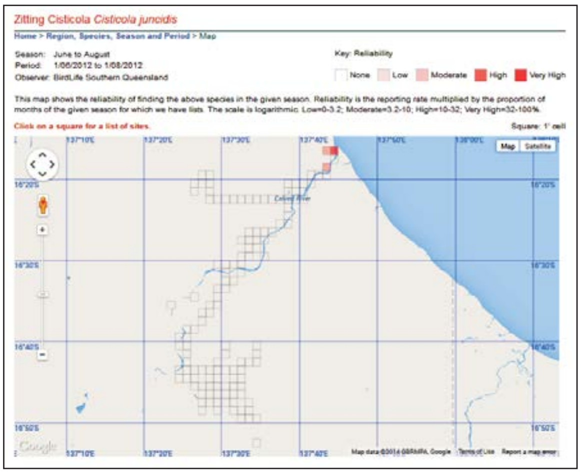

Yellow White-eye *Zosterops luteus*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite


White-winged Triller *Lalage tricolor*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite


Yellow-throated Miner *Manorina flavigula*
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None Low Moderate High Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map Satellite


Yellow-tinted Honeyeater Lichenostomus flavescens
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None
Low
Moderate
High
Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite


Zebra Finch Taeniopygia guttata
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None
Low
Moderate
High
Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite


Zitting Cisticola Cisticola juncidis
Home > Region, Species, Season and Period > Map
Season: June to August
Period: 1/06/2012 to 1/08/2012
Observer: BirdLife Southern Queensland
Key: Reliability
None
Low
Moderate
High
Very High
This map shows the reliability of finding the above species in the given season. Reliability is the reporting rate multiplied by the proportion of months of the given season for which we have lists. The scale is logarithmic. Low=0-3.2; Moderate=3.2-10; High=10-32; Very High=32-100%.
Click on a square for a list of sites.
Square: 1' cell
Map
Satellite

A study of biological soil and rock crusts with a focus on terrestrial cyanobacteria from Pungalina-Seven Emu Nature Reserve

Wendy Williams[1*], Colin Driscoll[2], Steve Williams[1], Lea Ezzy[3]

(*Corresponding author)

SAFS, Gatton Campus, The University of Queensland[1]; The University of Newcastle[2]; Queensland Parks and Wildlife[3], Australia

Abstract Worldwide, in deserts and savannahs, specialist microbial communities made up of cyanobacteria, algae, lichens, liverworts, mosses, micro-fungi and bacteria form biological crusts on and within the first few millimetres of soil and rock surfaces. Most of these organisms photosynthesise so they require light and moisture for growth. Over time diverse and complex communities have adapted to a range of habitats influenced by temperature extremes, high levels of ultra violet light, seasonal droughts and floods. At several spatial scales cyanobacteria function as ecosystem engineers through the transformation of their environment. The cyanobacterial crust matrix controls small-scale functions, traps sand particles and minerals, regulates water infiltration and contributes to soil nutrient cycles through carbon sequestration and biological nitrogen fixation.

At Pungalina-Seven Emu we surveyed a 60 km north-south transect extending from coastal dunes to open savannah woodlands. There were extensive cyanobacterial crusts estimated to cover at least 76,500 ha of the soil and rock surfaces. These were dominated by 'Red Crusts' named due to the rich red pigmentation used as a UV protectant. Crusts varied in their successional state from thin patchy forms to diverse cyanobacterial crusts that also contained some liverworts, mosses and lichens, many of which represented species range extensions. The Red Crusts were perennial in nature, apparently unique to northern savannah landscapes, where they remain in an inactive state during the dry season and disintegrate, sacrificing many cells, before regrowing during the wet season. Cyanobacteria *Symploca, Symplocastrum, Scytonema, Stigonema* and *Porphyrosiphon* were the most abundant. in eucalypt woodlands there were no crusts found where fire had occurred recently. Likewise disturbance from trampling appeared to have a negative impact on the crust presence in cypress pine woodlands and dunes.

A number of cyanobacterial crust communities were closely associated with well-defined edaphic gradients however, the Red Crusts were cosmopolitan. There were exceptional crust communities recorded throughout ephemeral creeks, Cycad Creek area, an exposed duricrust outcrop and a fossilised stromatolite reef. At Cycad Creek and the duricrust regions there were broad tracts of diverse cyanobacterial crusts where large pieces of crust could be lifted from the surface. In this study we showed the importance of protecting ecologically significant hotspots that are rich in habitat specialists and are biologically unique.

Introduction

A study of cyanobacterial crusts was undertaken at Australian Wildlife Conservancy's (AWC) Pungalina-Seven Emu, 306,000 ha private nature reserve located in the north east of the Northern Territory, Australia, extending inland from the Gulf of Carpentaria. Cyanobacteria crusts (also known as biological soil crusts) form on and within the first few millimetres of the soil surface and on rocks (Büdel, 2002). These complex microbial communities are comprised of a diverse range of macro- and micro-organisms that include cyanobacteria, algae, lichens, mosses, liverworts, as well as micro-fungi and bacteria (Büdel, 2002; Belnap and Lange, 2003).

The importance of community structure is evident in cyanobacterial crusts that have developed over time to withstand a range of diverse

Figure 1. (a) Large areas of cyanobacterial crusts were clearly visible on the ground (black in colour); (b) the crusts were dry and had started to crack, its colour representative of the pigmentation that protects against UV; (c) Red Crusts were the most dominant group throughout the sample sites and in some cases large pieces could be picked up; (d) when moist *Symplocastrum* (red) formed pincushion-like structures on top of other cyanobacterial crusts (also shown dry in (c)).

environmental extremes (Potts, 1999). Cyanobacteria are photosynthetic prokaryotes that have evolved to live on land since emerging from the oceans, and were responsible for creating Earth's oxygenic atmosphere in the Precambrian Era or Age of Cyanobacteria (Whitton and Potts, 2012). Cyanobacterial dominated crusts can be found where higher plants struggle to survive due to high levels of UV exposure, temperature extremes, erratic rainfall, poor soil nutrient availability, drought, fire and flood. Typical habitats include rock surfaces and the interspaces between grass plants.

The cyanobacterial crust matrix controls fine-scale functions, like regulation of water infiltration into soils, nutrient cycling and micro-faunal activity, and as such act as 'ecosystem engineers' of their environment (Eldridge et al., 2010). In the natural environment ecosystem engineers can function at several scales. Non-vascular plants such as cyanobacteria secrete mucilaginous organic compounds, exopolysaccharides (EPS). Many cyanobacteria fix atmospheric nitrogen in a plant-available form with excess (to their immediate needs) stored in the EPS (Potts, 1999; Williams and Eldridge, 2011). These processes aid in the regulation of infiltration, percolation, retention and evaporation of water, reduction of soil erosion and influence over seedling emergence (West, 1990; Jones et al., 1994; Eldridge et al., 2010). Over time, at high densities on both large and small spatial scales, microorganisms like cyanobacteria that would normally have small individual impacts can instigate enormous positive ecological effects (Jones et al., 1994), affecting macro- and micro-nutrients (Bowker et al., 2005).

Most biological crust organisms use oxygenic photosynthesis as their source of energy. Light, temperature and moisture are all key drivers of photosynthesis that provide cellular energy through the creation of carbohydrates. In order for carbon sequestration (CO_2 uptake) via cyanobacterial crusts to occur photosynthetic processes must be activated by light and moisture. In arid, semi-arid and savannah landscapes it is estimated that biological crusts net primary productivity is ~7% of terrestrial carbon and biologically fix (from the air) ~45% of plant available nitrogen (Elbert et al., 2012).

In contrast to high-order plants, cyanobacteria and lichens can photosynthesise with as little as 0.2 mm precipitation and many function in response to dews (Lange et al., 1994). When dry, cyanobacteria shut down and remain in a desiccated (inactive) state until moist again (Potts, 1999). Once moisture is available cyanobacteria have the capacity to rehydrate within seconds and commence photosynthesis within minutes (Rascher et al., 2003; Lange, 2003). Yet, in the savannah of northern Australia it has been shown that cyanobacteria do not respond to intermittent rain events during the dry season (Williams et al., 2014).

Disturbance can have a profound effect on cyanobacterial crust cover, diversity and physiological function. The impact is governed by landscape characteristics, as well as the severity, frequency and timing of the disturbance (Belnap and Eldridge, 2003). Environmental perturbations such as drought (Williams et al., 2008) and fire (Greene et al., 1990) have been shown to have negative impacts on crust continuity. Fire is commonplace across the Australian landscape and can play an important role in maintaining biodiversity. However little is known of its impact on biological soil crusts.

Disturbance and long-term degradation of soil surfaces as a result of hard hooved animals has been well documented (Warren and Eldridge, 2003). Declines in cyanobacterial diversity and abundance have been linked to a reduction in soil nutrient concentrations following grazing or mechanical disturbance (Williams and Eldridge, 2011; Rao et al., 2012). Following disturbance, regeneration of cyanobacterial crusts is often dependent on seasonal conditions and can take many years to return to high levels of diversity (Belnap and Eldridge, 2003).

The overall objectives of this research were to gain insight into the structure and function of cyanobacterial crusts at the study site. Our specific aims were to:

- describe the extent of cyanobacterial crusts;
- discover their diversity and distribution;
- distinguish crust types based on their morphology and composition;
- identify spatial influences on distribution; and
- identify the potential impact of fire or disturbance.

Methods

Pungalina-Seven Emu

This was the first time cyanobacterial soil and rock crusts had been surveyed at Pungalina-Seven Emu. Ecosystems included coastal tidal flats and dunes, tussock grasslands, grassy eucalypt woodlands, riparian and floodplain vegetation. Topography consisted of low lying land, sandstone ridges and plateaus incised by deep gorges. A complex network of ephemeral streams ultimately combines in the Calvert River that flows into the Gulf. Historically, the climate has been strongly influenced by summer monsoonal rains, with a distinctly dry winter-spring season with little or no rain for several months. Mean annual rainfall at nearby Wollogorang Station is 965 mm with considerable variation (428–1706 mm, 5–95 percentile [www.bom.gov.au]). During the wet season heavy rains flood many low-lying areas, ephemeral wetlands form, and dry creek beds recover, with herbage and aquatic life forms. Across the reserve there has been a broad biodiversity recorded with over 500 plant, 190 bird, 40 mammal and 95 frog and reptile species documented thus far.

Cyanobacterial soil crust sampling

Sixty five sites were sampled along a north-south 60 km transect that incorporated coastal dunes to woodlands. Methodical cyanobacterial sampling and data collection were based on stratification of the range of primary and secondary landscape ecosystems. Due to the size of the reserve these were targeted specifically to cover the different ecosystems at a landscape scale but limited by accessibility via four-wheel drive or on foot. These sites were randomly selected along the transect, and ranked according to vegetation community and soil type, with a minimum of three sites per type sampled (Appendix 1, page 224).

The fore-dunes were not accessible by vehicle so a helicopter was used to access one of the dune areas just behind the beach (refer to Figure 2, page 204, only coastline site, and Figure 9, page 215). Samples were collected from the

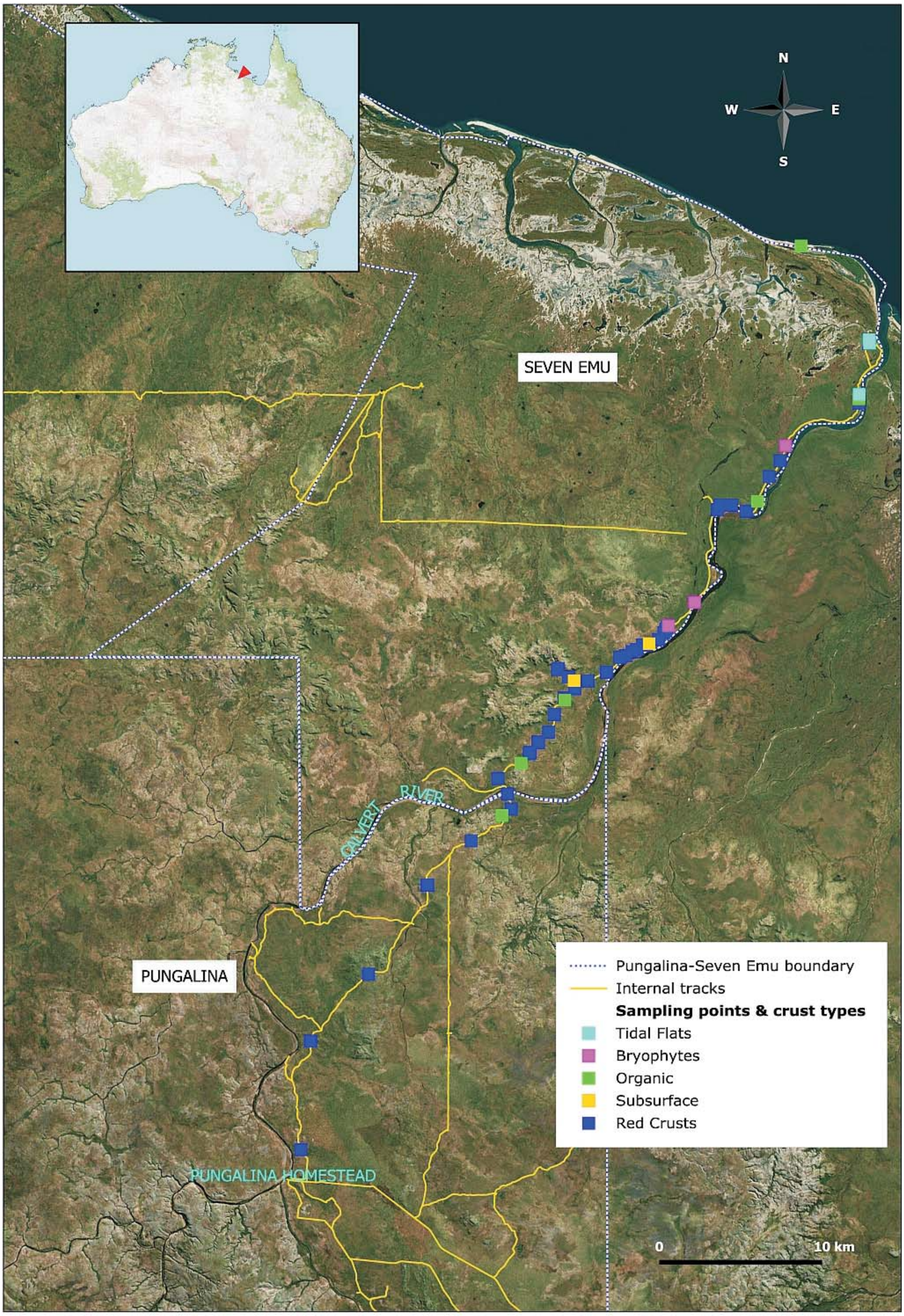


Figure 2. Satellite image of Pungalina-Seven Emu tracks and sampling points across 60 km north-south transect. Coloured symbols represent the sample points that defined the five crust groups.

leeward and windward sides of the dunes as well as the crest and swale, both in the open and under shrubs. Most of the material collected showed some signs of desiccated cyanobacteria, nevertheless on rehydration there were only a few dead filaments evident. Recent disturbance was highly visible (dung and trampling by cattle, and pig tracks), that had resulted in wind erosion.

Three contiguous sites were also selected to represent burnt and unburnt regions (of similar vegetation type). The samples were collected in the dry season of August 2012. A minimum of two Petri dishes (and occasional rock samples) of soil crust were collected from multiple land and vegetation types (n=370). At each site samples were selected to best represent the overall soil condition and crust cover. These samples were air dried and returned to the laboratory for analysis. In the field, crust types were also recorded and later these were compared to the corresponding diversity data.

To determine photosynthetic activity (PSII), five randomly selected cyanobacterial crust areas of 0.25 m^2 from near Cycad Creek were soaked with rainwater. A Pocket-PAM (Gademann Instruments, Germany) was used to test for chlorophyll fluorescence and photosynthesis at hourly intervals for three hours and 24 hours later. The Pocket-PAM applies a saturation pulse as a non-destructive means of analysing the photosynthetic performance of cyanobacterial soil crusts. This provides an assessment of the quantum yield (YII) of energy conversion at PSII reaction centres. Each time the crust was re-wet to maintain moisture levels and measurements were made approximately ten minutes after wetting.

Percentage cyanobacterial crust cover was determined across four contiguous 0.25 m^2 quadrats randomly selected from each site. To estimate the cover across the reserves, the total area of each vegetation type was calculated with the aid of satellite imagery and multiplied by average crust cover recorded for that type.

Laboratory Methods

Representative subsamples from field samples were incubated for a period of two weeks at which stage cyanobacteria appeared rehydrated sufficiently for identification and analysis. Initial inspection of the soil crusts and the separation of individual species were made using an Olympus SZH10 microscope at 40–70 x magnification. The presence of lichens, mosses and liverworts (bryophytes), algae, diatoms, micro-fungi and, cyanobacteria were ranked for all samples. For cyanobacteria, morphological features and measurements were carried out from multiple wet mounts that were prepared from each sample. Cyanobacterial filaments or colonies were carefully extracted with forceps to recover sufficient material that included important morphological features such as their colour, encasing sheaths as well as cellular structure. Live material was examined by Nomarski differential interference contrast (DIC) microscopy with a Jenaval (Jena Zeiss) and an Olympus BX51 compound microscope (magnification x 400). Photomicrographs were taken using an Olympus SC100 digital microscope camera, and morphological measurements of vegetative cells were made from digital images of live material taken at 200 and 400 x magnification using Olympus cellSens® digital imaging software.

Cyanobacterial identification was performed to a species level (wherever possible) in the laboratory using appropriate taxonomic references, (Geitler, 1932; Komárek and Anagnostidis, 1999; Komárek and Anagnostidis, 2005; Skinner and Entwisle, 2001). It was often necessary to record the closest named species as attributes varied somewhat from those of the temperate climate and aquatic specimens described in literature. Using a graticule at 70 x magnification, abundance was ranked on a scale of 1–8 where the main taxa were ranked according to their dominance in decreasing order of their occurrence (Biggs and Kilroy, 2000). Crust types were identified according to (Büdel et al., 2009) taking into account thickness, structure and the range of crust organisms found.

Soil pH and electrical conductivity (EC) were determined with duplicate samples using a 1:5 (soil to water) ratio. Measurements were taken with a TPS pH meter MC-80 using an ionode IJ44C electrode. EC was measured using a Crison Conductivity Meter 525.

Statistical Methods

Ordination using non-metric multi-dimensional dimensional scaling (nMDS) (Primer 6, Clarke and Gorley, 2006) was used to assess the similarity of the species' content at sample sites, as well as relationships between selected environmental variables. Analysis of similarity (ANOSIM) was used in Primer to assess the significance of the nMDS groupings.

Results

At Pungalina-Seven Emu the extent of cyanobacterial crusts was estimated to occupy at

Figure 3. (a) The protective mucilaginous sheaths (arrow) of *Symploca* protect the inner filament that contains its sensitive photosynthetic apparatus, these are made up of polysaccharides that also store biologically fixed nitrogen; (b) inside a desiccated (inactive) cyanobacterial sheath, cells shrink (arrow) and their contents are concentrated however, they maintain their structure and once rehydrated by rain or dew can photosynthesise very quickly; (c) cyanobacteria are both filamentous, cellular and colonial in form, often forming an entangled mat of many species; (d) *Scytonema* and many other cyanobacteria form heterocysts (arrow) that exclude oxygen in order for nitrogen fixation to take place.

least 76,500 ha (25%) of the soil surfaces (e.g. Figure 1a, page 202) across the reserve (306,000 ha). These cyanobacterial crust communities ranged from <10% cover (early successional) to 50-100% cover (intermediate to late successional) and represented a distinctive and unusual ecosystem of cyanobacteria, bacteria, algae, micro-lichens (cyanolichens and chlorolichens), bryophytes (liverworts and mosses), diatoms, and micro-fungi.

These macro- and micro-organisms combined to form an intricate and diverse community that often covered entire soil surfaces (Figure 1a,b, page 202), and when dry could be lifted up in large pieces (Figure 1c, page 202). Cyanobacteria dominated the majority of crusts both in diversity and abundance. Cyanobacterial crusts sampled from, and documented across the 60 kilometre north-south transect, formed five distinct groups (Figure 2, page 204). The dominant group was 'Red Crusts' that described the often distinctive deep reddish-black pigmentation generated by cyanobacteria as a UV sunscreen (Figure 1c,d, page 202).

There were several sites (described in detail in Exceptional Crust Communities section) whose crust form and nature encompassed special features that exemplified the distinctive and evolutionary nature of cyanobacterial crusts. Specialist adaptations by cyanobacteria to extreme UV exposure resulted in highly coloured pigmentation illustrated by the frequently recorded 'Red Crusts' (Figures 1, page 202, and 3, page 206). Examples of desiccation tolerance were evident with the dehydration of

Table 1. Crust types found at Pungalina-Seven Emu (after Büdel et al., 2009). Perennial cyanobacterial crusts differ in that they break down annually then regrow during the wet season.

CRUST TYPE	Crust description
TYPE 1	Patchy thin crust, easily broken, early successional stage, low diversity
TYPE 2	Diverse well-formed *perennial cyanobacterial crust*, intermediate successional stage
TYPE 3	Diverse *perennial cyanobacterial crust*, with liverworts and mosses, intermediate successional stage
TYPE 4	Diverse *permanent cyanobacterial crust* with lichens, or liverworts and mosses, late successional stage

Table 2. Statistical values for separation of crust types

Groups	R Statistic	Significance Level %	p-value	Possible Permutations	Actual Permutations
Red Crusts, Bryophytes	0.692	0.2	0.002	1035	999
Red Crusts, Tidal Flats	0.723	0.1	0.001	16215	999
Red Crusts, Subsurface	0.592	0.7	0.007	1035	999
Red Crusts, Organic	0.672	0.1	0.001	1906884	999
Bryophytes, Tidal Flats	1	10	0.1	10	10
Bryophytes, Subsurface	1	33.3	0.333	3	3
Bryophytes, Organic	0.818	4.8	0.048	21	21
Tidal Flats, Subsurface	1	10	0.1	10	10
Tidal Flats, Organic	0.846	1.8	0.018	56	56
Subsurface, Organic	0.8	4.8	0.048	21	21

cyanobacterial cells within their protective sheaths (Figure 3a,b, page 206). A well preserved stand of fossilised stromatolites formed through the cement like EPS of cyanobacteria, links geological time around 3.5 billion years ago with cyanobacteria found at Pungalina-Seven Emu today. On the microscopic scale there was evidence of stratification (surface and sub-surface species), as well as diversity in morphology across species, and specialist nitrogen fixing cells called heterocysts (Figure 3c,d, page 206).

During the dry season the cyanobacterial crusts remain in a desiccated (inactive) state irrespective of unseasonal or small rainfall events (Williams et al. 2014). A few days prior to sampling there had been an unusual 14 mm rain event. One week later cyanobacterial crusts were watered (with rain water) and tested for photosynthetic activity using a Pocket PAM. Although chlorophyll fluorescence was clearly present, no photosynthesis was recorded at hourly periods over three hours on the first morning or the following morning (24 hours). Recently, it has been discovered that at the commencement of the wet season the perennial crusts structurally break down followed by regrowth and reformation of the crust (Williams et al. 2014; Büdel and Williams, unpublished data). The crust breakdown occurs as the EPS changes its permeability and allows water to penetrate to the cells. At this time the sheaths that encase the cyanobacterial filaments disintegrate and many cells are 'sacrificed' a process believed to provide nutrients and facilitate regeneration. As the wet season progresses cyanobacteria multiply and diversify to create a 'new' highly productive crust (Williams et al. 2014 and unpublished data).

Habitat and diversity of cyanobacterial crusts

Across all sites, four cyanobacterial crust types were classified according to their successional stage (Table 1, page 207), with examples illustrated in Figure 4, page 209. Although these ranged from early to late successional stages, the majority were grouped into an intermediate successional stage that contained diverse well-established cyanobacterial communities.

Table 3. Total diversity across the Cycad Creek site was 22 species made up of 17 cyanobacteria (numbers of species in brackets)

Cyanobacteria		Other
Surface dwellers	**Sub-surface**	**Surface dwellers**
Chroococcales (1) *Gloeocapsa* (1) *Gloeocapsopsis* (1) *Phormidium* (1) *Porphyrosiphon* (1) *Scytonema* (2) *Stigonema* (3) *Symploca* (1) *Symplocastrum* (2)	*Schizothrix* (3) *Microcoleus* (1)	Chlorolichens (2) Mosses (2) Algae (1)

Independent of their successional stage, cyanobacterial crusts were found to be separated into five main groups: Tidal Flats, Bryophytes, Organic, Sub-surface and Red Crusts (Figure 5, page 211). There was no pattern of association with either pH or higher order vegetation type. An analysis of similarity (ANOSIM) was conducted in Primer to determine whether there was a significant difference between the crust types (Table 2, page 207). These results showed the composition of Red Crusts was significantly different from the other four types (p-values all <0.05). However, there was no significant difference between the other crust types (p-values >0.05). High regression statistics and the low number of possible permutations further confirmed that the compositions of the other types were not significantly different from each other.

Figure 6, page 212, shows the transition across broad soil types with Bryophytes and Tidal Flats restricted to alluvial soils, Organic and Subsurface limited to colluvial and sandstone soils and, Red Crusts distributed evenly across both soil types. In the red crust group, cyanobacteria *Symploca* red (25.8%), *Scytonema* (24.9%), *Porphyrosiphon* (19.3%), *Stigonema* (8.4%), *Symplocastrum* (8.3%), *Symploca* brown (2.8%) and Moss 3 (2.5%) were ranked as the most abundant species (Figure 7, page 213). Although cyanobacteria dominated the crusts that often completely covered soil or rock surfaces with distinctive red and black crusts; liverworts, mosses and lichens (rare)[1] were also recorded at several sites (Crust types 3 and 4). These crusts were not restricted in their distribution however, they were not found across the tidal flats and dunes. Bryophytes that included mosses and liverworts as a group were only found at three sites although were also recorded in other crust communities. An Organic group occurred randomly across all sites its composition of dead cyanobacterial filaments and micro-fungi. A Sub-surface (group), dominated by cyanobacterium *Microcoleus paludosus*, was found in colluvium and sandstone; however it was also occasionally found in other Red Crust communities.

Although pH ranged from 4.9–6.4 across all sample sites, it did not appear to be a driving factor in species distribution or crust type.

Tidal flats and dunes

The most abundant cyanobacteria in the tidal flats and grassy steppe (Figure 8, page 214) were *Microcoleus chthonoplastes* and *Gloeothece* sp., (Figure 8d,e, page 214) as well as some bryophytes (Moss 1) that were restricted to alluvium and sediments. On the tidal flats (and dunes) pH averaged 8.3 with the gradient from the flats rapidly decreasing to 7.3 in the transition grassy steppe and 6.1 across the upper level tussock grasses. Here the diversity and abundance of crust communities increased with thick black or red crusts (e.g. Figure 8c,e, page 214) and, a small range of bryophytes found in sheltered habitats.

Samples were also taken from an inter-dune summer wetland area vegetated by *Melaleuca* (Figure 9, page 215). This had clearly visible fibrous-like, filamentous mats. These were dominated by an unidentified alga that is apparently an important part of this ecosystem. Although algae can represent recovery from disturbance, in this environment its role in a niche environment that is subject to extreme conditions ranging from saline to freshwater and broad temperature gradients may well be very important.

1 Positive identification of the bryophytes and lichens is yet to take place however they almost certainly represent range extensions and potentially new species.

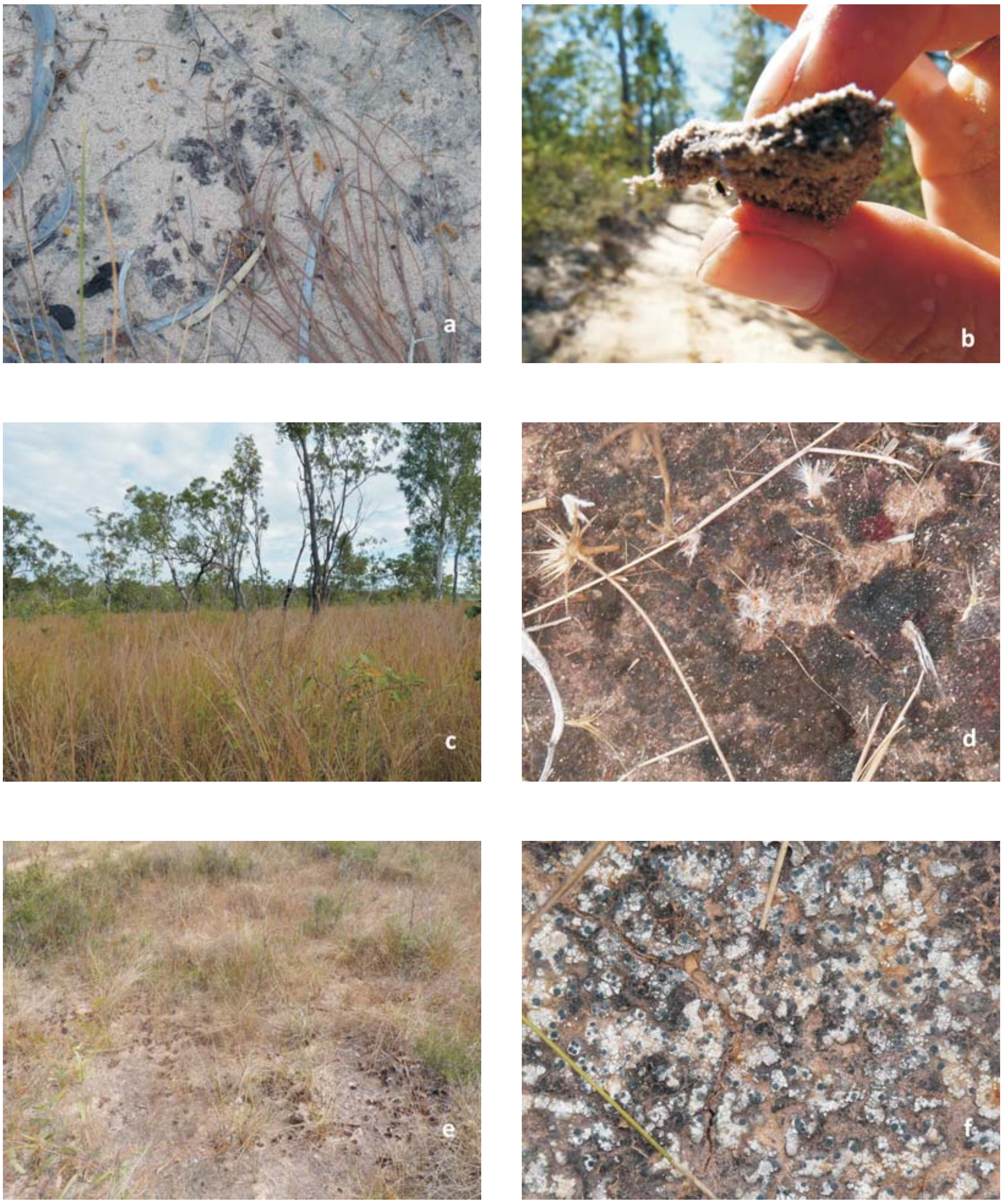


Figure 4. (a) Type 1 early successional crust, fragile and easily broken; (b) with a network of sub-surface filaments binding the sand and soil particles together so it is able to be lifted out in one piece; (c) Types 2 and 3 crusts visible as greyish discolouration with darker red patches (dry) and dark greenish black to red (wet); (d) Type 4 crusts include patches of lichen *Acarospora* sp. (whitish-grey with black apothecia), sometimes with mosses and/or liverworts.

Fire

At Pungalina-Seven Emu there were several areas that had been burnt (cool fires) a few weeks prior to our visit or within 1–2 years. At three different locations samples were collected from burnt and immediately adjoining unburnt habitat. In all cases only dead filaments and micro-fungi were found in the burnt area samples compared to a range of cyanobacteria and occasional mosses from the unburnt sites.

Table 4. Environmental factors influencing the strategies and attributes of the key cyanobacterial genera from Pungalina-Seven Emu, based on global studies in relation to diversity, stratification and preferred soil habitat. This includes surface (immobile) and subsurface species (mostly mobile).

Genera	Environmental factor	Attribute or strategy	References
Soil surface			
Symploca 'red'	Tolerance of high UV intensities Tolerance of high light intensity Wet-dry cycles Optimisation of short growing season	Spectral adaptation, sheath pigmentation	Castenholz & Garcia-Pichel, (2002)
Scytonema		Spectral adaptation (pigmentation)	Bowker et al., (2002)
Porphyrosiphon		Crust formation with EPS	Mazor et al., (1996)
Stigonema		Osmotic adaptation	Billi and Potts, (2000)
Symplocastrum	Drought resistance, desiccation	Accumulation of sugars	Hershkovitz et al., (1991)
Symploca 'brown'	Substrate transformation	Bio-alkalisation, substrate weathering	Büdel et al., (2004)
Soil subsurface			
Porphyrosiphon	Tolerance of low light intensity Optimisation of short growing season Wet-dry cycles Filamentous forms	Resistance to photo-inhibition	Harel et al., (2004)
Symploca		Sheltered growth habitats	Palmer and Friedmann, (1990)
Schizothrix		Protein sensory system	Mann, (2002)
Leptolyngbya		Hydrotaxis (mobility)	Pringault & Garcia-Pichel, (2004)
*Microcoleus**	Tolerance of high salinity*	Osmotic regulation, EPS synthesis	Chen et al., (2006)

Exceptional Crust Communities

Cycad Creek area

Certain habitats favoured the presence of well developed, diverse crust communities. One such example was located in the Cycad Creek area, particularly on the track leading up to the cycad forest escarpment (Figure 10, page 216). This area included colonies of *Nostoc commune* (Figure 10, page 216, inset) known for its association with cycad palms (Lindblad et al., 1991). On the northern side of the track there were almost continuous red and black crusts (Figure 11, page 217) with large communities of *Symplocastrum* (also Figures 4 d,e, page 209). Soil lichens (Figure 4f, page 209) were also abundant and represented a range extension with no previous records from the Northern Territory savannah.

Creeks

Multiple samples were collected from five dry and drying creek beds, from material floating in remaining waterholes and areas that had dried out where the water had stopped flowing. Much of the material was desiccated (inactive) or breaking down (in structure). These were ephemeral creeks that normally run only in the wet season (Figure 12, page 218). This provided valuable information about the cyanobacteria that live in these conditions—in an aquatic environment in summer and drought equivalent conditions in winter. We used the Pocket PAM to test some moist yet drying creek crusts and there were small levels of fluorescence but no photosynthesis (YII), indicative of their inactivity during the dry season.

Overall there were 21 cyanobacteria, two algae, one liverwort and three mosses found within the creek bed zones. The rocks and creek embankments also offered varied microhabitat and there were often diverse crusts containing cyanobacteria, algae (Figure 12b, page 218), lichens, liverworts and mosses. *Symploca, Symplocastrum, Porphyrosiphon, Scytonema* and *Leptolyngbya* dominated the various communities while *Stigonema*, *Microcoleus* and *Gloeocapsa* were common. *Nostoc* was more commonly found on creek terraces and embankments. Cyanolichen *Synalissa* was occasionally found on large sandstone slabs.

Duricrust system

There was a rocky plateau intercepted by a road with large areas of duricrust[2] that were encrusted with cyanobacterial mats (Figures 13, page 219, and 14, page 220). Many areas nearby

2 The material of the duricrust has been formed by physicochemical processes involving reactions between the atmosphere, ground water, and soil and rock (www.springerreference.com/docs/html/chapterdbid/4256.html)

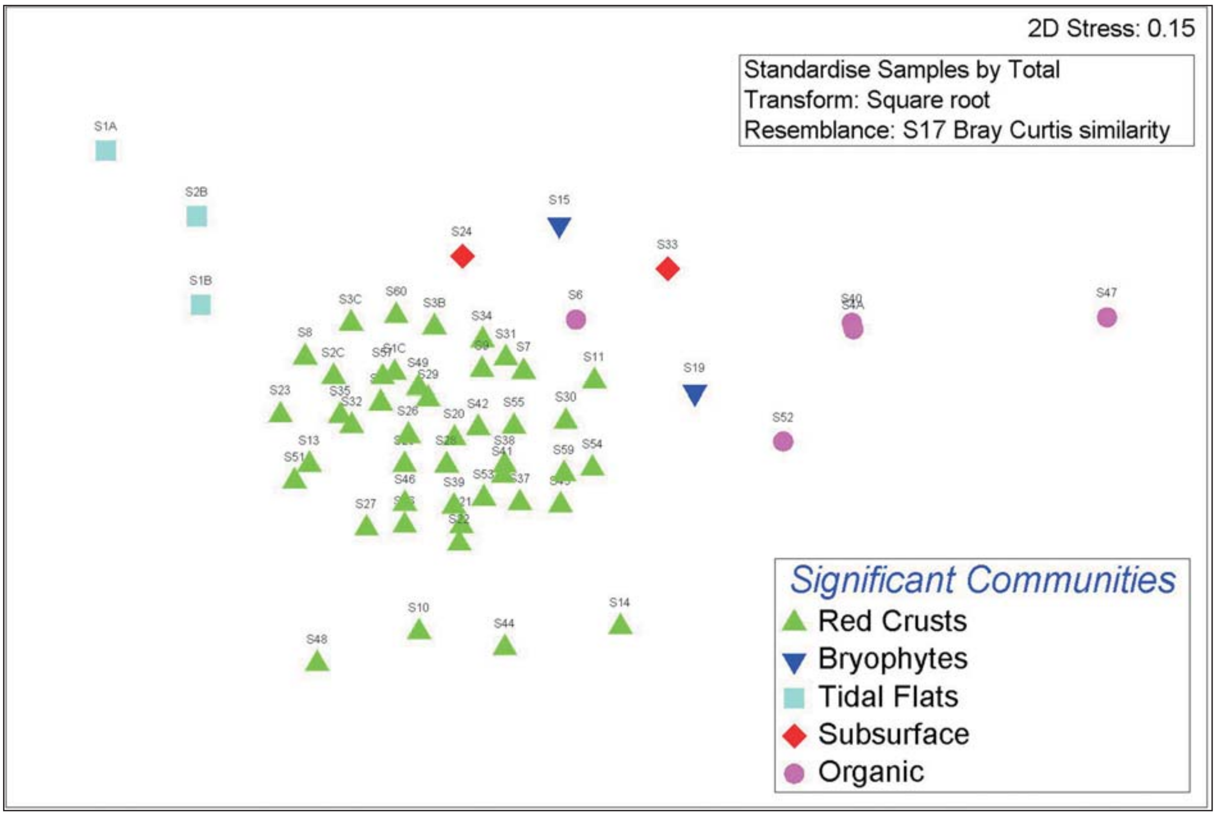


Figure 5. Red Crusts (green triangle) were the most significant crust community in diversity and abundance where other smaller groups were generally isolated in their distribution.

were sandy soils and these were also covered by continuous crusts (black and red and some greyish ones) in amongst the Spinifex and on the edge of gravelly water courses. In this area there were large sheets of crusts that were sampled for additional laboratory tests. Red crusts had grown in shallow basins of the duricrust apparently where water would pool. These crusts had extremely long filaments that appeared spaghetti-like and were later identified as red *Porphyrosiphon*–like cyanobacteria.

There were also examples of ‘rippled’ rock formations (Figure 14b, page 220), and areas of crust were observed that had formed similar rippled patterns as the rock formations (Figure 14c,d, page 220). In marine environments microbial induced sedimentary structures (MISS) are formed as a result of the interaction of cyanobacteria-microbial mats with physical sediment dynamics in shallow-marine settings (Noffke, 2009). When sediment is deposited onto the mat surface, the filamentous cyanobacteria (Figure 14e, page 220) trap and bind sand particles to form mat fabrics (Figure 14a,f, page 220), and later MISS. Bio-stabilization occurs when EPS ‘cements’ sand grains and minerals together and has been observed using high-powered scanning electron microscopy (SEM) of *Symplocastrum* mats from Boodjamulla National Park that are similar to those found at Pungalina-Seven Emu (Figure 14f, page 220).

Stromatolites

The stromatolitic outcrops at Pungalina appeared as domed and encrusted domical laminites (Figure 15, page 221), believed to be formed through biogenesis in the early Archaean Era of Australia (Allwood et al., 2006). These fossilised stromatolites have granular sediment in their laminae indicating the past presence of a cyanobacterial-dominated microbial mat (Allwood et al., 2006). In addition to the fascinating geological perspective of the stromatolites, there was a diverse cyanobacterial community found on the exposed fossilised surfaces (Figure 15, page 221). The most common cyanobacteria were *Stigonema, Scytonema, Gloeocapsopsis* and *Chroococcidiopsis.*

Discussion

In this study we have described a diverse cyanobacterial crust community that likely

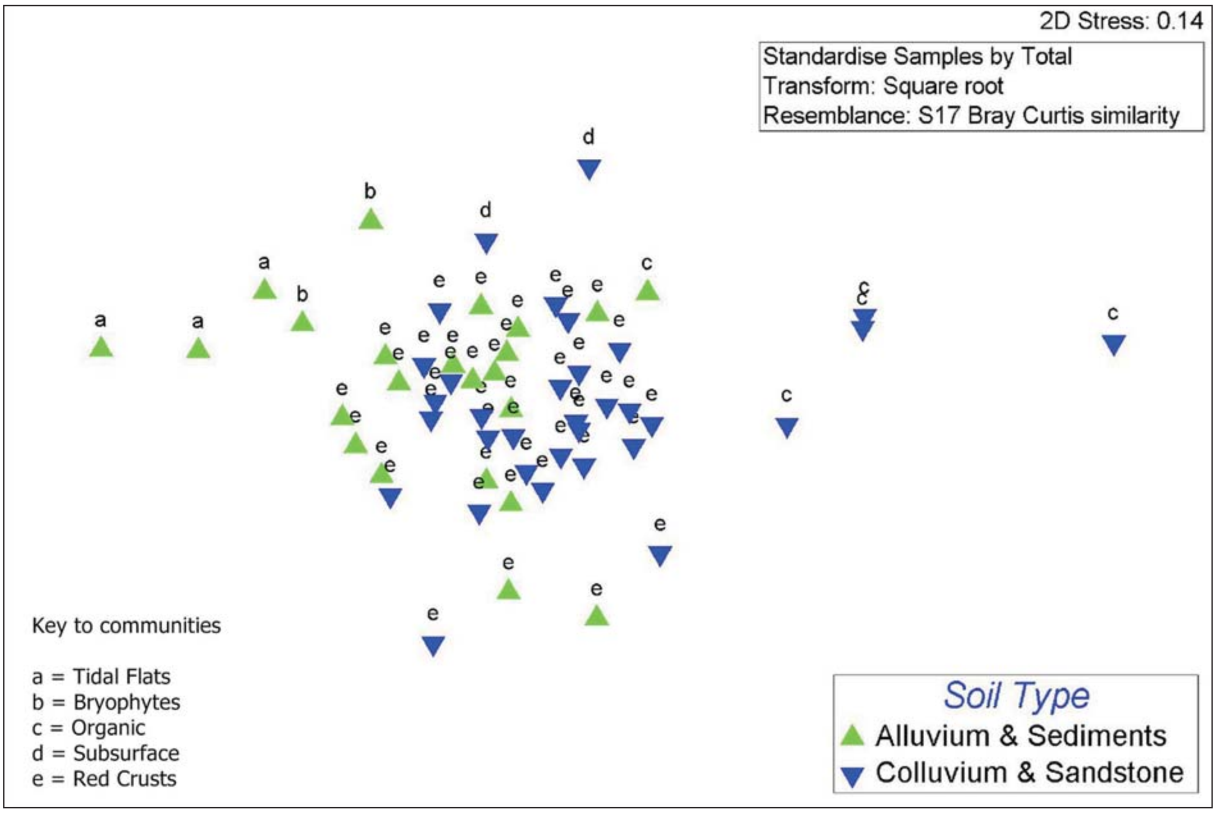


Figure 6. Red Crusts and Organic groups were found across all soil types, whereas the Tidal Flat and Bryophyte groups were restricted to the alluvium and sediments and the sub-surface communities to the colluvium and sandstone.

covers an estimated 76,500 hectares of soil surfaces across Pungalina-Seven Emu. These living crusts represent significant microbial ecosystems that would contribute greatly to soil structure, stability, infiltration and nutrient cycling. Cyanobacteria, as ecosystem engineers, bind and trap soil particles and scavenge minerals, create organic and inorganic layers through the secretion of EPS and, provide a stable environment for plants (Hu et al., 2002). Comparatively, in the northern Australian savannah these Pungalina-Seven Emu records of cyanobacterial crusts, their diversity and extent, substantially add to the recent growth in knowledge of their distribution. Similar regions include Boodjamulla National Park and the Queensland Gulf Savannah (e.g. Normanton, Burketown, Bowthorn, Kingfisher and others) as well as Cape York Peninsula including AWC's Piccaninny Plains (Williams et al., 2009). On a global scale these vast tracts of cyanobacterial crusts are significant contributors to terrestrial soil carbon and nitrogen pools (Elbert et al., 2012).

Ancient landforms at Pungalina-Seven Emu exemplified through duricrusts (with a number of other similar formations observed by air) and, preserved microbial reefs in the form of stromatolites, link the past to the present. Over time cyanobacteria have evolved and adapted from the ocean to a terrestrial environment. Adaptations have included the capacity to remain in a desiccated state for hours, months and years, and upon rehydration resume photosynthesis (Lange, 2003). An apparently special adaptation by cyanobacteria to the seasonal fluctuations of the northern Australian savannah environment is the capacity to remain inactive (in a desiccated state) throughout the course of the dry season (Williams et al., 2014). At the Cycad Creek site this was substantiated (mid dry season) with PAM measurements following unseasonal rain and rewetting, at which time no photosynthetic activity was recorded (Table 4, page 210). It is now believed that the changes to EPS permeability are an adaptation in order to avoid using precious resources for growth when there would be no follow-up rain (Williams et al., 2014). Typically, throughout the northern savannah dry season there is just a few millimetres of rain over several months. Due to evaporation (drier winter air), and the lack of dewfall, cyanobacteria, if they were to respond to small amounts of rain, would not have sufficient time

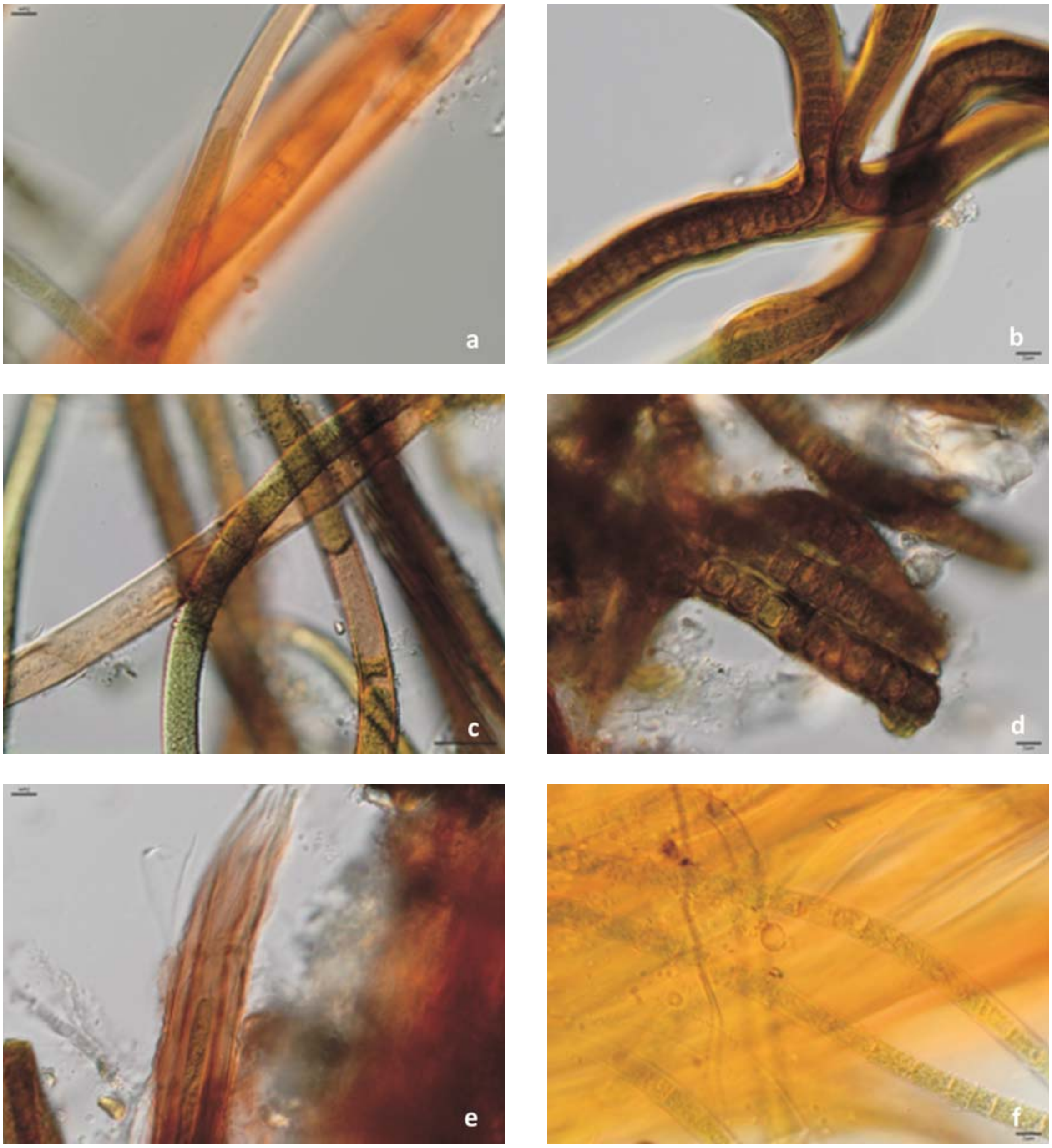


Figure 7. Microscopic images of most commonly recorded cyanobacteria illustrating their distinctive coloured outer sheaths that protect them against UV damage. When observed in the field most of these cyanobacteria appeared reddish to black or brown and sometimes shiny: (a) *Symploca* (red) grew in large mats; (b) *Scytonema*—an unusual cyanobacteria with distinct morphological features and most likely represents a new species; (c) *Porphyrosiphon* (red) often entangled amongst other cyanobacteria and sometimes dominant and mat forming; (d) *Stigonema* grows in small cushions amongst other cyanobacteria in undisturbed habitats; (e) *Symploca* (brown) formed mats and tufted surfaces; (f) *Symplocastrum* (gold) often dominant in mats and formed tufts of multiple filaments.

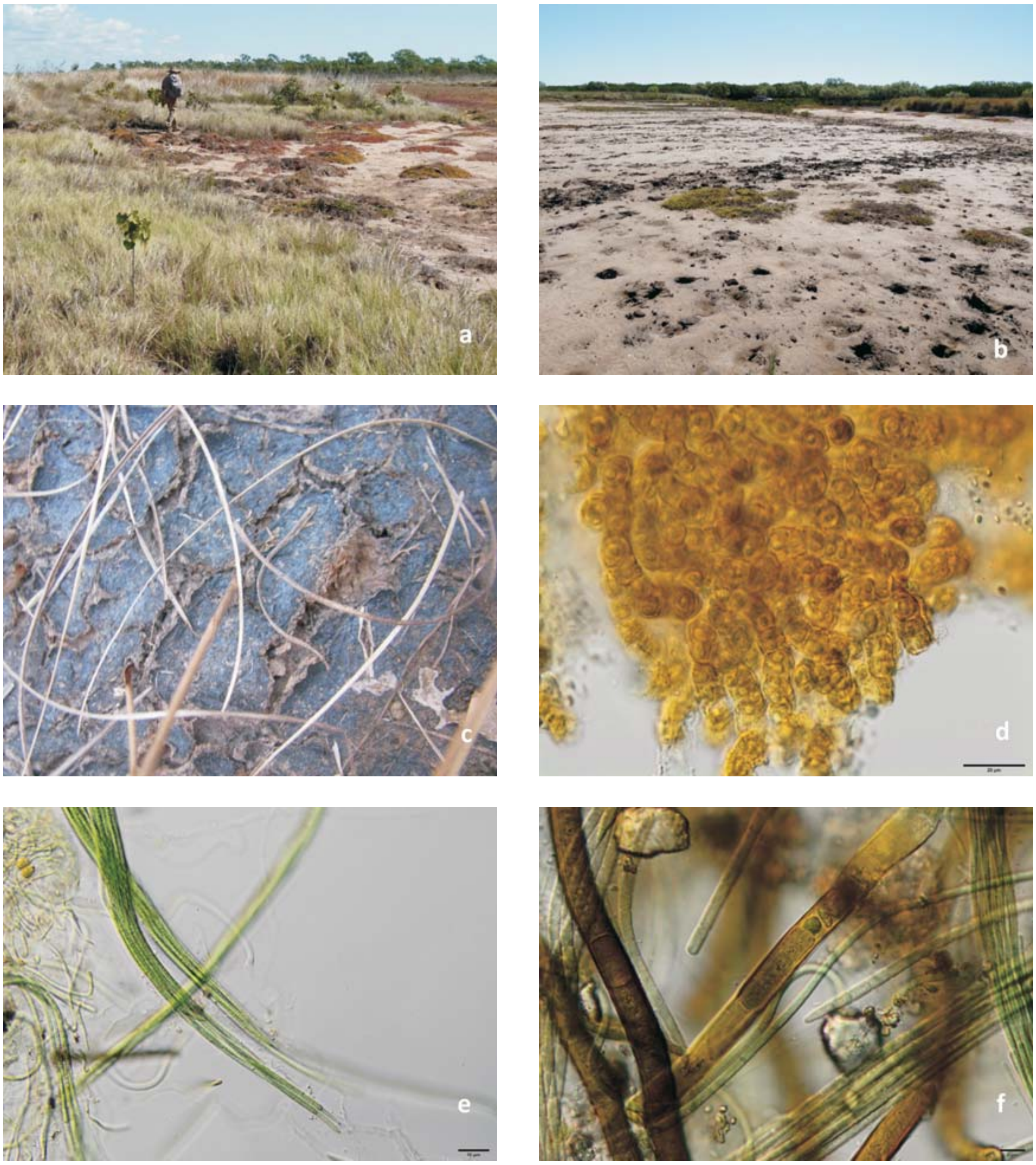


Figure 8. Cyanobacterial crusts found in the tidal flats varied from invisible subsurface species that did not usually form mats, to thick black crusts that were diverse and well developed. (a) On the edge of the tidal flats where there was a transition zone that was occasionally affected by tides although generally stable, leading into the upper level of tall perennial tussock grasslands; (b) tidal flats variably bare or vegetated by salt tolerant plants like *Sarcornia* and mangroves in the background; (c) thick black cyanobacterial crusts found in the transition zones; (d) *Gloeothece* like cyanobacteria commonly found in the transition zone, likely to be a new species; (e) *Microcoleus chthonoplastes* a salt tolerant cyanobacteria was common in the tidal flats and the transition zone. Multiple filaments are bundled together in a common clear sheath and can glide through the substrate; (f) *Scytonema* (brown) was common in the transition zones and tall grasslands. These cyanobacteria had multiple heterocysts indicating active nitrogen fixation taking place.

Figure 9. Aerial view of dunes in area of those sampled illustrating vegetated inter-dune area where brown algal mats were found.

to multiply and would use up their intra- and extra-cellular resources without the benefit of growth. During the summer wet season, the cyanobacterial crust structure breaks down into organic matter. Peak growth occurs around the height of the summer rains, with new crust growth in a relatively short time (Williams et al., 2014).

Species diversity provides for variation in responses to both climate and micro-environmental conditions (Williams and Büdel, 2012). Surface dwelling cyanobacteria that inhabit the crusts of the northern savannah must have the capacity to survive exposure to extreme UV and light intensities, and they do so in part through the production of sunscreen pigments to protect the light-sensitive PSII (Table 4, page 210). Indicative of the high levels of UV exposure, as well as small-scale micro-environmental variation, even those crusts found in the tall grass savannah were heavily pigmented. These cyanobacteria are especially adapted to the annual cycle of dry season 'droughts', followed by the soaking rains of the monsoonal season that often result in flooding. Optimisation of short growing season is paramount, demonstrated by the regrowth of the crust matrix on an annual basis (Williams et al., 2014). Table 3, page 208 describes a range of strategies and attributes derived from global studies that cyanobacteria found at Pungalina-Seven Emu employ for survival. The variability in cyanobacterial diversity recorded across Pungalina-Seven Emu appeared driven by environmental conditions and geology. The relative abundance of different cyanobacterial genera fluctuated according to habitat suitability but was not restricted by pH or vegetation community.

On the tidal flats *Microcoleus chthonoplastes* was the only commonly occurring cyanobacteria, possibly indicative of the higher level of tidal disturbance as well as floods in summer. Often tidal flats are unique habitats of diverse microbial community assemblages however globally *M. chthonoplastes* has been recorded as the most abundant cyanobacteria present in these saline habitats (Stal, 1995). There was greater diversity and abundance amongst the mangrove samples and the transition zones above the tidal flats.

Late successional Type 4 crust communities confirmed the extent and complexity of biological crusts that are located in many areas throughout northern Australia. Recently, lichens (in smaller numbers) have been located at similar latitudes on Cape York Peninsula by Williams et al. (2009). The Cycad Creek area needs to be mapped for crust communities in more detail and should be regarded as a 'hotspot' of diverse and abundant biological crust communities. Walking tracks, motor vehicle tracks and camping in this particular area should be minimised.

Figure 10. Cycad palms on escarpment with cyanobacterial crusts amongst grass consisted primarily of *Porphyrosiphon, Symploca,* and *Nostoc commune* (inset) that is known for its symbiotic relationship with Cycad coralloid roots and dependence as a source of nitrogen.

Fire

Little is known about the effects of fire on microbial activity, especially in the northern savannah where burning is part of natural episodic events. We had suspected cool fires, typically used in hazard reduction, would not affect cyanobacterial crusts; however we found no live material in the burnt areas. Even though the unburnt areas investigated contained only low levels of cyanobacterial crust cover (%) this led us to question what the short and long-term effects of fire on landscape stability and nutrient cycling were. Lightning strikes are also a common cause of savannah fires and generally result in hot fires as they mostly occur during the build up to the wet season when the vegetation is very dry. The effects of fire on the more established areas of crust communities should be further studied in order to assess the need for preservation of fire-sensitive crust ecosystems. In some areas these may be crucial to maintaining soil stability and nutrient loss could occur if the crusts are damaged.

Disturbance by stock and feral animals

Damage from stock trampling was most evident in the fore-dunes and cypress pine woodlands. In the cypress pine areas there was substantial evidence of stock use (trampling and dung). Although remnants of dead cyanobacterial filaments were found, no live material was collected. The soils in these woodlands were generally coarse and sandy with little understorey or perennial grass cover. These sandy soils were similar to some desert regions (Northern Territory) where in undisturbed habitats a diverse sub-surface cyanobacterial community existed (Williams and Tongway, unpublished data). It could be anticipated that over time, if left undisturbed, these woodlands and dunes would support a range of cyanobacterial communities that would assist in stabilisation and infiltration.

Coastal wetlands, soaks, clay pans and salt pans were only able to be observed aerially.

Figure 11 Open *Viridiflora* woodland with grassy understorey near Cycad Creek (top) that had extensive cyanobacterial crust communities; including large areas of *Symplocastrum* (bottom) often around the bases of soft spinifex.

Figure 12. Typical creek illustrating: (a) often shallow aquatic environment that can dry out in winter; (b) long strands of green algae floating in the water; (c) shallow pools with cyanobacteria present and, (d) ripple rocks where the water flow has dried leaving thick black cyanobacterial communities encrusted over the rock surface; note where the water has pooled longer in the grooves there are more cyanobacteria present.

Functional ecosystems such as these should contain diverse microbial flora that are important contributors to ecosystem integrity (Bowker et al., 2008). Pigs were observed to be abundant throughout and their removal would greatly enhance the condition of these important ecosystems.[3]

Protecting, monitoring and presenting reserve values

This study has highlighted the diversity, value and functional role of cyanobacterial crusts at Pungalina-Seven Emu. This has provided a foundation towards the establishment of a database of cyanobacterial crusts based on diversity and their association with vegetation communities, soil types and underlying geological formation. There is a need to improve the understanding of the breadth of diversity through a polyphasic approach that includes DNA sequencing. Within this framework it is important to register a database and lodge samples with state herbaria so that there are records of increases in distribution ranges of different crust taxa along with any new records for Australia. There is a need for further identification and mapping of the extent and structure of crust ecosystems that include those of special ecological significance.[4]

This would assist with the protection of important areas whereby construction of new camping areas, roads or walking trails did not intercept these areas. Cyanobacteria and lichens respond quickly to persistent changes in precipitation patterns. Monitoring changes in diversity over time in relation to changing climate and

3 For detailed reviews on nutrient cycling, degradation and rehabilitation of biological crusts refer to Belnap and Lange, (2003), Chapters 20-29

4 This should be linked to an Australia-wide biogeographical database that will provide predictive tools for identifying biodiversity hot spots. It can also be taken into consideration in the rehabilitation of degraded areas, where biological crusts should exist as a natural part of the natural landscape.

Figure 13. Aerial view of duricrust system that was sampled indicating the coverage was quite broad in area, with the darkness of the cyanobacterial crust still clearly visible from the air.

rainfall gradients can be an indication of changes to the nutrient status of soils, therefore useful in predicting the effects of a changing climate on plant communities. This can be achieved through the inclusion of microbiotic crusts in vegetation monitoring programs with the aid of programs such as Landscape Function Analysis (LFA) (Tongway and Hindley, 2004).

Information about cyanobacterial crusts, including their ancient history in Australia (with fossils dating back ~3.5 billion years) should be publicised in the context of their relative importance at Pungalina-Seven Emu and the natural landscape. This can be achieved by the inclusion of the ecological importance of cyanobacterial crusts in the promotion of the natural features of the reserve. Active encouragement and support of scientific research projects associated with the ecological values and rehabilitation of cyanobacterial crusts within the reserve is needed.

Conclusion

At Pungalina-Seven Emu cyanobacterial soil crusts were prominent throughout the landscape, estimated to cover thousands of hectares of soil surface. Specialist adaptations and strategies employed by the various crust organisms have enabled them to survive in extreme environment as a diverse community. Species diversity and their range of responses to fluctuations in light, temperature and moisture have provided resilience within their environment. The extent of cyanobacterial crusts at Pungalina-Seven Emu was a positive field indicator of the functional status of the landscape condition. Cyanobacteria were found to represent a key component of the landscape as ecosystem engineers of their environment.

The preservation of cyanobacterial soil crusts to fulfil their role in landscape function is an important part of conservation. Although the savannah climate is unique, in itself supporting a range of perennial crusts, we have shown here that edaphic gradients are more influential to the

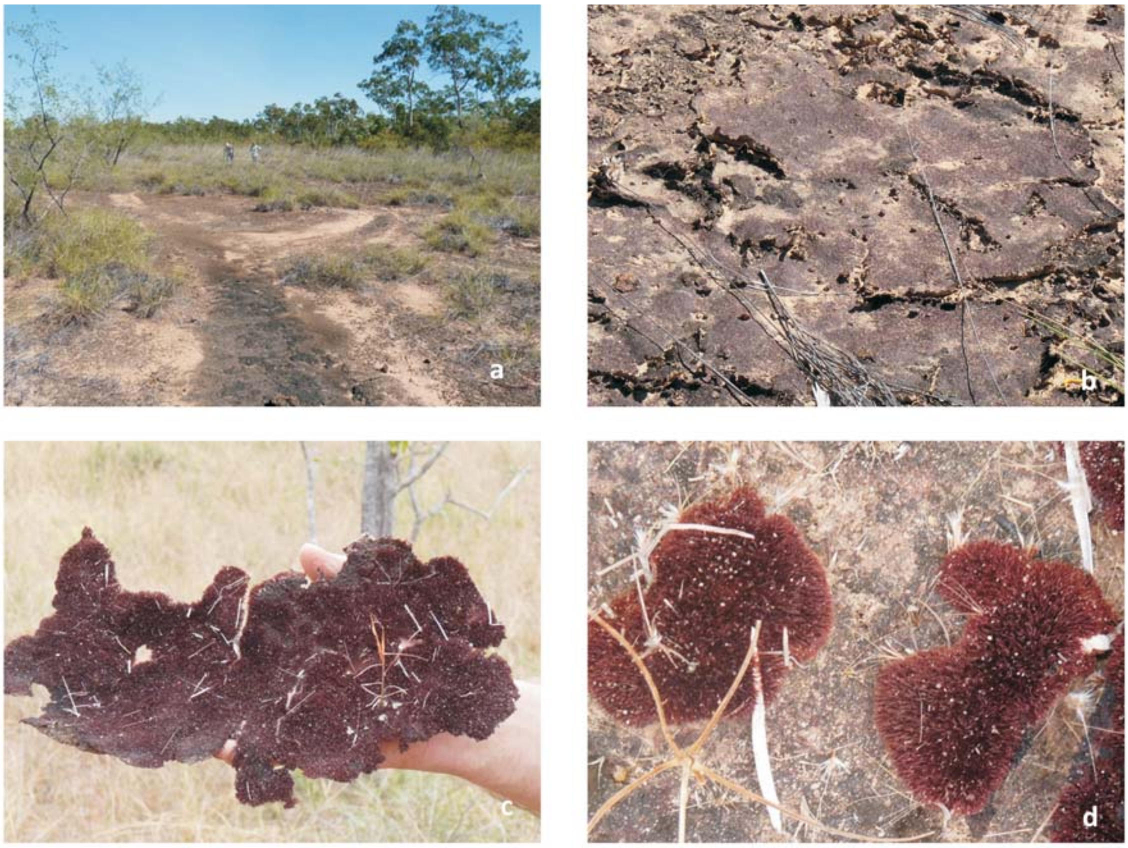


Figure 14. (a) Large areas of duricrust surfaces encrusted with cyanobacterial mats; (b) ripple rocks that are thought to have been formed by MISS; (c) area that was previously under water and dried out illustrating sandy deposition partially covering dark cyanobacterial mats; (d) close up view of rippled surface of cyanobacterial mats after water has dried out; (e) cyanobacterial filaments (*Scytonema*) with thick and sticky outer sheath that assists in trapping sand grains; (f) vertical cross section (SEM) of multiple *Symplocastrum* filaments in a crust with sand grains trapped within the tufted basal layer (image by C. Colesie and B. Büdel, University of Kaiserslautern, Germany).

structure of crust communities. It is therefore important to capture ecological 'hotspots' that are rich in habitat specialists and are biologically unique (Bowker et al., 2008).

Acknowledgements

This project was supported by the Royal Geographical Society of Queensland and Australian Wildlife Conservancy. In particular, we would like to thank Hayley Fremantle and the volunteers from RGSQ who made camping and surveying in a remote location so much easier through the provision of meals, necessities and good company—fixed campsite bases and daily support was very much appreciated. Special thanks to Rod Low Mow (pilot) from Adele's Grove (Lawn Hill, QLD) who volunteered to fly his plane to Pungalina-Seven Emu that enabled us to carry out an aerial assessment of the reserve. We would also like to thank Dr Glenn McGregor for the use of his microscope that provided the excellent images of the cyanobacteria and Prof Burkhard Büdel and Dr Claudia Colesie (University of Kaiserslautern, Germany) for the SEM image, David Tongway and an anonymous reviewer for editing.

References

Allwood, A.C., Walter, M.R., Kamber, B.S., Marshall, C.P., Burch, I.W., 2006. Stromatolite reef from the Early Archaean era of Australia. *Nature* 441, 714–718.

Figure 15. Cross section view of exposed stromatolite reef with colonies of cyanobacteria in amongst the crevasses and across the surface.

Belnap, J., Eldridge, D., 2003. Disturbance and Recovery of Biological Soil Crusts, in: Belnap, J., Lange, O.L. (Eds.), Biological Soil Crusts: Structure, Function, and Management, *Ecological Studies*. Springer Berlin Heidelberg, pp. 363–383.

Belnap, J., Lange, O.L., 2003. Structure and Functioning of Biological Soil Crusts: a Synthesis, in: Belnap, J., Lange, O.L. (Eds.), Biological Soil Crusts: Structure, Function, and Management, *Ecological Studies*. Springer Berlin Heidelberg, pp. 471–479.

Biggs, B., Kilroy, C., 2000. *Stream periphyton monitoring manual*. NIWA, Christchurch NZ.

Billi, D., Potts, M., 2000. Life without water: Responses of prokaryotes to desiccation, in: K.B. Storey and J.M. Storey (Ed.), *Cell and Molecular Response to Stress, Environmental Stressors and Gene Responses*. Elsevier, pp. 181–192.

Bowker, M.A., Belnap, J., Bala Chaudhary, V., Johnson, N.C., 2008. Revisiting classic water erosion models in drylands: The strong impact of biological soil crusts. *Soil Biology*. Biochem. 40, 2309–2316.

Bowker, M.A., Belnap, J., Davidson, D.W., Goldstein, H., 2006. Correlates of biological soil crust abundance across a continuum of spatial scales: support for a hierarchical conceptual model. *Journal of Applied Ecology.* 43, 152–163.

Bowker, M.A., Reed, S.C., Belnap, J., Phillips, S.L., 2002. Temporal Variation in Community Composition, Pigmentation, and Fv/Fm of Desert Cyanobacterial Soil Crusts. *Microbial Ecology*. 43, 13–25.

Büdel, B., Darienko, T., Deutschewitz, K., Dojani, S., Friedl, T., Mohr, K.I., Salisch, M., Reisser, W., Weber, B., 2009. Southern African Biological Soil Crusts are Ubiquitous and Highly Diverse in Drylands, Being Restricted by Rainfall Frequency. *Microbial Ecology.* 57, 229–247.

Büdel, B., Weber, B., Kühl, M., Pfanz, H., Sültemeyer, D., Wessels, D., 2004. Reshaping of sandstone surfaces by cryptoendolithic cyanobacteria: bioalkalization causes chemical weathering in arid landscapes. *Geobiology 2*, 261–268.

Büdel, B., 2002. Diversity and Ecology of Biological Crusts, in: Esser, K., Lüttge, U., Beyschlag, W., Hellwig, F. (Eds.), *Progress in Botany*. Springer Berlin Heidelberg, pp. 386–404.

Castenholz, R.W., Garcia-Pichel, F., 2002. Cyanobacterial Responses to UV-Radiation, in: Whitton, B.A., Potts, M. (Eds.), *The Ecology of Cyanobacteria*. Springer Netherlands, pp. 591–611.

Chen, L.Z., Li, D.H., Song, L.R., Hu, C.X., Wang, G.H., Liu, Y.D., 2006. Effects of Salt Stress on Carbohydrate Metabolism in Desert Soil Alga Microcoleus vaginatus Gom. J. Integr. *Plant Biology*. 48, 914–919.

Clarke, K.R., Gorley, R.N., 2006. *PRIMER v6: User Manual/Tutorial*. PRIMER-E, Plymouth.

Elbert, W., Weber, B., Burrows, S., Steinkamp, J., Büdel, B., Andreae, M.O., Pöschl, U., 2012. Contribution of cryptogamic covers to the global cycles of carbon and nitrogen. *Nature Geoscience*. 5, 459–462.

Eldridge, D.J., Bowker, M.A., Maestre, F.T., Alonso, P., Mau, R.L., Papadopoulos, J., Escudero, A., 2010. Interactive Effects of Three Ecosystem Engineers on Infiltration in a Semi-Arid Mediterranean Grassland. *Ecosystems* 13, 499–510.

Geitler, L., 1932. *Cyanophyceae von Europa, Kryptogamen–Flora von Deutschland, Österreich und der Schweiz*. Koeltz Scientific Books, Koenigstein Germany.

Greene, R., Chartres, C., Hodgkinson, K., 1990. The effects of fire on the soil in a degraded semiarid woodland .I. Cryptogam cover and physical and micromorphological properties. *Soil Research.* 28, 755–777.

Harel, Y., Ohad, I., Kaplan, A., 2004. Activation of Photosynthesis and Resistance to Photoinhibition in Cyanobacteria within Biological Desert Crust. *Plant Physiology.* 136, 3070–3079.

Hershkovitz, N., Oren, A., Cohen, Y., 1991. Accumulation of Trehalose and Sucrose in Cyanobacteria Exposed to Matric Water Stress. *Applied Environmental Microbiology*. 57, 645–648.

Hu, C., Liu, Y., Zhang, D., Huang, Z., Paulsen, B.S., 2002. Cementing mechanism of algal crusts from desert area. *Chinese Science Bulletin*. 47, 1361–1368.

Jones, C.G., Lawton, J.H., Shachak, M., 1994. *Organisms as Ecosystem Engineers*. Oikos 69, 373–386.

Komárek, J., Anagnostidis, K., 1999. *Cyanoprokaryota - Teil 1 / Chroococcales, Süßwasserflora von Mitteleuropa*. Gustav Fischer, Jena, Germany.

Komárek, J., Anagnostidis, K., 2005. *Cyanoprokaryota 2. Teil Oscillatoriales, Süßwasserflora von Mitteleuropa*. Gustav Fischer, Jena, Germany.

Lange, O.L., 2003. Photosynthesis of Soil-Crust Biota as Dependent on Environmental Factors, in: Belnap, J., Lange, O.L. (Eds.), Biological Soil Crusts: Structure, Function, and Management, *Ecological Studies*. Springer Berlin Heidelberg, pp. 217–240.

Lange, O.L., Meyer, A., Budel, B., 1994. Net Photosynthesis Activation of a Desiccated Cyanobacterium Without Liquid Water in High air Humidity Alone. Experiments with Microcoleus sociatus Isolated from a Desert Soil Crust. *Functional Ecology*. 8, 52.

Lindblad, P., Atkins, C.A., Pate, J.S., 1991. N2-Fixation by Freshly Isolated Nostoc from Coralloid Roots of the Cycad Macrozamia riedlei (Fisch. ex Gaud.) Gardn. *Plant Physiology*. 95, 753–759.

Mann, N.H., 2002. Detecting the Environment, in: Whitton, B.A., Potts, M. (Eds.), *The Ecology of Cyanobacteria*. Springer Netherlands, pp. 367–395.

Mazor, G., Kidron, G.J., Vonshak, A., Abeliovich, A., 1996. The role of cyanobacterial exopolysaccharides in structuring desert microbial crusts. FEMS *Microbial Ecology*. 21, 121–130.

Noffke, N., 2009. The criteria for the biogeneicity of microbially induced sedimentary structures (MISS) in Archean and younger, sandy deposits. *Earth Science Reviews.* 96, 173–180.

Palmer, R.J., Friedmann, E.I., 1990. Water relations and photosynthesis in the cryptoendolithic microbial habitat of hot and cold deserts. *Microbial Ecology*. 19, 111–118.

Potts, M., 1999. Mechanisms of desiccation tolerance in cyanobacteria. *European Journal of Phycology.* 34, 319–328.

Pringault, O., Garcia-Pichel, F., 2004. Hydrotaxis of Cyanobacteria in Desert Crusts. *Microbial Ecology.* 47, 366–373.

Rao, B., Liu, Y., Lan, S., Wu, P., Wang, W., Li, D., 2012. Effects of sand burial stress on the early developments of cyanobacterial crusts in the field. *European Journal of Soil Biology*. 48, 48–55.

Rascher, U., Lakatos, M., Büdel, B., Lüttge, U., 2003. Photosynthetic field capacity of cyanobacteria of a tropical inselberg of the Guiana Highlands. *European Journal of Phycology*. 38, 247–256.

Skinner, S., Entwisle, T., 2001. Non-marine algae of Australia: 2. Some conspicuous tuft-forming cyanobacteria. *Telopea 9*, 683–712.

Stal, L.J., 1995. Physiological ecology of cyanobacteria in microbial mats and other communities. *New Phytologist*. 131, 1–32.

Tongway, D.J., Hindley, N.L., 2004. Landscape Function Analysis: Procedures for monitoring and assessing landscapes. *CSIRO Sustainable Ecosystems*, Canberra, Australia.

Warren, S.D., Eldridge, D.J., 2003. Biological Soil Crusts and Livestock in Arid Ecosystems: Are They Compatible?, in: Belnap, J., Lange, O.L. (Eds.), Biological Soil Crusts: Structure, Function, and Management, *Ecological Studies*. Springer Berlin Heidelberg, pp. 401–415.

West, N.E., 1990. Structure and Function of Microphytic Soil Crusts in Wildland Ecosystems of Arid to Semi-arid Regions, in: Begon, M., Fitter, A.H., Macfayden, A. (Eds.), *Advances in Ecological Research*. Academic Press, pp. 179–223.

Whitton, B.A., Potts, M., 2012. Introduction to the Cyanobacteria, in: Whitton, B.A. (Ed.), *Ecology of Cyanobacteria II*. Springer Netherlands, pp. 1–13.

Williams, W.J., Büdel, B., 2012. Species diversity, biomass and long-term patterns of biological soil crusts with special focus on Cyanobacteria of the Acacia aneura Mulga Lands of Queensland, Australia. *Algal Studies.* 140, 23–50.

Williams, W.J., Büdel, B., Driscoll, C., 2009. *Cyanobacterial soil and rock crusts from the Mitchell Downs, Gulf Plains and Cape York, Queensland, 1*. The University of Queensland, Gatton, Queensland.

Williams, W.J., Büdel, B., Reichenberger, H., Rose, N., 2014. Seasonal transformations of northern Australian perennial soil crusts regulated by cyanobacterial extracellular matrix and environment. *Biodiversity and Conservation*

Williams, W.J., Eldridge, D.J., 2011. Deposition of sand over a cyanobacterial soil crust increases nitrogen bioavailability in a semi-arid woodland. *Applied Soil Ecology*. 49, 26–31.

Williams, W.J., Eldridge, D.J., Alchin, B.M., 2008. Grazing and drought reduce cyanobacterial soil crusts in an Australian Acacia woodland. *Journal of Arid Environments*. 72, 1064–1075.

Appendix 1. Vegetation community descriptions of all sites

Vegetation	Site
Callitris intratropica woodland	S40, S45
Callitrix achaeta Astromyrtus symphocarpus Melaleuca viridiflora scrubland	S28
Corymbia bella	S10
Corymbia bella Erythrophleum chlorostachys grassy woodland	S60, S13
Corymbia bella Erythrophleum chlorostachys weedy with *Hyptis suaveolens*	S17
Corymbia bella Eucalyptus tetradonta Eucalyptus tectifica Erythrophleum chlorostachys grassy woodland	S28
Corymbia bella grassland	S8
Corymbia bella shrubby/grassy woodland	S14, S15
*Corymbia grandiflora Corymbia dichromophloia Petalostigma pubescens Terminalia canescen*s grassy woodland	S38
Corymbia grandiflora Eucalyptus tectifica Erythrophleum chlorostachys Petalostigma pubescens grassy woodland	S42
Corymbia grandiflora Eucalyptus tectifica grassy woodland	S21
Corymbia greeniana Erythrophleum chlorostachys woodland burnt/unburnt samples	S59
Corymbia terminalis Erythrophleum chlorostachys Eucalyptus tetradonta Melaleuca viridiflora grassy woodland	S32
Corymbia terminalis Erythrophleum chlorostachys grassy woodland	S27
Corymbia terminalis Erythrophleum chlorostachys grassy woodland. Cycad Creek	S33
Disturbed regrowth. *Acacia* sp. *Erythrophleum chlorostachys Alphitonia excelsa*	S25
Acacia holosericea Astromyrtus symphocarpus Ludwigia octovalvis Alphitonia excelsa drainage line	S24
Melaleuca viridiflora Alphitonia excelsa drainage line	S20
Eucalyptus pruinosa Erythrophleum chlorostachys Eucalyptus tectifica woodland	S41
Eucalyptus tectifica Corymbia bella Erythrophleum chlorostachys grassy woodland	S48
Eucalyptus tectifica Erythrophleum chlorostachys Petalostigma pubescens grassy woodland	S39
Eucalyptus tetradonta (stunted) *Triodia bitextura* stony woodland burnt side of track	S55
Eucalyptus tetradonta Corymbia bella Erythrophleum chlorostachys grassy woodland	S23
Eucalyptus tetradonta Corymbia ferruginea shrubby/grassy woodland burnt/unburnt samples	S57
Eucalyptus tetradonta Erythrophleum chlorostachys Corymbia terminalis grassy woodland	S23
Eucalyptus tetradonta Erythrophleum chlorostachys grassy woodland	S30, S31, S11, S12, S19
Eucalyptus tetradonta Erythrophleum chlorostachys Triodia bitextura spinifex/grassy woodland	S26
Eucalyptus tetradonta Eucalyptus miniata grassy woodland	S61, S63
Eucalyptus tetradonta Eucalyptus tectifica Corymbia bella dry grassy woodland	S22
Eucalyptus tetradonta heath/shrubland	S51, S52
Eucalyptus tetradonta post fire regeneration ~2yr	S18
Eucalyptus tetradonta Terminalia canescens Triodia bitextura spinifex/grassy woodland	S56
Eucalyptus tetradonta Corymbia terminalis grassy woodland with scattered *Pandanus*	S9
Grevillea pteridifolia Acacia sp. dense shrubland	S44, S47
Foredune helicopter sample	S4
Melaleuca viridiflora grassy low woodland	S46, S36
Melaleuca viridiflora Petalostigma pubescens Melaleuca nervosa grassland	S37
Sarcornia salt flats against mangroves	S1C
Sarcornia salt flats against mangroves. Sand couch	S2B
Sedgeland beside Cycad Creek	S34
Triodia bitextura Acacia sp exposed rock platform	S53
Upper Calvert crossing grassy floodplain	S49

Index of scientific names