



Department of Biodiversity,
Conservation and Attractions



Biodiversity and
Conservation Science

Biodiversity and Conservation Science

Annual Research Report **2018-2019**



Acknowledgements

This report was prepared by the Department of Biodiversity, Conservation and Attractions (DBCA).

For more information contact:

Executive Director, Biodiversity and Conservation Science
Department of Biodiversity, Conservation and Attractions
17 Dick Perry Avenue
Kensington
Western Australia 6151

Locked Bag 104
Bentley Delivery Centre
Western Australia 6983

Telephone (08) 9219 9943

dbca.wa.gov.au

The recommended reference for this publication is:

Department of Biodiversity, Conservation and Attractions, 2019,
Biodiversity and Conservation Science Annual Research Report 2018-19,
Department of Biodiversity, Conservation and Attractions, Perth.

Images

Front cover main photo: Kalbarri National Park. *Photo – Judy Dunlop/DBCA*

Front cover top photos left to right:

Matuwa (Lorna Glen). *Photo – Judy Dunlop/DBCA*

Albino quoll. *Photo – Judy Dunlop/DBCA*

Caulerpa flexilis. *Photo – John Huisman/DBCA*

Rangers at Eighty Mile Beach. *Photo – Sabrina Fossette-Halot*

Back cover top photos left to right:

Eil Eil Springs. *Photo – Adrienne Markey/DBCA*

Matuwa (Lorna Glen). *Photo – Paul Rampant/DBCA*

Badjaling Nature Reserve. *Photo – Jill Pryde/DBCA*

Rufous hare-wallaby. *Photo – Saul Cowen/DBCA*

Department of
Biodiversity, Conservation and Attractions
Biodiversity and Conservation Science
Annual Research Report
2018–2019



Department of **Biodiversity,
Conservation and Attractions**



**Biodiversity and
Conservation Science**

Director's Message

I am pleased to present our research report for 2018-19 as we continue to deliver on the government's commitment to building and sharing biodiversity knowledge for Western Australia. The Chief Scientist, Professor Peter Klinken, launched our *Science Strategic Plan 2018-21* for the department in August 2018 and since then we have developed science plans for each of our 10 programs. These plans articulate how the work of each program contributes to delivery of the themes identified in the strategic plan. The science undertaken through the programs delivers against the biodiversity science priorities for the State and is essential to ensure we conserve and appreciate the unique biodiversity we have around us.

In conjunction with our strategic planning we are continuing the renewal of our capability to provide innovative science that informs current and future conservation initiatives. The strength of Biodiversity and Conservation Science resides in our people, and in the past year we welcomed new staff with expertise in forest science, structured decision-making, plant ecology and ecoinformatics.

We have continued to deliver effective science to support the department's functions. Highlights of our scientific research for this year include confirmation of eradication of feral cats from Dirk Hartog Island, development of a conceptual model of the hydrology of freshwater springs at Walyarta (80 Mile Beach Ramsar site), production of 900 seedlings of the spider orchid *Caladenia busselliana* for a translocation of this rare species, monitored the outbreak of the harmful algae *Alexandrium* spp. and determined toxin uptake in fish, crabs and mussels, development of spinifex cover measures from satellite imagery to inform prescribed burning activities, and analysis of data from a 30 year experimental study to understand how understorey plants in the jarrah forest respond to different combinations of fire interval and season. We have published the final report of the WAMSI Kimberley Marine Research Program, and published a book describing the red algae of Western Australia's tropical coast. We also celebrated 50 years of forest research at the Manjimup Research Centre. Our staff in Species and Communities Program made important contributions to the Biodiversity Conservation Regulations gazetted in January 2019 to give effect to the *Biodiversity Conservation Act 2016*. We are working with regional staff and members of the community to implement new provisions supporting conservation of our plants, animals and ecosystems.

As we consolidate after the major change of the past year, I am confident we will continue to deliver excellent science and remain active in pursuing opportunities and seeking innovative ways to underpin effective biodiversity conservation in Western Australia. We have continued to communicate our scientific outputs and outcomes to a diverse range of audiences through a variety of avenues, including scientific papers, technical and popular articles, social media, conference talks, seminars and other presentations.

Much of our work is undertaken in partnership with conservation staff in the Parks and Wildlife Service, and at Kings Park and Botanic Garden, Perth Zoo and the Rottnest Island Authority. We also engage with a wide range of external partners at universities, CSIRO, NGOs, WABSI, WAMSI and the NESP Threatened Species Recovery and Northern Australia Environmental Resources hubs. We have a large number of active science partnerships and our scientists are involved in co-supervision of many Honours, Masters and PhD students.

I look forward to continuing to work effectively with all our partners to deliver excellent science that informs conservation and management of our diverse and inspiring plants, animals and ecosystems, and supports effective management of our parks and reserves, delivery of our fire program and engagement of visitors with our natural attractions.

Dr Margaret Byrne
Executive Director
Biodiversity and Conservation Science
November 2019

Contents

Service Delivery Structure	1
Animal Science	3
Conservation of the night parrot	3
Understanding and reducing python predation of the endangered Gilbert's potoroo	4
South West Threatened Fauna Recovery Project: Southern Jarrah Forest	5
Dirk Hartog Island National Park Ecological Restoration Project – fauna reconstruction	6
Improved fauna recovery in the Pilbara – benefitting the endangered northern quoll through broad-scale feral cat baiting.	8
Cat eradication on Dirk Hartog Island	9
Monitoring of threatened birds on Dirk Hartog Island	10
Improving the use of remote cameras as a survey and monitoring tool	11
Decision support system for prioritising and implementing biosecurity on Western Australia's islands	13
Conservation and management of the bilby in the Pilbara	14
Genetic assessment for conservation of rare and threatened fauna	15
Genetic approaches for evaluating the contribution of the reserve system to fauna conservation	17
Barrow Island threatened and priority fauna species translocation program	18
Rangelands restoration: reintroduction of native mammals to Matuwa (Lorna Glen)	19
Feral cat control and numbat recovery in Dryandra Woodland and other sites	21
Conservation of south coast threatened birds	21
Ecology and management of the northern quoll in the Pilbara	23
Conservation of the graceful sun-moth	24
Impact of cane toads on biodiversity in the Kimberley	25
Development of effective broad-scale aerial baiting strategies for the control of feral cats	26
Gilbert's potoroo recovery plan	27
Plant Science and Herbarium	29
Molecular characterisation of stinking passionflower (<i>Passiflora foetida</i>)	29
Is restoration working? An ecological genetic assessment	30
Interactive key and taxonomic studies of Myrtaceae tribe Chamelaucieae	31
Strategic taxonomic studies in families including Amaranthaceae and Fabaceae (<i>Ptilotus</i> , <i>Gom- phrena</i> , <i>Swainsona</i>) and other plant groups	32
The Western Australian Plant Census and Australian Plant Census	33
The Western Australian Herbarium's specimen database	34
Herbarium collections management	35
Biodiversity informatics at the Western Australian Herbarium	36
Taxonomy of undescribed taxa in the Ericaceae subfamily Styphelioideae, with an emphasis on those of conservation concern	38
Resolving the systematics and taxonomy of <i>Tephrosia</i> in Western Australia	39
Taxonomy of selected families including legumes, grasses and lilies	40
Systematics of the triggerplant genus <i>Stylidium</i>	41
Taxonomic review and floristic studies of the benthic marine algae of north-western Australian and floristic surveys of Western Australian marine benthic algae	42
The Western Australian marine benthic algae online and an interactive key to the genera of Australian marine benthic algae	43
Taxonomic resolution and description of new plant species, particularly priority flora from those areas subject to mining in Western Australia	44
Genetic and ecological viability of plant populations in remnant vegetation	45

Translocation of critically endangered plants	46
Mating system variation, genetic diversity and viability of small fragmented populations of threatened flora, and other key plants of conservation importance	47
The population ecology of critically endangered flora	48
Seed biology, seedbank dynamics and collection and storage of seed of rare and threatened Western Australian taxa	49
Genetics and biosystematics for the conservation, circumscription and management of the Western Australian flora	50
Ecosystem Science	53
Investigating the causes of change in forest condition	53
Do hotter and drier regions harbour adaptive variation for climate change?	54
Hydrological function of critical ecosystems	56
Responses of aquatic invertebrate communities to changing hydrology and water quality in streams and significant wetlands of the south-west forests of Western Australia	57
South-west wetlands monitoring program	58
Advancing the hydrological understanding of key Wheatbelt catchments and wetlands to inform adaptive management	59
Taxonomy, zoogeography and conservation status of aquatic invertebrates	60
Understanding peat wetland resilience: evaluating the impact of climate and landuse change on the hydrodynamics and hydrogeochemistry of peat wetlands in the Warren (Muir-Byenup) District	61
Restoring natural riparian vegetation systems along the Warren and Donnelly Rivers	62
South-western Australia transitional transect	63
Responses of terrestrial vertebrates to timber harvesting in the jarrah forest	64
Western Australian flora surveys	65
Long-term stand dynamics of regrowth forest in relation to site productivity and climate	66
Management of invertebrate pests in forests of south-west Western Australia	67
Western Australian wetland fauna surveys	68
Protecting the safe havens: will granite outcrop environments serve as refuges for flora threatened by climate change?	69
Identification of seed collection zones for rehabilitation	70
FORESTCHECK: Integrated site-based monitoring of the effects of timber harvesting and silviculture in the jarrah forest	71
Hydrological response to timber harvesting and associated silviculture in the intermediate rainfall zone of the northern jarrah forest	72
Genetic analysis for the development of vegetation services and sustainable environmental management	73
Marine Science	74
Long-term monitoring in the area of the proposed Dampier Archipelago marine reserves	74
Habitat use, distribution and abundance of coastal dolphin species in the Pilbara	75
Distribution and abundance estimate of Australian snubfin dolphins at a key site in the Kimberley region, Western Australia	76
Improving the understanding of West Pilbara marine habitats and associated taxa: their connectivity and recovery potential following natural and human induced disturbance	78
The influence of macroalgal fields on coral reef fish	79
Understanding movements and identifying important habitats of sea turtles in Western Australia	80
Marine monitoring program	81
North West Shelf Flatback Turtle Conservation Program	82
WAMSI 2: Kimberley Marine Research Program	83
Effects of Gorgon project dredging on the marine biodiversity of the Montebello/Barrow Islands marine reserves	84
Spatial and temporal patterns in benthic invertebrate communities of the Walpole and Nornalup Inlets Marine Park	85
Interactive effects of fishing and climate change on coral reef fish populations	86
Spatial and temporal patterns in the structure of intertidal reef communities in the marine parks of south-western Australia	87

Fire Science	89
Evaluation of synergies among fire and weed management in urban biodiversity and fire management	89
Understanding the changing fire environment of south-west Western Australia	90
Long term response of jarrah forest understorey and tree health to fire regimes	91
North Kimberley Landscape Conservation Initiative: monitoring and evaluation	92
Fire regimes and impacts in transitional woodlands and shrublands	93
Burning for biodiversity: Walpole fine-grain mosaic burning trial	95
Kings Park Science	96
Seed science	96
Restoration science	97
Conservation genetics	99
Orchid conservation and recovery	100
Conservation biotechnology	101
Perth Zoo Science	103
Western ground parrot husbandry	103
Using dataloggers to determine the effects of handling and temperature on packages travelling along Australian postage routes used to illegally transport native fauna	104
Olfactory and auditory based behavioural enrichment for Perth Zoo's Asian elephants.	105
Memory of recent actions in large-brained mammals (<i>Elephas maximus</i>).	105
Behavioural observations of Perth Zoo collection animals for animal welfare purposes and establishment of baseline data	106
<i>Geocrinia</i> frog breed and rear for release program	107
Western swamp tortoise breed for release program	108
Dibbler breed for release program	109
Numbat breed for release program	110
Survival and dispersal of black cockatoos in south-west Western Australia	110
Rivers and Estuaries Science	112
Incident investigations and response	112
Seagrass monitoring and evaluation	113
Algal blooms: investigations and control	114
Alfred Cove eutrophication investigation: gaining insights to apparent eutrophication-related stress exhibited by seagrass in the Swan Estuary Alfred Cove Marine Park	115
Investigating fish communities as an indicator of estuarine condition	115
Assessment of multi-wavelength fluorometer technology for chlorophyll <i>a</i> and gross phytoplankton composition estimation	116
Explaining foreshore vegetation die-off	117
Application of FlowCAM® to biological monitoring in the Swan Canning Riverpark	118
Stock enhancement of western school prawn: evaluation recruitment limitation, environment and release strategies	119
Model frameworks for estuarine reporting	120
Dolphin health - toxicogenomics and pathology investigations	121
Remote Sensing and Spatial Analysis	123
Spatial data management	123
Remote sensing and spatial analysis for fire management	125
Spatial analysis and modelling	126
Remote sensing monitoring	127
Dirk Hartog Island vegetation monitoring	129
Species and Communities	130
Wetland conservation	130
Ecological communities conservation and recovery	131
Off-reserve conservation	133
Flora conservation and recovery	134
Fauna conservation and recovery	136
Ecoinformatics	139
BioSys – the Western Australian Biological Survey Database	139
Provision of authoritative names of Western Australian taxa	140

Online GIS biodiversity mapping (<i>NatureMap</i>)	141
External Partnerships	143
Student Projects	152
Student Project Reports	159
Ecology of the feral cat in coastal heaths of the south coast of Western Australia	159
Assessing the effect of cryopreservation on mitochondrial function in plant shoot tips	159
How does seed maturity affect cell membrane composition and cryotolerance / cryosensitivity? A biochemical and biophysical study	160
Orthodox but non-conformist: the perplexing problem of cryopreserving short-lived native orchid seeds	160
Oxidative damage to cell membranes during cryopreservation	161
Responses of southern boobooks to threatening processes across urban, agricultural and woodland ecosystems	161
Ecology and conservation biology of the night parrot	161
Molecular and morphometric analysis of two disputed subspecies, <i>Banksia seminuda</i> subsp. <i>remanens</i> and <i>Banksia occidentalis</i> subsp. <i>formosa</i>	162
Adaptive and phylogeographic variation in sympatric parasitic and non-parasitic species in Western Australia	162
<i>Reedia spathacea</i> F. Muell.: a study of phylogeography, population structure and co-occurrence	163
<i>Conospermum undulatum</i> : insights into genetics and ecology of an endangered species	163
Vegetation responses to Noongar land management practices in old and young landscapes	164
Mating systems, reproductive output and progeny fitness of translocated plant populations compared to wild populations	165
Factors affecting the success of threatened flora translocations	165
Phytoplankton in a microtidal temperate estuary: drivers, historical trends and future predictions	166
Phylogeny, systematics and evolution of the Australian arid-zone <i>Ptilopus</i>	166
Thermal, physical and prey requirements for northern quoll denning habitat	166
The influence of invasive predators and fire regimes on northern quolls in the Pilbara	167
Predicting the vulnerability of flatback turtle rookeries to a changing climate	167
Foraging ecology and energetics of green turtles in the Ningaloo coast world heritage area	168
A cost benefit analysis for the collection of reef fish density data with a micro remote operated vehicle versus SCUBA divers.	168
Integrated study of shallow and deep-sea fish communities status and their main stressors in a highly dynamic Galapagos seascape	169
A comparison of stereo-BRUV, diver operated and remote stereo-video transects for assessing reef fish assemblage	169
Cyclone impact or natural variation? Assessment of damage on coral and fish in Kubulau District, Fiji by cyclone Winston	170
Conservation of elasmobranchs - ecology, public perception, and legal protections	170
Persistence of tropical herbivorous fish in temperate ecosystems and its impact on habitat-forming macrophytes	171
Conservation genetics of the critically endangered <i>Styphelia longissima</i>	171
Optimising seed sourcing for effective ecological restoration	171
A genecological assessment of seed sourcing strategies for plant community restoration under environmental change.	172
Novel consequences of bird pollination in the kangaroo paw <i>Anigozanthos manglesii</i>	172
Evolution and conservation consequences of bird pollination: an ecological and genetic study of mating, pollen dispersal and recruitment in <i>Eucalyptus caesia</i>	173
Resource competition between co-existing threatened mammals in a predator-free enclosure in central Western Australia	173
Reintroduced digging mammals and ecosystem restoration	174
Optimising collaboration between secondary schools and informal science advisers: a stakeholder alignment perspective.	174
The effect of diet on the growth and reproduction of western swamp tortoise at Perth Zoo	174
Optimising energy provision at Perth Zoo via a renewable energy micro-grid.	175
Social dynamics in a tufted capuchin group following the introduction of a novel male	176

Evaluation of the welfare and reproductive biology of captive tigers using non-invasive conservation physiology techniques	176
Monitoring the behaviour of ghost bats before, during and after the reproductive season	177
Hindlimb paralysis syndrome in Carnaby's cockatoos	177
The effect of incubation temperature on development rates of <i>Geocrinia alba</i> and <i>G. vitellina</i> frog embryos	178
Epidemiology of the clinical syndrome 'lumpy jaw' in captive macropods: influence of housing and husbandry	178
Disease risk analysis in support of the translocation of dibblers from the Jurien Bay Islands to Dirk Hartog Island National Park	179
The prevalence of arenavirus, bornavirus, nidovirus/coronavirus, sunshinevirus and ferlavivirus in captive and wild populations of Stimson pythons, pygmy pythons and carpet pythons . .	179
Predicting effects of climate change and thinning on growth, health and water yield of jarrah and karri stands using individual-based modelling	180
The impacts of severe wildfire on the interactions among regenerating vegetation, fungi and small foraging marsupials in south-west Australia	180
The use of soil amendments and alternative soil substrates to increase soil function and seedling recruitment in post-mining arid landscapes	181
Design and testing of novel seed processing equipment and methods to improve seed-based restoration	181
Native seeding mechanisation to facilitate efficient large-scale restoration of degraded lands . .	182
Ecologically tolerable fire regimes for key <i>Banksia</i> woodland plant species	182
Fire intensity, seasonal variation and seeds traits may influence seed fates in <i>Banksia</i> woodlands	183
The assessment of ecosystem risk in <i>Banksia</i> woodlands of the Swan Coastal Plain, Western Australia	183
Population genomics of the burrowing bettong at Matuwa: a case study on the implications of genetic mixing	184
Ecological responses of the northern quoll to a large-scale feral cat baiting program in the western Pilbara region, Western Australia	184
The impact of a drying climate on the alpha, beta and gamma biodiversity of freshwater macroinvertebrates in wetlands in a salinised landscape	185
Taxonomy of the salt lake gastropod, <i>Coxiella</i> : how useful are empty shells as a source of taxonomic information?	185
Aquatic invertebrate food resources in western swamp tortoise translocation sites	186
Influence of fire history and seed distribution on the movements of granivorous finches in the East Kimberley	186
Is there a housing crisis in tropical savannas? Changing fire regimes, hollows and declining arboreal mammals	187
Evolution of C ₄ photosynthesis in the genus <i>Tecticornia</i> at the anatomical and molecular levels .	187
Restoring highly degraded <i>Banksia</i> woodlands through innovative seed enhancement technology	188
The influence of drought on plant morphology, physiology and establishment in the post iron ore mining environments of semi-arid Western Australia	188
Near-surface remote sensing of plant condition in mine site restoration environments	189
Soil-microbial-plant signals and effects on plant eco-physiological performance for mine site restoration	189
Implications for wind management in restoration ecology, linking ecosystem aerodynamics to physiological drivers in arid and semi-arid systems	190
How do species interactions drive community assembly of <i>Banksia</i> woodlands?	190
Identification of controls on the metabolism of the Swan-Canning Estuary using numerical modelling and high-frequency data	191
Evaluating the population genetics, recruitment limitations and release strategies of western school prawns during a restocking program in the Swan-Canning Estuary	191
Investigating habitat values of seagrass, macroalgae and wrack in the Swan Canning Riverpark	191
Modelling species interactions and other environmental factors in the Upper Warren	192
The population and spatial ecology of the numbat in the Upper Warren	192
Survey methods and ecology of the numbat population at the Upper Warren region	193
Evidence based management of foxes adjacent to turtle beaches in Western Australia	193

Understanding the early offshore movement of flatback turtle hatchlings and the effects of anthropogenic light	193
The health status of marine turtles in northern and western Australia	194
Habitat quality as a driver of epinepheline serranid productivity and replenishment	194
How does environmental disturbance effect macroalgal assemblages at Ningaloo	195
The effect of patch habitat networks in shaping the distribution, abundance and diversity of coastal fishes	195
Publications and Reports	196
Summary of Research Projects	210



Service Delivery Structure

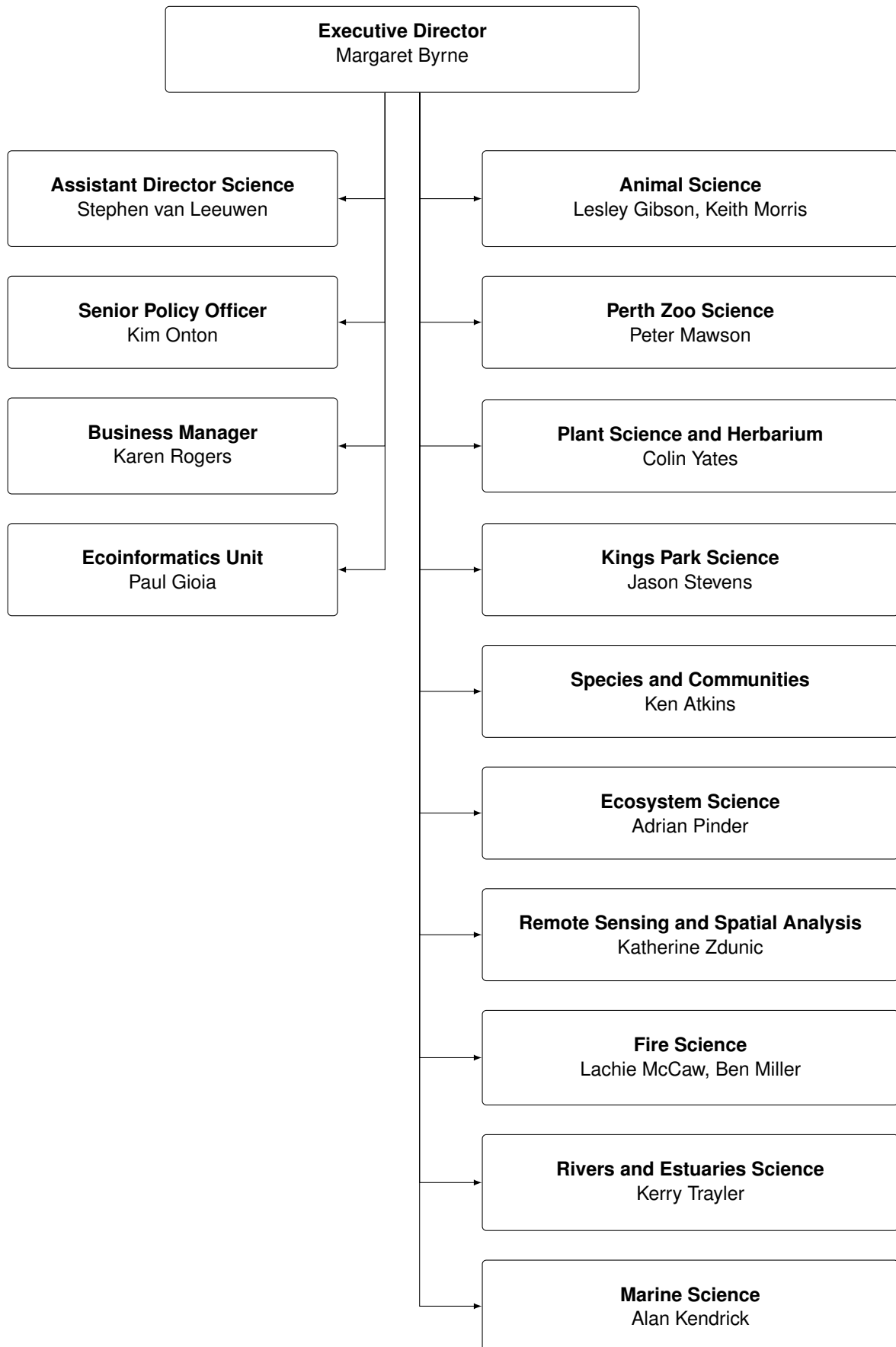
Science in the Department of Biodiversity, Conservation and Attractions is undertaken in accordance with the departmental Science Policy, where science refers to scientific research, scientific monitoring and science communication undertaken in relation to the biological, physical and social environments.

Biodiversity and Conservation Science coordinates and delivers science in the Department of Biodiversity, Conservation and Attractions, providing science and biodiversity knowledge to support the functions of the Parks and Wildlife Service, Botanic Gardens and Parks Authority, Zoological Parks Authority and Rottnest Island Authority.

Biodiversity and Conservation Science is structured into programs focused on key themes for the delivery of targeted science to support evidence-based decision making and the conservation and land management functions of the department. Science and research is undertaken using both Western Australian Government and external funding sources.

Biodiversity and Conservation Science operates from a range of locations including Kensington, Kings Park, Perth Zoo, Woodvale, Manjimup, Bunbury, Busselton, Kununurra, and Albany, and includes the Western Australian Herbarium.

Biodiversity and Conservation Science staff have expertise in animal biology, animal breeding, aquatic ecology, biological survey, collections management, conservation biotechnology, conservation genetics, conservation medicine, conservation policy, ecology, ecological restoration, ecoinformatics, ecophysiology, fire behaviour, hydrology, marine biology, plant biology, remote sensing and spatial analysis, seed biology, systematics and taxonomy.





Animal Science

Program Leader: Lesley Gibson Applied research undertaken by the Animal Science Program seeks to understand the factors and processes that are critical for the conservation of Western Australia's rich and unique native fauna. The major objectives of the program are to ensure the persistence of threatened species through local and landscape-scale management actions, including reducing key threats such as predation by foxes and feral cats, inappropriate fire regimes, competition and predation by introduced rodents on islands, as well as assessing cane toad impacts and reconstructing the fauna of rangeland and arid areas.



Conservation of the night parrot

SP 2017-036

A Burbidge, N Hamilton

Context

The critically endangered night parrot has been confirmed breeding in only two locations - one in Queensland and one in Western Australia. The night parrot has not been adequately surveyed across much of its potential habitat, and a lack of knowledge of foraging and roosting habits has hampered progress in understanding the ecology of the species. This constrains possible recovery actions and management relating to resource development proposals. Identifying the conservation requirements of the night parrot is essential for informed management of this poorly known species.

Aims

- Assess the spatial extent of the population in Matuwa/Lorna Glen and surrounding areas, and subsequently the entire Lake Carnegie catchment.
- Determine where the birds are foraging by identifying vegetation types they are using and the spatial relationship between roosting and foraging habitat.
- Determine differences in the vegetation at occupied versus non-occupied roost sites and foraging sites to inform predictive models.
- Engage with Traditional Owners to encourage survey for night parrots and sensitive management for the species.

Progress

- A small number of audio recording units have been deployed in known or suspected night parrot habitat in the east Murchison to detect calls.
- A paper documenting all known calls of night parrots across Australia, including some calls known only from WA, was published in *Australian Field Ornithology*.

Management implications

- Documentation of known night parrot calls will improve survey and monitoring for the species and facilitate a better understanding of their distribution and conservation status.
- Information on distribution will guide conservation management and assessments of the impacts of resource developments on the species.

Future directions

- Deploy autonomous recording units to better understand the area of occupancy and extent of occurrence of night parrots in the Lake Carnegie catchment.



Understanding and reducing python predation of the endangered Gilbert's potoroo

SP 2017-001

D Pearson, A Friend, T Button, S Hill

Context

Carpet pythons are predators of a range of threatened mammal fauna, including the endangered Gilbert's potoroo (*Potorous gilberti*). Python predation can reduce adult survival and curtail recruitment. Current 'predator proof' fences, while effective at reducing or eliminating predation by foxes and feral cats, are likely to have little or no effect on levels of python predation.

Python predation has been identified as a significant threat to the Gilbert's potoroo population in the Waychinicup National Park enclosure. In a review of options following the 2015 fire that impacted the only known wild population at Two Peoples Bay, it was considered that management intervention is required to reduce python predation of potoroos within the enclosure. It appears that python predation is limiting population growth and hence the production of individuals for translocation.

Aims

- To determine the most effective ways to locate and remove carpet pythons from within and around Gilbert's potoroo populations and so reduce the current level of predation of this critically endangered mammal.

Progress

- Active searching by day and night for pythons resulted in few captures.
- Intensive radio-tracking during the November breeding season was successful in locating more pythons with a total of 11 captured in November 2018 (eight males and three females). All were fitted with transmitters.
- A total of five large females were relocated from the potoroo enclosure to distant sites in the national park to reduce predation of potoroos.
- A trial of shelter box traps was completed. No pythons were detected using them.

Management implications

- A reduction in the abundance of carpet pythons in and around the Waychinicup enclosure should reduce the incidence of potoroo predation and allow potoroo population growth.
- The best means to locate and remove pythons is to radio-track male pythons to locate reproductive females each November. Probably about a third of adult female pythons breed each year and since the existing fence is not a barrier to python movement, annual removal of pythons is likely to be required.
- The results of the study could have application for controlling python predation of other threatened species.

Future directions

- If a suitable heat pad can be developed, shelter box traps may aid in helping capture pythons in the cooler months.
- Results of the radio-telemetry and the relocation of female pythons will be written up for publication.
- Male pythons are assumed to not be serious predators of potoroos on account of their small size; however, some dietary analysis is needed to establish if they are indeed predators of potoroos or similarly-sized mammals.



South West Threatened Fauna Recovery Project: Southern Jarrah Forest

SP 2016-068

A Wayne, M Maxwell, C Ward

Context

The primary goal of the South West Threatened Fauna Recovery Project (SWTFRP) is to contribute to the recovery of key threatened mammal and bird species at four key sites in south-western Western Australia, through integrating feral cat baiting with existing introduced predator control programs, undertaking monitoring of threatened species and translocations to supplement and establish new, secure populations where necessary. The key sites selected were South Coast reserves, Upper Warren reserves, Dryandra Woodland and Kalbarri National Park.

This project is a component of the SWTFRP, focussing on the southern jarrah forest, which is an important area for the conservation of several mammal and bird species threatened by introduced predators. To date there has been no effective cat control within the southern jarrah forest, including the priority conservation areas within the Upper Warren region. *Eradicat*[®] presents an opportunity for developing an important tool within an effective cat control program that is essential to the long-term conservation of imperilled fauna threatened by introduced predators.

Aims

- To recover wild populations of western ringtail possums, woylies and numbats in the Upper Warren area, through developing effective integration of feral cat control with existing fox control in the southern jarrah forest.
- Identification of the efficacy of *Eradicat*[®] baiting according to current operational delivery methods (aerial and ground) and time of year.
- Quantification of the risk to potentially vulnerable non-target native mammals in the southern jarrah forest to operational use of *Eradicat*[®].
- Improve live capture of feral cats in the southern jarrah forest by minimising non-target captures.
- Engaging effectively with neighbours about the control of introduced predators and the recovery of native species.

Progress

- Stage 1 of the *Eradicat*[®] bait uptake trials ran over 65 weeks, deployed 5,666 baits at 40 sites, and involved 54,361 camera trap nights, which resulted in 1.2 million images of fauna within the proximity of, or interacting with *Eradicat*[®] baits.

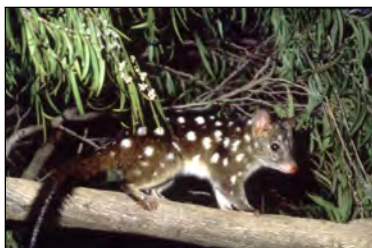
- Despite cat and fox occupancy in the southern jarrah forest being high (92% and 84%, respectively), encounter rates were modest (100 and 154 independent events, respectively) and bait consumption rates were low for both introduced predators. A high level of bait interference and removal by non-target fauna resulted in baits still being present on less than half of the occasions when a cat or fox visited a bait location. When a bait was available, cats and foxes consumed or removed the bait on at least 9% and 20% of occasions, respectively.
- The probability of detecting a cat or fox was substantially greater on ground transects than aerial deployment sites. Encounter rates of cats were greater closer to forest tracks and hydrographic features, while encounter rates of foxes were higher closer to private property and tracks, with more baits consumed by foxes closer to private property.
- Stage 2 investigated whether *Eradicat*[®] baiting effectiveness could be improved by targeting areas immediately after planned prescribed burning. Four burned and three reference sites were used (involving 1,649 baits along ground transects and 15,032 camera trap nights). There were no significant differences in encounter rates or bait removals by cats or foxes immediately after autumn burns compared with reference sites.
- Stage 3 (nine sites, 449 baits, 9800 camera trap nights) demonstrated that cat and fox encounter rates and baiting opportunities can be substantially improved having the cameras/baits on forest tracks compared with 5-20 m off track. There were no bait removals by cats, and foxes removed 19 baits, all of which were on track.
- The risks to potentially vulnerable non-target native species (chuditch and phascogale) is generally low but is being investigated further, focusing on the effects of deployment method and timing.
- Cat trapping trials using leg-hold traps with a refined elevated platform successfully reduced non-target interference but also resulted in low capture rates of cats and foxes.
- GPS-tracking of feral cats is increasing our understanding of their spatial ecology and movement patterns.
- The remote sensor camera data for this study was used to quantify the distribution, occupancy and activity of introduced and native mammal species across the southern jarrah forest, with over 1.6 million fauna images captured (69,393 camera trap nights).
- Over 40 volunteers contributed >4,000 hours (476 days) to the project.

Management implications

- Controlling feral cats in the southern jarrah forest has been shown to be challenging. The effectiveness of *Eradicat*[®] baiting using existing protocols has been demonstrated and provides clear direction on how further improvements can be made.
- The *Eradicat*[®] baits have been shown to be effective at controlling foxes, and a low risk to vulnerable species, such that they provide an additional method to complement existing methods.
- Improvements to live trapping of feral cats that vastly reduces the risks to non-target native species have been made.
- Improved understanding of cat spatial ecology through GPS-tracking will directly inform improvements in the effectiveness of future cat control efforts.

Future directions

- Complete bait uptake trial data analysis and manuscripts for publication, including bait longevity, non-target removal, cat and fox bait interaction.
- Build on the pilot spatial ecology trial to improve knowledge on the home range, fecundity and behaviour of cats in the forest to assist control methods.



Dirk Hartog Island National Park Ecological Restoration Project – fauna reconstruction

SP 2016-030

S Cowen, C Sims, K Morris, K Ottewell, S Garretson, J Angus, K Rayner, L Gibson, M Page, A Burbidge

Context

The Dirk Hartog Island National Park Ecological Restoration Project (DHINPERP) aims to restore the ecological condition of Western Australia's largest island to that seen by Dirk Hartog when he landed on the island in 1616. The establishment of populations of 12 mammal species and one bird species on Dirk Hartog Island (DHI) over a 12 year period is a key part of this project. Of these species, four are listed as Endangered and six as Vulnerable under the national *Environment Protection and Biodiversity Conservation Act 1999*, and their successful re-establishment will contribute towards improving the conservation status of these species. The translocation of 13 native species to an island 633 square km in area, makes it the largest fauna reconstruction project in Australia and one of the largest in the world. To allow this to proceed, sheep, feral goats and feral cats have been removed and the eradication of feral cats represents the largest eradication program achieved globally. Genetic information on source populations has been and will be used to inform founder selection and genetic monitoring of released animals will inform ongoing management practices.

Aims

- Identify the most suitable source populations to act as founders for new populations on DHI, using the criteria set out in the *Dirk Hartog Island National Park Ecological Restoration Strategic Plan*.
- Establish new populations of 12 mammal species and one birds species on DHI, using the species selection criteria set out in the Strategic Plan.
- Confirm that the translocations are successful and that all new populations on DHI are healthy and self-sustaining, using criteria set out in the Strategic Plan and approved Translocation Proposals.
- Promote scientific research associated with the translocations, monitoring and establishment of fauna, and publish scientific findings.

Progress

- The first full-scale translocation of banded and rufous hare-wallabies was successfully implemented with 90 and 50 individuals of each species released respectively. Animals were transferred by helicopter rather than boat, reducing transit time by 90% (30 mins compared with 5 hours). There were no known mortalities of adult hare-wallabies, although a rufous hare-wallaby pouch young died after being abandoned after release.
- Survivorship and movement were determined using VHF-transmitters collars fitted to nine individuals of each species and home-range size assessed as well for an additional three GPS-collared individuals of each species.
- When hare-wallabies were examined when trapped or having radio-collars removed, there was evidence of breeding (11 pouch young, lactating teats) and most individuals maintained the condition they were in when released on DHI. Some post-capture weight loss was observed but it was much lower than in 2017.
- A trial to assess the rate of degradation of DNA on banded hare-wallaby faecal pellets was undertaken in collaboration with Australian Wildlife Conservancy at Mt Gibson and Faure Island. Results suggest that faecal DNA represents a sound method of monitoring populations for this species (and rufous hare-wallaby) and a trial survey will be run to develop a robust monitoring methodology.
- A population genomic survey of mainland, island and translocated populations of rufous hare-wallaby was undertaken to assess genetic diversity, inbreeding and genetic divergence of Shark Bay island populations. Analysis showed the Shark Bay island populations are divergent to the mainland and have lower diversity. Bernier and Dorre Island populations are differentiated but mixing source populations is expected to exhibit an increase in genetic diversity.
- Thirteen duffers were taken from Whitlock (8) and Escape (5) Islands in Jurien Bay in November 2018 and transferred into a captive breeding program at Perth Zoo. Two of these duffers died and a further five animals were captured in January and February 2019.
- Nine 40 x 40m enclosure fences were erected for monitoring the restoration of ecosystem processes as a result of the fauna reintroductions. These will be monitored for the duration of the project using remote sensing and regular soil and vegetation surveys.
- A population genomic survey was undertaken of boodie populations from Shark Bay and Barrow islands and indicated significant differentiation between all three islands. Mixing Bernier and Dorre island founders for DHI is expected to increase genetic diversity.
- Genomic analysis of duffers and banded hare-wallabies commenced. Samples have been submitted for duffer and collation is underway for banded hare-wallabies.

- Population genetics of the Shark Bay mouse was commenced, using samples from Bernier, Northwest and Faure islands in collaboration with Australian Wildlife Conservancy. DNA extractions have been completed and samples have been sent for genomic analysis.
- Preliminary population viability models of banded hare-wallabies, Shark Bay bandicoots and dibblers developed in collaboration with The University of Western Australia and University of Sydney have been completed.
- The monitoring of small vertebrates on DHI was undertaken in conjunction with the Global Gypsies.
- A Wildlife Population Health residency has been established with Murdoch University and the resident will commence in July 2019.

Management implications

- Establishing large and viable populations of banded and rufous hare-wallabies (and the other species) on DHI will significantly reduce their risk of extinction and may lead to an improvement in conservation status for several threatened species.
- Hare-wallabies (and the other translocated species) undoubtedly play a role in maintaining and improving ecosystem function, through grazing, browsing and endozoochory. There may be potential for the browsers and grazers that are established on DHI to control some of the weed species on the island.
- The presence of medium-sized mammals on DHI will ultimately lead to increased likelihood of interactions with the general public, especially with vehicles. Signs encouraging road users to drive slowly during hours of darkness were erected in 2018. However, the first road-kill rufous hare-wallaby was picked up in May 2019 north of the signed area, indicating more signs and better public information may be required to avoid these interactions.

Future directions

- Translocations of Shark Bay bandicoots and dibblers are planned for spring 2019, as well as a potential supplementation of rufous hare-wallabies.
- Monitoring of hare-wallabies will incorporate radio-tracking (including the use of drones) and cameras as well as other techniques that will continue to be trialled to refine an effective monitoring protocol for these species (e.g. faecal DNA).
- Planning has commenced for the order of future translocations to DHI with the development of a structured decision-making approach.
- Population genomic analyses on dibblers, boodies, banded hare-wallabies and Shark Bay mouse will be progressed. Novel microsatellite markers for faecal DNA analysis will be developed and validated for rufous hare-wallaby.
- Population viability models of banded hare-wallabies, Shark Bay bandicoots and dibblers developed in collaboration with The University of Western Australia and University of Sydney will be finalised.



Improved fauna recovery in the Pilbara – benefitting the endangered northern quoll through broad-scale feral cat baiting.

SP 2015-016

R Palmer, H Anderson, B Richards, N Birch

Context

The northern quoll (*Dasyurus hallucatus*) is one of a suite of terrestrial mammal species that has declined in the Pilbara over the last 100 years. Predation by feral cats is a key threat to this endangered species. The development of the *Eradicat*[®] feral cat bait has provided the opportunity to control this invasive predator at a landscape scale in the southwest of Western Australia but questions remain as to the potential risks of broad-scale feral cat baiting programs on northern quolls and other native carnivores in the Pilbara. A trial baiting program undertaken on the Yarraloola pastoral lease in 2015 demonstrated that the *Eradicat*[®] bait presents no detectable risk to northern quolls. Based on this evidence, annual winter baiting of feral cats with *Eradicat*[®] over

145,000 ha of Yarraloola will occur from 2016 to 2019. Monitoring programs will measure its success in reducing cat numbers and the response by northern quolls.

Aims

- Conduct a broad-scale aerial baiting program using *Eradicat*® to target feral cats on Yarraloola.
- Assess the effectiveness of broad-scale aerial baiting program using *Eradicat*® to target feral cats on Yarraloola.
- Assess the potential benefits of broad-scale cat baiting on northern quoll populations by comparing their abundance and demographics over time within the baited Yarraloola site with the neighbouring unbaited reference site on Red Hill pastoral lease.

Progress

- Sixty camera trap sites were deployed on both Yarraloola (baited) and Red Hill (reference site) for 25 nights, both before and after baiting in July 2018, to monitor changes in feral cat occupancy.
- A strong recovery in the cat population was detected.
- Aerial baiting using *Eradicat*® baits was undertaken over 141,594 ha on Yarraloola in July 2018.
- Cat detection rates declined from 1.7 (pre-bait) to 0.6 (post-bait) cats per 100 camera trap nights.
- Northern quoll populations were monitored at 18 trapping sites at both Yarraloola and Red Hill in September 2018. Capture rates of both male and female quolls continued to be higher in the cat-baited cell.
- GPS Radio-telemetry data were collected from 16 cats, providing considerable insight into their movement behaviour and habitat use.
- Increased detections of quolls on camera trap arrays used for cat monitoring indicate an ongoing expansion of their habitat occupancy in response to cat control on Yarraloola. The presence of high value rodent prey has also continued to increase in the diet of quolls from inside the bait cell. Both observations are consistent with the mesopredator release hypothesis.

Management implications

- There is no evidence that *Eradicat*® baiting has any harmful impact to northern quolls. The evidence suggests that quolls benefit both directly and indirectly from landscape level control of feral cats and that using aerial baiting is possible in other parts of the Pilbara where quolls occur.

Future directions

- Publication of the project outcomes.
- Provide recommendations regarding the registration of *Eradicat*® feral cat baits for operational use in areas where northern quolls are present.



Cat eradication on Dirk Hartog Island

SP 2014-003

D Algar, G Desmond, J Fletcher, N Hamilton, M Johnston, M Onus, C Tiller

Context

On Dirk Hartog Island (DHI), the largest island off the Western Australian coast, 10 of the 13 species of native terrestrial mammals once present are now locally extinct most likely due to predation by cats. The island was established as a national park in November 2009, which now provides the opportunity to reconstruct the native mammal fauna. DHI could potentially support one of the most diverse mammal assemblages in Australia and contribute significantly to the long-term conservation of several threatened species. Eradication of feral cats would be a necessary precursor to any mammal reintroductions.

Aims

- Facilitate native fauna reintroductions to DHI through researching feral cat behaviour and susceptibility to baiting programs.
- Implementing a cat eradication program.
- Developing effective cat monitoring protocols that will allow success of eradication programs to be assessed.

Progress

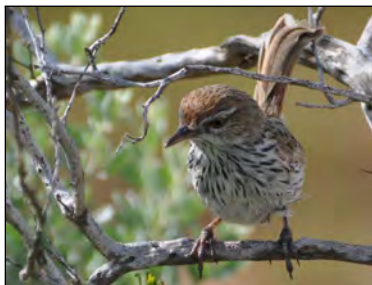
- Surveillance and monitoring on the island were completed in September 2018. No feral cats were detected.
- Feral cats were declared eradicated in October 2018, with an independent evaluation of the process and methodology used to undertake cat detection and eradication corroborated by the organisation Island Conservation. The estimated likelihood that feral cats have been successfully eradicated from the island is given as 99.99%.
- A manuscript, detailing the feral cat eradication program, has been written and submitted for publication.

Management implications

- Eradication of cats will enable fauna reconstruction on DHI.
- Cat eradication will also assist the conservation of the extant fauna, including three threatened bird species.
- Globally, the Dirk Hartog project is the largest successful island feral cat eradication campaign attempted to date. There is global interest in the outcomes of this project and the techniques used.
- Transfer of the knowledge gained and technology, will have significant benefits for the successful control and/or eradication of cats on lands managed by the department and other agencies both nationally and internationally.

Future directions

This project is now completed.



Monitoring of threatened birds on Dirk Hartog Island

SP 2013-021

A Burbidge

Context

This project was designed to develop and implement a monitoring program for the three extant threatened bird species on Dirk Hartog Island (DHI): DHI southern emu-wren, DHI rufous field-wren, and DHI white-winged fairy-wren. This project is part of the broader Dirk Hartog Island National Park Ecological Restoration Project. The intent is to allow assessment of the distribution, status and population trends of the threatened bird species, and enable monitoring of change in relation to management actions aimed at restoring the island's plant and animal communities to a state similar to that which existed before pastoralism and the introduction of exotic weeds, herbivores and carnivores.

Aims

- Determine historical and contemporary occurrence of threatened bird species across Dirk Hartog Island.
- Model and map occurrence of each species across the island in relation to vegetation characteristics.
- Develop a robust monitoring program.
- Clarify the conservation status of each of the threatened bird taxa.

Progress

- As part of a taxonomic appraisal of the rufous fieldwren, an objective method to measure subtle changes in feather colour and complex markings has been developed, in order to quantify geographic patterning in this species.

Management implications

- The three threatened bird taxa have been found to be abundant and widespread on the island, albeit with slightly different habitat preferences.
- This means that there are no especially sensitive sites, so management actions need not be constrained due to specific characteristics of these particular species.
- The needs of the three bird species should be covered by normal management considerations for a conservation reserve of the size of DHI.

Future directions

- For the species of interest, publish accounts of the modelling of species distribution across the island, and the population estimates of the species.
- Finalise an analysis of morphological variation in the rufous fieldwren and submit for publication along with the analysis of genetic variation and conclusions in relation to taxonomy and conservation status.
- Establish an optimal monitoring design for each species across the island.



Improving the use of remote cameras as a survey and monitoring tool

SP 2013-005

M Cowan, B MacMahon

Context

The use of camera traps is often regarded as an effective tool for fauna survey and monitoring with the assumption that they provide high quality, cost effective data. However, our understanding of appropriate methods for general survey and species detection, particularly in the small to medium sized range of mammals, remains poorly understood. Within the department, the use of camera traps to date has usually been restricted to simple species inventories or behavioural studies and beyond this there has been little assessment of deployment methods or appropriate analytical techniques. This has sometimes led to erroneous conclusions being derived from captured images. Camera traps have the potential to offer a comparatively reliable and relatively unbiased method for monitoring medium to large native and introduced mammal species throughout the state, including several significant cryptic species that are currently not incorporated under the Western Shield fauna monitoring program. Research is required to validate and test different survey designs (temporal and spatial components) and methods of deploying camera traps, and to interpret the results in a meaningful way. Work is needed to determine how best to use remote cameras to provide rigorous data on species detectability, and species richness and density.

Aims

- Establish suitable methodology for the use of camera traps to estimate the presence and relative abundances of native and introduced mammal species in the south-west of Western Australia.
- Investigate the effectiveness of baited (active) and un-baited (passive) cameras set to inventory targeted species.
- Investigate and assess the most appropriate methods of image analysis and data storage.
- Develop analytical tools for interpretation of camera trap data.

Progress

- A program for analysing camera trap data in the statistical language R has been completed. Analysis focuses on spatial and temporal activity patterns and provides statistically based graphical representations of these data as well as outputting a number of formatted data files for subsequent analysis.
- Implementation of the data analysis program has been made available via a web server to support ongoing camera trap monitoring programs in more than five reserves over three DBCA Regions.
- Camera trap monitoring programs mirroring that at Dryandra have been established at Tutanning and Boyagin Nature Reserves as well as within three satellite blocks at Dryandra.
- Interrogation of the Dryandra dataset (over 250,000 mammal detections) is continually undertaken to inform on appropriate methods and issues for camera trap data analysis. This information is disseminated to DBCA staff undertaking biodiversity research and monitoring activities with camera traps.
- Updated information on current technical aspects of camera models, survey design parameters, peripheral hardware, software and analytical techniques derived from this project is regularly disseminated to DBCA staff.
- A large set of images for a range of species from Dryandra has been collated to support a research program attempting to use deep machine learning to automate species recognition from camera trap imagery.

Management implications

- Assessment of variation in detection rates over time for all critical weight range species from this project is providing essential data on monitoring population stability and trends. This same data is used to examine the effectiveness of control measures on introduced predators.
- The camera array at Dryandra now forms a reference location against which comparisons from equivalent camera arrays at Boyagin, Tutanning and a fenced satellite block at Dryandra, can be compared and assessed in relation to management actions and the effects on critical weight range fauna.
- Analysis has shown that camera traps are an effective tool for detecting a suite of species currently not adequately monitored by the Western Shield program. However, there is evidence that baiting camera traps can lead to detection bias for some species and this needs to be taken into consideration for monitoring and survey programs. There is also some evidence that when cameras are first placed in an environment, detection rates for some species are elevated. This may result from the novelty of a new object in an animal's environment. Other issues identified include an indication that external temperatures may have technical implications on a camera's capacity to be triggered and thus detection rates may be affected.
- Careful consideration is essential in regard to the specific species being targeted, questions being addressed, and type of camera trap utilised. Survey design considerations include camera setup for target species, timing (especially if repeat sampling for detection rates e.g. monitoring), duration, camera numbers, camera spacing, logistics of implementing field components and skills and expertise to identify, manage and analyse data.
- Reconyx camera traps (models HC600 and PC900) are among the most effective commercially available camera traps for departmental requirements and currently remain recommended for use. It should be noted that technology is constantly changing in this field and improvements in performance and price are likely in the future. Differences in performance may have considerable ramifications for comparative data where camera models change over time.

Future directions

- Continue assessment of variation in camera deployment methodology, image capture and data analysis techniques to understand the implications for survey and monitoring programs. Provide this information to DBCA staff as assessments are completed.
- Continue to assess improvements and changes in camera trap technology against benchmark sites established at Dryandra to help inform best practice in use of camera trap technology by DBCA.
- Further development of the software application for camera trap data analysis to ensure it meets the primary needs of end users, and development of the analysis software into a standalone package that can be distributed more broadly.
- An analysis of conventional trapping data comparing Western Shield information to that from cameras over the same timeframes at Dryandra.
- Publication of peer reviewed paper from the project.



Decision support system for prioritising and implementing biosecurity on Western Australia's islands

SP 2013-001

C Lohr, K Zdunic, K Morris

Context

The goal of this project is to prioritise island management actions such that we maximise the number of achievable conservation outcomes for island biodiversity in the face of threats from invasive species. Western Australia has over 3,700 islands, many of which are essential for the survival of threatened species and provide critical breeding sites for seabirds and sea turtles. Many islands are also popular sites for recreation, and contain culturally significant sites. Invasive species are the single biggest cause of loss of native species from islands. The increased use of islands by the public for recreation, and oil, gas and mining industries, means an increased likelihood that invasive species will colonise pristine islands. This project will develop decision support software for day-to-day use in making accountable and cost-effective decisions on the management of islands to promote the persistence of native species; and an island biosecurity model for prioritising biosecurity actions. The project will focus on the 600+ islands along the Pilbara coast.

Aims

- Develop a single comprehensive database on Pilbara island characteristics, fauna and flora values, and threats.
- Develop an operational decision support software (DSS) for day-to-day use in making accountable and cost-effective decisions about where to spend limited funding on management of islands to promote the persistence of native species (Islands DSS).
- Develop an island biosecurity model for use in prioritising surveillance tasks for non-indigenous species on Pilbara islands (Biosecurity Bayesian Belief Network (BBN) software).

Progress

- The Pilbara island biodiversity database has been completed and is available on NatureMap.
- Further coding and validation of the software has been progressed.
- Several bugs have been removed from the Islands DSS and a software engineer from James Cook University is working with departmental staff to reintegrate the prioritisation model with the user interface.
- A second manuscript discussing use of the Biosecurity Bayesian Belief Network for identifying islands that are high priority weed management sites is in preparation.

Management implications

- The Islands DSS will result in more cost-effective management of island conservation reserves.
- The Biosecurity BBN software will allow more cost-effective surveillance of islands for invasive species.
- A single comprehensive and easily accessible database on Pilbara island characteristics, biodiversity values and threats will facilitate island planning and management.
- A species demographic attributes and interactions database will facilitate development of population viability assessments and community ecology models for species management across Western Australia.
- Easier access to the cost and efficacy of past management actions will be beneficial when planning future management actions.

Future directions

- Reintegrate the revised prioritisation code with the Islands DSS user interface.
- Publish manuscripts describing the Island DSS software.
- Use the revised Islands DSS to draft an initial set of management priorities for Pilbara islands.
- Publish the methodology used to map habitats on the Pilbara Islands.



Conservation and management of the bilby in the Pilbara

SP 2012-035

M Dziminski, D Moro, S van Leeuwen, F Carpenter

Context

The greater bilby (*Macrotis lagotis*) is listed as Vulnerable under the *Commonwealth's Environment Protection and Biodiversity Conservation Act 1999*. Increases in threats, including pressure from mining activities across the Pilbara, means that greater understanding of the distribution, abundance and ecology of the bilby is necessary to ensure appropriate conservation and management measures are implemented. This project will aim to increase our understanding of the bilby in the Pilbara Bioregion of Western Australia and allow for the development of a regional survey and monitoring program. The current focus is to determine the distribution of the bilby in the Pilbara and to establish appropriate survey and monitoring techniques, including genetic approaches.

Aims

- Improve our understanding of the distribution and demographics of bilbies in the Pilbara.
- Provide information to environmental regulators, resource development companies and contractors that will allow appropriate management to ensure the long-term persistence of the greater bilby in the Pilbara.
- Design, establish and implement a long-term monitoring program for bilbies in the Pilbara.

Progress

- An extensive dataset of bilby records in the Pilbara continues to be collated from existing sources and field surveys. New populations along the Shaw River were detected.
- The analysis technique of monitoring abundance using spatially explicit capture-recapture analysis continues to be developed and improved.
- A collaborative project with the Warralong Community, Roy Hill, and Greening Australia was initiated to continue monitoring the Warralong bilby population and implement fire, feral predator and grazing management on the Coongan Pastoral lease.
- The monitoring of population abundance technique using DNA extracted from scats quantitatively collected from populations in the field continues to be implemented.
- Advice on bilby occupancy survey, abundance monitoring and management has been continually delivered to mining and consultancy companies through meetings and workshops.

Management implications

- Development of refined survey and monitoring techniques for bilbies in the Pilbara bioregion will enable standardisation and comparability in occupancy surveys and monitoring, and surveys to detect the presence or absence of bilbies, and provides a means of assessing the importance of habitat. The protocol can be used for broader state and national applications.
- Improved understanding of bilbies in the Pilbara and elsewhere in Western Australia enables improved habitat modelling and predictions of bilby distribution. This will inform future management of bilby populations and assist in the assessment of mining and development proposals.
- Use of a standardised technique for examining abundance of bilbies will provide reliable and comparable measures of numbers of animals within populations. It is recommended that scat samples for DNA extraction be stored and transported in tubes with silica gel beads and cotton wool to protect the sample, to ensure increased sample viability.
- Populations in the Pilbara are geographically isolated and consist of a small number of individuals, and they are likely to be vulnerable to threats, a key one being unmanaged fire regimes, indicating that fire management is an important aspect of managing habitat for bilbies.

- It is recommended that any surveys using remotely piloted aircraft (RPA) require ground-truthing of both positive and non-detections to determine false positive and false negative error. This technique shows future potential and will be further developed.

Future directions

- Continue development of modelling of the distribution of bilbies in the Pilbara, and ground truth sites to validate the resulting models.
- Continue to optimise RPA technology to survey for bilbies.
- Initiate collaborative implementation of threat management with initial focus on fire management at selected populations with community and stakeholder engagement and support.
- Continue population genetics project using existing bilby DNA library collected from population monitoring and opportunistically collected scats.
- Continue diet analysis of surplus scats collected during population monitoring and opportunistically collected scats.
- Focus on data consolidation and preparation of scientific publications.



Genetic assessment for conservation of rare and threatened fauna

SP 2012-034

K Ottewell, M Byrne, S McArthur, R Sun

Context

Genetic analysis of threatened species can provide important information to support and guide conservation management. In particular, genetic tools can be used to aid resolution of the taxonomic identity of species to determine whether they have appropriate conservation listing. At a population level, analysis of the genetic diversity present in extant populations provides information on genetic 'health' of threatened species and how this may be maintained or improved through management actions, leading to long-term positive conservation outcomes.

Aims

- Resolve taxonomic boundaries of Western Australian bandicoots (*Isoodon* sp.), particularly *I. auratus* and *I. obesulus* and their subspecies, to determine appropriate conservation rankings and management units.
- Investigate genomic diversity of island and mainland populations of golden bandicoots (*I. auratus*) and assess success of reintroductions in WA and NT.
- Develop molecular identification of golden and northern brown bandicoots to assist in morphological identification of bandicoots in the field in the Kimberley.
- Investigate the role of fauna underpasses in providing connectivity between quenda (*I. obesulus* ssp. *fusciventer*) populations impacted by main road construction.
- Assess the genetic diversity and genetic structure of extant populations of black-flanked rock wallaby (*Petrogale lateralis* ssp. *lateralis*) to inform future conservation management, including translocations.
- Assess the genetic diversity and patterns of introgression of boodies translocated to Matuwa.
- Contribute to assessment of sub-species boundaries within northern quolls (*Dasyurus hallucatus*) using genomic sequencing of museum and contemporary specimens.
- Investigate genetic diversity of translocated brushtail possums (*Trichosurus vulpecula*) and their source populations at Matuwa.
- Contribute to taxonomic assessment of brushtail possums, including resolution of Western Australian sub-species.
- Assess genetic diversity, genetic structure and monitor cave use of ghost bat (*Macroderma gigas*) populations in the Pilbara, and develop high-throughput genotyping array and molecular sexing markers for individual identification of ghost bats from faecal DNA.

- Assess species composition and individual relatedness of Hamelin Bay pilot whale stranding.
- Assess whether collection of blow from humpback dolphins using drones is suitable for non-invasive DNA sampling

Progress

- Mitochondrial DNA sequencing of *I. obesulus*, *I. auratus* and *I. macrourus* was undertaken in collaboration with the South Australian Museum with a draft manuscript well progressed. MtDNA was insufficient to fully resolve taxonomic issues for some species and consequently genomic analyses are planned to provide further resolving power. Samples have been collated and preliminary exon capture analysis has been trialed on museum skins.
- DNA samples have been sourced for island, mainland and reintroduced populations of *I. auratus* and DNA extractions are underway.
- Analysis of genetic diversity and structure of wheatbelt and mid-north west rock wallaby populations has been completed, including analysis of all individuals translocated to Kalbarri National Park from 2016 to 2018. Genetic analysis of new individuals borne into the population at Kalbarri is currently being undertaken. Samples have been collated for a further genomic analysis of black-flanked rock wallaby populations using both contemporary samples and museum skins.
- A manuscript detailing patterns of mtDNA and microsatellite diversity and introgression amongst Shark Bay and Barrow Island boodies translocated to Matuwa has been submitted.
- Museum specimens and contemporary samples of northern quolls have been identified with type specimens to be sourced from the Natural History Museum for sequencing.
- DNA barcoding was used to confirm species identity of several stranded cetaceans, a striped dolphin, and beaked whales.
- DNA analysis of dolphin blow samples from drone sampling were analysed and a manuscript submitted.
- DNA barcoding and microsatellite analysis of pilot whales stranded at Hamelin Bay has been completed and preliminary analyses are underway. Methods for molecular ageing are being investigated in collaboration with The University of Western Australia.
- Genetic monitoring of ghost bats at West Angelas, the Robe Valley and South Flank mining precincts were completed and reports provided to Biologic. Genetic diversity analyses of additional northern Pilbara and East Hamersley populations was also undertaken to contribute to a Pilbara-wide population genetic study.
- Design and initial trial of a SNP genotyping array for ghost bat faecal DNA has been successful and further validation is underway. Whole genome sequencing of a male and female ghost bat has been completed and potential molecular sexing markers identified. Primers have been ordered and will be trialed against individuals of known sex.

Management implications

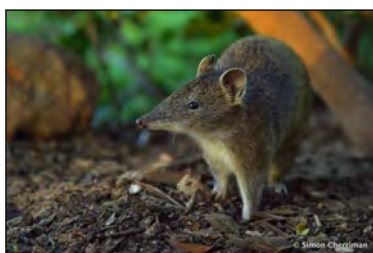
- An Australia-wide phylogenetic assessment of *I. obesulus* and related species/subspecies has enabled a more informed evaluation of taxonomic boundaries, showing that *I. o. obesulus* is restricted to eastern and southeastern Australia, and identifying a range extension of *I. fusciventer* (Western Australia) into South Australia. This information has informed evaluation of threat status by the Commonwealth for the eastern and Tasmanian sub-species of *I. obesulus*.
- Genetic assessment of Western Australian bandicoots will inform the identification and management of species and sub-species across Western Australian. Molecular identification of golden and northern brown bandicoots in the Kimberley will assist development of additional characters for field identification.
- Population viability analysis of quenda populations impacted by road development has shown that fauna underpasses can provide demographic connectivity to reduce extinction risks. Mating system analysis will be used to confirm whether they also facilitate genetic connectivity.
- Genetic and genomic analysis of rock wallaby populations will assess the genetic health of extant and historical populations, including an assessment of the effectiveness of past management interventions to inform planning of future conservation actions. Assessment of the Kalbarri National Park translocation of rock wallabies showed establishing founder populations from mixed divergent sources increased genetic diversity relative to source populations. Analysis confirmed successful reproduction between extant Kalbarri animals and introduced animals, suggesting no pre-zygotic reproductive barriers are present.
- Mixing divergent source populations of boodies in a translocation to Matuwa has increased genetic diversity of the reintroduced population, but there is trend of asymmetrical introgression towards crosses between smaller-sized Barrow Island males and larger-sized Shark Bay Island females. Assessment of

survivorship and fecundity of introgressed individuals relative to their ancestry indicated no fitness impacts of introgression.

- Genetic and population viability analyses of brushtail possums at Matuwa showed that low genetic diversity or inbreeding are not likely contributing to the small population numbers. Modelling suggests that if population size remains small then augmentation is required to maintain genetic diversity.
- Microsatellite genotyping of ghost bat faecal DNA has proven an effective, non-invasive method to assess genetic diversity of ghost bat populations as well as to monitor movement of individual bats in space and time. Monitoring projects have indicated individual bats remain in caves over multiple years and most frequently use caves within ~10km. Information on ghost bat cave use is informative for environmental impact assessment. Development of high-throughput SNP genotyping methods will enable more rapid and reproducible screening of faecal DNA samples for future monitoring projects.

Future directions

- Phylogenomic analysis of *Isoodon* spp. will be undertaken to formally resolve the species boundaries across the group. Analyses of historical (using museum skins) and contemporary genetic diversity will be used to document their recent evolutionary history.
- Genomic assessment of island, mainland and reintroduced populations of *I. auratus* will be undertaken.
- Analysis of *I. auratus* and *I. macrourus* species identifications will be finalised.
- Comparison of historic and contemporary population genomics of wheatbelt rock wallaby populations will be undertaken to monitor genetic change and investigate the impact of past management actions. Monitoring and genetic analysis of the Kalbarri National Park translocated rock wallaby populations will be completed.
- Phylogenomic assessment of northern quolls will be undertaken.
- Further sampling of Pilbara and Kimberley ghost bat populations will be conducted, in addition to ongoing monitoring of populations in BHP and Rio Tinto mining precincts. Validation of the SNP genotyping array and molecular sexing markers will be completed.
- Statistical analyses of the Hamelin Bay pilot whale stranding will be completed.



Genetic approaches for evaluating the contribution of the reserve system to fauna conservation

SP 2012-033

K Ottewell, M Byrne, S McArthur

Context

Human-mediated landscape disturbance can affect the amount of genetic diversity present in populations of threatened species and their distribution across the landscape. One challenge facing conservation managers is understanding how management tools can be used to protect and facilitate genetic patterns and processes. For example, reserve design principles (comprehensiveness, adequacy, representativeness; single large or several small) can be just as well applied to conserve genetic diversity as species diversity. We aim to use genetic approaches to investigate patterns of contemporary and historical diversity in target species to understand how best to conserve the processes that generate these patterns.

Aims

- Determine genetic diversity and gene flow amongst quenda (*Isoodon obesulus* ssp. *fusciventer*) populations in fragmented and continuous habitat in the Perth region to assess the impacts of vegetation connectivity on genetic and demographic processes.
- Identify landscape elements that are associated with high genetic diversity and gene flow in quenda populations using GIS and connectivity modelling, and how well these features are captured in the reserve system.

- Assess the genetic diversity and genetic structure of small mammal species in the Pilbara, how this relates to climate and environmental features (soils, landforms, etc.), and how well it is captured in the current reserve system.

Progress

- A manuscript describing genetic diversity and gene flow amongst 42 quenda populations distributed through the Perth Hills and Swan Coastal Plain regions has been published in *Landscape and Urban Planning*. Connectivity of quenda populations across the Perth metropolitan region is strongly associated with the presence of remnant vegetation, and to a lesser extent, the presence of low shrub vegetation. Quenda form four genetic clusters that are delimited by geomorphic features such as the Swan River and wetland boundaries. Populations north of the Swan River have low genetic diversity, suggesting low population sizes.
- Genetic diversity, connectivity and generalised dissimilarity modelling analyses for three small mammal species (*Pseudomys chapmani*, *P. hermannsburgensis* and *Ningauai timealeyi*) in the Pilbara has been published in *Journal of Biogeography*. Analysis showed that genetic diversity and genetic structure were not strongly associated with any one particular landscape element (rivers, mountains), and the reserve system did not harbor high genetic diversity relative to the surrounding landscape since genetic diversity was high across the region.

Management implications

- Genetic analyses of population structure of quenda across the Perth region demonstrated that landscape elements such as remnant vegetation and presence of low vegetation assist in maintaining connectivity among quenda populations. The identification of four genetic clusters that represent management units and are delimited by geomorphic features, such as the Swan River and wetland boundaries, provides information for management of the species across the Perth region.
- Analysis of genetic diversity and structure of the three small Pilbara mammals provides information to manage the broader landscape to ensure effective maintenance of these species, and demonstrates the effects of the boom-bust cycles of arid mammals, and a relatively high capacity for dispersal in the maintenance of spatial genetic patterns.

Future directions

- Further landscape genetic analyses will be completed for quenda that will involve landscape resistance modelling to determine connectivity pathways across the Perth metropolitan region.



Barrow Island threatened and priority fauna species translocation program

SP 2012-025

K Morris, A Burbidge, J Dunlop, J Angus, M Blythman, S Garretson

Context

Barrow Island Nature Reserve is one of Australia's most important conservation reserves, particularly for mammal and marine turtle conservation. It has also been the site of a producing oil field since 1964. In 2003 the Western Australian Government approved the development of the Gorgon gas field off the north west of Barrow Island, and associated LNG plant on Barrow Island, subject to several environmental offset conditions. One of these offsets was the threatened and priority fauna translocation program that provided for the translocation of selected Barrow Island fauna species to other secure island and mainland sites. This will assist in improving the conservation status of these species, and also allow the reconstruction of the fauna in some areas. It also provides an opportunity to examine the factors affecting translocation success, and improve these where necessary. Targetted species are the golden bandicoot, brushtail possum, spectacled hare-wallaby, boodie, water rat, black and white fairy-wren, and spinifex bird.

Aims

- Translocate selected mammal and bird species from Barrow Island to other secure island and mainland sites.
- Reconstruct the fauna in areas where these species have become locally extinct.
- Develop and refine protocols for fauna translocation and monitoring.

Progress

- A report on the genetic uniqueness of Barrow Island vertebrate fauna was finalised.
- The spectacled hare-wallabies on Hermite Island were monitored using a camera trap array and showed that 93% of the island was now occupied.
- The translocated black and white fairy-wrens and spinifex birds were monitored on the Montebello Islands; although numbers were down due to dry conditions, both populations are well above founder numbers.
- The LNG jetty and Materials Offloading Facility on Barrow Island were surveyed for water rats in preparation for a potential translocation to the Montebello Islands.
- Golden bandicoots and boodies translocated from Barrow Island to the fenced enclosure at Matuwa in 2010 were monitored using methodology similar to that used on Barrow Island.
- Intensive introduced predator management continued at Matuwa and Cape Range National Park.

Management implications

- Arid zone rangelands fauna reconstruction and conservation techniques developed by this project will have broad state and national application.
- The outcomes of the project are contributing to the management of DBCA and jointly managed rangeland properties and providing guidance for other fauna reconstruction projects such as the Dirk Hartog Island National Park Ecological Restoration Project.
- This project has contributed to an improvement in the conservation status of several threatened fauna taxa (e.g. boodie) and provided the basis for ongoing monitoring of fauna of the Montebello Islands.

Future directions

- Continue to implement the Barrow Island fauna translocation strategy, including the ongoing monitoring of translocated populations according to the schedule. This will include monitoring boodies and golden bandicoots on the Montebello Islands in 2019.
- Continue monitoring the effectiveness of integrated fox and feral cat baiting at Cape Range and consider a fauna translocation contingent on the effective control of introduced predators.
- Publish paper on the Barrow Island fauna translocations.



Rangelands restoration: reintroduction of native mammals to Matuwa (Lorna Glen)

SP 2012-024

C Lohr, K Morris, M Blythman

Context

Operation Rangelands Restoration commenced in 2000 with the acquisition of Lorna Glen (Matuwa) and Earraheedy (Kurrara Kurrara) pastoral leases by the Western Australian Government. This 600,000 ha area lying across the Gascoyne and Murchison bioregions is now the site for an ecologically integrated project to restore ecosystem function and biodiversity in the rangelands. This is being undertaken in collaboration with the traditional owners. In 2014 Native Title (exclusive possession) was granted to Tarlka Matuwa Piarku Aboriginal Corporation (TMPAC) over Matuwa and Kurrara Kurrara.

The area around Matuwa once supported a diverse mammal fauna that was representative of the rangelands and deserts to the north and east. These areas have suffered the largest mammal declines in Western Australia. This project seeks to reintroduce 11 arid zone mammal species following the successful suppression of feral

cats and foxes, and contribute significantly to the long-term conservation of several threatened species. Mammal reconstruction in this area will also contribute significantly to the restoration of rangeland ecosystems through activities such as digging the soil and grazing/browsing of vegetation, and assist in the return of fire regimes that are more beneficial to the maintenance of biodiversity in the arid zone.

The first of the mammal reintroductions commenced in August 2007 with the release of bilby (*Macrotis lagotis*) and brushtail possums (*Trichosurus vulpecula*). Between 2010-2012, mala (*Lagorchestes hirsutus*), Shark Bay mice (*Pseudomys fieldi*), boodies (*Bettongia lesueur*) and golden bandicoots (*Isoodon auratus*) were translocated into an 1,100 ha introduced predator free fenced enclosure. The intention is to use these as a source for translocations to areas of Matuwa outside the enclosure where cats are being effectively suppressed, and ultimately the establishment of free-ranging self sustaining populations.

Aims

- Develop effective feral cat control techniques in a rangeland environment.
- Reintroduce 11 native mammal species to Matuwa by 2023, and contribute to an improved conservation status for these species.
- Re-establish ecosystem processes and improve the condition of a rangeland conservation reserve.
- Develop and refine protocols for fauna translocation and monitoring.
- Determine the role of digging and burrowing fauna in rangeland restoration.

Progress

- The persistence of bilbies across the Bullimore Sand Plain land system has been confirmed via 120 camera traps and occupancy analysis.
- The persistence of brushtail possums was confirmed from nine camera traps and multiple detections of scratch marks and scats on *Eucalyptus* trees.
- Golden bandicoot tracks continue to be detected in the Bullimore Sand Plain land system, albeit at low densities.
- The camera trap system and 100 km linear track counts continue to be used to monitor the cost-effectiveness of feral cat baiting and trapping.
- Boodies, golden bandicoots and mala are persisting in the enclosure.
- Two vocational training units in 'Apply animal trapping' and 'Survey pests' were completed by selected Martu Rangers.

Management implications

- Fauna reconstruction increases the probability of species persistence through the establishment of multiple populations, and it re-establishes ecosystem processes lost during localised extinctions.
- Flexibility in timing is a key consideration in the planning of reintroductions, which should also take into account the effects of environmental conditions (droughts) and annual cycles of reproduction/behaviour in potential predators/competitors on reintroduction success.
- Detailed monitoring to identify causes of mortality and the subsequent identification of predators and their removal in a timely fashion are critical to the success of reintroduction programs. Monitoring has demonstrated that additional cat control techniques to landscape scale baiting are required to successfully re-establish threatened vertebrate fauna in the rangelands.
- Sourcing founder animals from multiple locations has proven valuable in increasing genetic diversity in reintroduced species.
- Increased involvement of traditional owner rangers with fauna monitoring has assisted collaborative management arrangements.

Future directions

- Develop more vocational training units for Martu Rangers and collaborative fauna monitoring activities.
- Ongoing monitoring of reintroduced species and introduced predators.
- Complete analysis of last 10 years of monitoring data.



Feral cat control and numbat recovery in Dryandra Woodland and other sites

SP 2012-023

A Friend

Context

Dryandra Woodland supports important populations of several threatened mammals, including the numbat, woylie and red-tailed phascogale, as well as significant populations of a number of threatened birds. Recent research has shown that feral cats are responsible for the majority of numbat and woylie deaths. This project investigates the feasibility and efficacy of using the *Eradicat*[®] feral cat bait to reduce numbat and woylie mortality and promote their recovery at Dryandra.

Aims

- Determine the uptake of rhodamine-labelled non-toxic *Eradicat*[®] baits by chuditch, red-tailed phascogales and mardos in Dryandra.
- Determine the survival or mortality of groups of radio-collared chuditch, red-tailed phascogales and mardos during a baiting campaign using toxic *Eradicat*[®] baits in Dryandra.
- Determine the survival or mortality of feral cats through a baiting campaign using toxic *Eradicat*[®] baits in Dryandra.

Progress

- A manuscript entitled 'Are red-tailed phascogales (*Phascogale calura*) at risk from *Eradicat*[®] cat baits?' has been submitted to *Wildlife Research*.
- A manuscript is in preparation on the movements and survival of feral cats through *Eradicat*[®] baiting campaigns at Dryandra and Tutanning.

Management implications

- *Eradicat*[®] can be used with minimal non-target impacts in the Dryandra Woodland. This is significant for the implementation of integrated fox and feral cat control programs at Dryandra and elsewhere in the south-west of Western Australia.

Future directions

- Finalise manuscripts on red-tailed phascogales and feral cat baiting.



Conservation of south coast threatened birds

SP 2012-022

A Burbidge, A Clarke, J Lane

Context

Identifying the conservation requirements of threatened south coast birds, such as the Critically Endangered western ground parrot, Endangered noisy scrub-bird, Vulnerable western bristlebird and western subspecies of the western whipbird, and the Endangered Australasian bittern, will aid *in situ* management of these taxa.

Understanding responses to fire and hydrological changes, biological and behavioural characteristics, such as vulnerability to predation, and nesting site requirements are essential knowledge for the conservation of these Western Australian birds (some of them endemic to the south-west) and the development of management programs.

Aims

- Develop an understanding of the biological and ecological factors that limit the distribution and numbers of south coast threatened birds, including interactions with predators, habitat requirements and response to fire.
- Increase the survival chances of south coast threatened birds and increase their total population size through creation of management prescriptions that will benefit all threatened south coast animals.
- Investigation of life history characteristics and ecological processes impacting on recruitment in the Australasian bittern.
- Survey and monitor Australasian bittern populations and habitat to assist tracking current trends.

Progress

- Population monitoring of western ground parrots has continued but preliminary examination of the data suggests that parrot abundance levels may be declining, and possibly associated with abundance of introduced predators.
- Ground parrot and bittern monitoring protocols are being further refined through use of audio recordings, field testing of performance characteristics of recording units, and analysis of trends in current data sets.
- Five new ground parrots were added to the captive population at Perth Zoo.
- In collaboration with staff from Perth Zoo, a trial of a tagging harness design for ground parrots was completed successfully.
- New data on roosting and foraging movements were gathered from five ground parrots fitted with tracking devices, and at least three of these birds survived a fire in Cape Arid National Park in early 2019.
- Modelling the future distribution of ground parrots in the face of climate change has filtered out unsuitable translocation sites and allowed a cost-effective approach to assessing and selecting potential translocation sites. A paper has been published in *Oryx - The International Journal of Conservation*.
- Analysis of monitoring data on scrub-birds at Two Peoples Bay has not led to identification of a reason for recent declines, although several potentially contributing factors (including fire and predators) have been identified.
- Information from camera trapping surveys is being analysed to inform knowledge of foraging behaviour and habitat preferences of Australasian bitterns.

Management implications

- Knowledge of the biology and responses to threats of south coast threatened birds provides a basis for decision making and management actions for their recovery, especially with respect to introduced predators and fire, in important conservation reserves on the south coast.
- The collection of high quality depth and water quality data will be critical to the development of modelling designed to predict the hydrological futures for high priority bittern breeding wetlands. These research findings will help inform stakeholders and land managers where to target mitigation strategies.

Future directions

- Finalise papers on response to fire by bristlebirds, changes in scrub-bird abundance and acoustic data.
- Continue to develop monitoring analyses and techniques, particularly for ground parrots, scrub-birds and Australasian bitterns, and finish writing up recent survey data.
- Conduct trial GPS tracking of Australasian bitterns, and continue to monitor key populations of Australasian bittern and their habitat so that trends can be tracked and communicated to stakeholders and inform management.
- Investigate feasibility of population tracking through DNA analysis of shed bittern feathers.



Ecology and management of the northern quoll in the Pilbara

SP 2011-005

J Dunlop, N Birch

Context

The northern quoll (*Dasyurus hallucatus*) is listed as a threatened species under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*. Funding from mining offset conditions are being used to gain a better understanding of quoll distribution, ecology, demographics and management requirements in the Pilbara. There are two major components of the project: regional monitoring and ecological research. Regional survey and monitoring of Pilbara northern quoll populations over 10+ years will provide a regional context for understanding population dynamics. Researching northern quoll ecology will provide information related to impacts, such as loss of known or potential habitat critical to the survival of the species, loss of known or potential foraging/dispersal habitat, and introduction of barriers restricting dispersal opportunities and genetic flow.

Aims

- Develop appropriate and standardised survey and monitoring methods for northern quoll.
- Define areas of critical habitat and better understand how disturbance affects habitat quality.
- Improve understanding of population dynamics.
- Better understand the key threats and interactions between these threats.
- Determine whether the northern quoll will colonise restored / rehabilitated areas or artificial habitat.

Progress

- Dietary analysis of northern quolls across the Pilbara region revealed a flexible, opportunistic omnivorous habit, including 23 vertebrate species and a surprising level of vegetation intake.
- Sequencing has been completed for approximately 1,800 tissue samples collected as part of this project to answer questions about patterns of dispersal, relatedness and life history.
- Female quolls were found to have very high levels of promiscuity, with pouch young having up to eight fathers within a litter of eight. Female northern quolls from island populations are exerting sexual selection pressure on males, and preferentially breeding with smaller males.
- A significant volume of presence records collected via camera and cage trapping has been analysed for detection probabilities and assessment of the efficacy of northern quoll survey methods.
- Trials of downward-facing cameras were undertaken for the purpose of individual identification and population estimation. Capture probabilities for northern quolls via live trapping and camera trapping were estimated to determine the survey effort required for 95% confidence of detection.
- Work on determining the characteristics of female northern quoll dens is ongoing, with the goal to provide guidelines for artificial habitat creation.
- Interactions between northern quolls and predators remains a focus, with current work examining the relationships between presence of quolls according to predators and habitat variables, as well as testing of the efficacy of Felixer grooming traps as another tool for managing feral cat numbers.
- Population viability modelling revealed northern quolls are highly sensitive to increased juvenile mortality.

Management implications

- Enhanced distributional data that is publicly available in an online repository will enhance decision-making relating to northern quolls in the Pilbara. Future monitoring of northern quolls can be aligned with the methods of the regional program, to enable regional comparisons of population trends and change.
- Sophisticated northern quoll population distribution maps can be used to predict the likelihood of occurrence, and inform management decisions. Areas without data collection have been identified as priorities

for ground-truthing, and key populations likely to be impacted by future threatening processes have been determined.

- Results from GPS tracking of northern quoll suggests that impacts can be limited if known quoll habitat is not fragmented or destroyed by infrastructure developments.
- Modelling the changes in mortality of different cohorts of northern quolls has enabled best-practice baiting regimes to be implemented for feral cats in the Pilbara.

Future directions

- Regional monitoring will continue, including collection of additional presence records. Once sufficient data has been collated, an assessment of the efficacy of the monitoring program will be undertaken.
- Continue an assessment of camera traps as a monitoring technique for northern quolls.
- Population genetics for Pilbara northern quolls will be assessed to reveal information about the important northern quoll conservation units, genetic diversity within the region and effective home range size.
- Continue investigation into the interactions between northern quolls and introduced species (including predators: feral cat, red fox, wild dog, and the invasive cane toad).
- Characterisation of northern quoll denning requirements will be published with the view to protecting these key habitat features, or recreating them with artificial habitat.
- Testing of Felixer feral cat control units will continue in the presence of native non-target species.



Conservation of the graceful sun-moth

SP 2010-006

M Williams

Context

This project focuses on a high-profile invertebrate that was a listed threatened species under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and as Scheduled Fauna under the Western Australian *Wildlife Conservation Act 1950* until 2012. The graceful sun-moth (*Synemon gratiosa*) is a day-flying moth restricted to the Swan Coastal Plain, and is threatened by urban and other development. This project will obtain information to resolve potential conflicts between conservation of the species and the impacts of land clearing. By involving community organisations and environmental consultants, it extends cooperative partnerships with the community.

Aims

- Undertake research to determine the distribution and habitat requirements of the graceful sun-moth.
- Develop survey techniques to accurately determine the presence of the species, and to assess its abundance in bushland areas.
- Document or identify which factors determine the realised niche of the species, using habitat suitability modelling.
- Review the conservation and taxonomic status of the graceful sun-moth using molecular genetic methods.
- Identify land clearance management strategies to enable effective conservation.

Progress

- A paper describing a mark-recapture study of the graceful sun-moth as a prelude to assessing its conservation status was published in *Records of the Western Australia Museum Supplement*.
- A paper detailing unrecorded information on the life history of the graceful sun-moth has been drafted. This provides information on fecundity and survival rates that is important for understanding population dynamics.

Management implications

- Previous assessments of the conservation status of the graceful sun-moth led to the species status being changed from Vulnerable to non-threatened (Priority 4).

Future directions

- Publication of graceful sun-moth biology, habitat use model and genetic results.



Impact of cane toads on biodiversity in the Kimberley

SP 2006-004

D Pearson

Context

The invasion of cane toads is impacting on the biodiversity of the Kimberley and no technique has been developed to prevent their spread across the landscape. Earlier research in this project has identified that predators, such as northern quolls and goannas, are especially vulnerable to poisoning by toads and we have identified that it is possible to train some native predators to avoid eating cane toads. A taste aversion bait to prevent quolls eating toads has been developed and is being trialed during this project. Monitoring of northern quoll and reptile populations on Adolphus Island is required to understand how these species are likely to respond to the arrival of toads on islands.

Aims

- Test of taste aversion baits and the use of metamorphs to induce an effective response from native species threatened by toads.
- Develop operational techniques to roll out taste aversion training across Kimberley landscapes.
- Research techniques for taxa not currently believed to be able to benefit from taste aversion training such as elapid snakes.
- Monitor populations of susceptible species behind the toad front, including those where taste aversion training took place and control sites.
- Investigate where and how toads survive in seasonally dry habitats to better understand their colonisation of islands and their potential to spread into the Pilbara region.

Progress

- Operational trials of helicopter dropped taste aversion baits continued at several sites in the north Kimberley on Wunambal-Gaambera land and conservation estate. These have been spaced 10-30 km apart so that quolls can reinvade suitable habitat after the toad front has passed. The spacing of drops aims to result in the retention of as much potential genetic diversity as possible. The effectiveness of these drops will be assessed during the next wet season.
- Taste aversion bait trials and monitoring of quoll and goanna populations were undertaken at Mitchell River National Park. Low capture rates of quolls in newly invaded sites at Mitchell River National Park may be due to the poor wet season or initial toad impacts.
- A poor 2018-2019 wet season resulted in lower quoll recruitment and less goanna activity so data analysis is currently being undertaken to separate the impact of rainfall and toads.
- There has been regular foot surveys and remote camera monitoring of quoll and goanna activity on Adolphus Island following the arrival of toads on the island. Both quolls and goannas have persisted in the presence of cane toads.

Management implications

- The monitoring techniques developed on Adolphus Island will assist with the monitoring of other Kimberley islands for the arrival of toads and their impacts on native fauna.
- The involvement of Wunamal-Gaamberra and Wilinggin rangers and Traditional Owners in the research means that the results have been shared with the land-owners and further co-operative work on native title lands can potentially occur in the future.

Future directions

- Further refine the production and effectiveness of the taste aversion bait for quolls and investigate its use or that of a variant to induce taste aversion in some reptiles.
- Run operational trials at other sites in the north and central Kimberley and monitor the effectiveness for conserving populations of susceptible species.
- Complete research on cane toad survivorship over the dry season to allow a more informed appraisal of the 'waterless barrier' concept and the threat of toads on offshore islands of the Kimberley.



Development of effective broad-scale aerial baiting strategies for the control of feral cats

SP 2003-005

D Algar, N Hamilton, M Onus

Context

The effective control of feral cats is one of the most important native fauna conservation issues in Australia. Development of an effective broad-scale baiting technique, and the incorporation of a suitable toxin for feral cats, is cited as a high priority in the national *Threat abatement plan for predation of feral cats*, as it is most likely to yield a practical, cost-effective method to control feral cat numbers in strategic areas and promote the recovery of threatened fauna.

Aims

- Design and develop a bait medium that is readily consumed by feral cats.
- Examine bait uptake in relation to the time of year, to enable baiting programs to be conducted when bait uptake is at its peak and therefore maximise efficiency.
- Examine baiting intensity in relation to baiting efficiency to optimise control.
- Examine baiting frequency required to provide long-term and sustained effective control.
- Assess the potential impact of baiting programs on non-target species and populations and devise methods to reduce the potential risk where possible.
- Provide a technique for the reliable estimation of cat abundance.

Progress

- Refinement of bait composition is continuing with the objective of further improving bait uptake. A series of pen trials have been completed, where tests were performed to determine if replacement of chicken fat in the bait matrix with beef tallow would improve bait palatability and also longevity as suggested in recent literature. This was proven not to be the case. Plant material has also been submitted to a laboratory in the United States of America for a process called 'critical distillation'. The plant elicits a chewing response in cats and it is hoped that the oil derived from 'critical distillation' will enhance bait palatability and bait consumption.
- Analysis of GPS radio-collar data, from across a number of sites across Western Australia, has been conducted to assess whether bait encounter rate can be increased by modifying bait deployment. A manuscript has been completed for final review and submission.
- Refinement of the trapping technique to minimise risk to non-targets yet maintain effectiveness in feral cat capture is ongoing. A Standard Operating Procedure for cat trapping is now being developed and a manuscript is in preparation.

- Trials of a bait that minimises the risk to wild dog/dingo hybrids while maintaining its effectiveness for feral cat control are being conducted. The utility of Apomorphine, a rapidly acting emetic, which causes dogs to vomit but has no effect on cats, is currently being examined. The emetic would be incorporated into the plastic polymer that encases the toxin. Results to date have demonstrated that ingestion of this bait by cats results in death; trials with dogs will be undertaken later this year.
- Work continues on improving and refining several cat lure options. A collaborative project is being undertaken with colleagues in Victoria to investigate visitation and re-visitation rates to olfactory attractants.
- A paper on the baiting associated with the feral cat eradication program on Dirk Hartog Island was published in 'Occasional Paper of the IUCN Species Survival Commission No 62'.

Management implications

- Development of effective baiting methods across climatic regions will ultimately provide efficient feral cat control at strategic locations across mainland Western Australia and lead to significant conservation benefits.
- Successful eradication of feral cats from a number of islands off the Western Australian mainland has occurred over the past ten years (i.e. Hermite, Faure and Rottnest islands), allowing the persistence of the native fauna on these islands and enabling effective reintroductions of mammals where appropriate. Successful eradication of feral cats on Dirk Hartog Island will now enable reconstruction of the native mammal fauna there and restore habitat and ecosystem processes.

Future directions

- Continue refinement of bait medium to improve bait consumption by feral cats.
- Analyse baiting effectiveness at the various research sites and refine the method of operation where necessary to optimise baiting efficacy.
- Further investigate bait consumption by non-target species and devise methods to minimise risk (e.g. toxin encapsulation).
- Refine and optimise cat lure options.



Gilbert's potoroo recovery plan

SP 1996-008

A Friend, S Hill

Context

Gilbert's potoroo (*Potorous gilbertii*) is the world's rarest marsupial. Since its rediscovery in Two Peoples Bay in 1994, implementation of actions under a series of recovery plans has resulted in the establishment of two new populations near Albany: one on Bald Island and the other inside a 380 hectare enclosure protected from foxes and cats. A catastrophic bushfire at Two Peoples Bay in October 2015 rendered 90% of potoroo habitat there uninhabitable and killed 60% of known individuals. Following closely monitored trial translocations in winter 2017 and late summer 2018 which indicated that potoroos could thrive on Middle Island, a full translocation of 10 animals to the island was completed in July 2018. The current objectives of the project are to assess the success of the Middle Island translocation, to monitor the rate of increase of use by potoroos of burnt habitat at Two Peoples Bay and to collect and analyse demographic data from all populations, followed by population viability analysis to inform future management options.

Aims

- Implement the *Gilbert's Potoroo Recovery Plan*.
- Increase the numbers of individual Gilbert's potoroos known to be alive in the wild and increase the number of locations in which they occur.

Progress

- After two successful trial translocations to Middle Island, the full translocation was carried out by transferring six potoroos from Bald Island in July 2018, to join four remaining on the island from the second trial.
- A survey of Middle Island for hypogeal fungi generated 37 collections. Morphological and DNA analysis confirmed the presence of 19 fungal species.
- Analyses of GPS unit/transmitter packages on six potoroos showed that the animals had all established home ranges at the western end of the island.
- At Two Peoples Bay, only one female and two male potoroos were captured during the year. One of these is a two-year-old male, indicating that breeding has occurred since the 2015 fire.
- GPS units have been fitted to potoroos at Two Peoples Bay whenever possible to study movements in the burnt and unburnt habitat. Movement of potoroos into burnt areas was first recorded in November 2017 and the latest data from April 2019 shows this activity has increased.
- Thrice-yearly monitoring in the 380 ha Waychinicup National Park potaroo enclosure has shown that since 2016 the population has achieved stability at between 20 and 30 animals known to be alive, with frequent breeding and recruitment of young into the population.
- The Gilbert's potaroo monitoring data is currently being analysed for a paper on potaroo demographics.

Management implications

- The establishment of two insurance populations and the earlier development of captive management protocols enabled effective management of potoroos from the Two Peoples Bay Nature Reserve population that was impacted by fire.
- While islands provide safety for potoroos from introduced, and in some cases native predators, careful prior evaluation of habitat suitability and in particular the adequacy of food resources is critical.
- Due to the small size of the Two Peoples Bay population, close management of all colonies to maximise numbers and genetic diversity will be required in planning translocations of potoroos.

Future directions

- Undertake analysis and publication of potaroo population demographics to determine future monitoring needs at all sites.
- Continue monitoring Middle Island translocation to evaluate its success.



Plant Science and Herbarium

Program Leader: Colin Yates Applied flora conservation research seeks to understand the factors and processes that are critical for the conservation of Western Australia's native plant diversity. Major objectives include ensuring the persistence of rare and threatened species, understanding key threats such as *Phytophthora* dieback and weeds, and improving the understanding of genetic and ecological factors that are vital for the long-term viability of plant species. Strong collaborative linkages exist with universities, cooperative research centres, CSIRO, other research providers such as the National Environmental Science Program and the corporate sector.

The program also includes the Western Australian Herbarium that houses the state collection of scientific specimens of plants, algae and fungi. Information in the collection underpins the conservation of the Western Australian flora. The Herbarium is responsible for: documenting and understanding the diversity of Western Australia's plants, algae and fungi; maintaining a research and archive collection of specimens of all species in these groups from throughout their range in Western Australia; helping the community, industry and researchers understand and identify plants, algae and fungi; contributing to, supporting and servicing the research, conservation and decision-making activities of government; contributing to taxonomic research by Australia's and the world's scientific community; providing authoritative information to government, industry and the community via the *FloraBase* website and the Herbarium's information management systems.



Molecular characterisation of stinking passionflower (*Passiflora foetida*)

SP 2018-041

T Hopley, M Byrne, S van Leeuwen

Context

Stinking passionflower (*Passiflora foetida*), a perennial vine native to South and Central America, is a highly invasive weed in the Pilbara and Kimberley regions of Western Australia, and in other parts of the world. In the Pilbara, the weed is rapidly expanding its abundance in areas with slightly higher moisture availability than the surrounding landscape, including coastal reserves and riparian habitats. Options for effective management of the weed in these areas are limited and biological control is being investigated as a potential management strategy in collaboration with CSIRO. Limited knowledge of the biology and life history of stinking passionflower is a significant impediment for implementing effective weed management strategies, including biological control. Ecological and genetic characterisation is required to understand the invasion ecology of the species and to guide the search for suitable biological control agents from the native range.

Aims

- Use molecular analysis of Australian collections, in the context of samples from the native range and other regions and countries where *P. foetida* is introduced, to identify and characterise the genetic entity(ies) present in Australia.
- Elucidate whether there are multiple origins for the Pilbara invasions.
- Confirm the level of relatedness of the invasive *P. foetida* to *Passiflora* species native to Australia and to commercial varieties.
- Characterise Pilbara populations relative to less invasive populations to identify any signal of adaption.

Progress

- A whole genome sequencing run was undertaken for a *P. foetida* sample to assist with whole chloroplast mapping and alignment as well as for future work on identifying SNPs for population genetic analysis and adaptation studies.
- Results from the whole genome sequencing were used to assemble a whole chloroplast genome of *P. foetida* and annotations from the publicly available *Passiflora* whole chloroplast sequences were used to annotate the completed whole chloroplast genome.
- Collections representing the introduced range in Australia have been made for 800 samples from 23 populations from Queensland, 18 populations from Northern Territory and eight populations from Western Australia. Of these, 438 samples representing 28 introduced range populations of Australia have had DNA extracted and been sent to Diversity Arrays Technology for sequencing.

Management implications

- Information on the potential taxonomic entities and origin of *P. foetida* in the Pilbara is essential to inform identification of, and guide the search for, putative control agents from the natural range.
- Information on local adaptation within invasive populations is important to understand the dynamics of invasion and determine the effectiveness of potential control agents.

Future directions

- Complete collection of samples for genetic work from across study populations in Australia.
- Prepare manuscript on whole chloroplast genetic analyses to clarify the species origin and invasion history in Australia.
- Undertake analyses to determine the genetic diversity and structure across the invaded range of Australia.



Is restoration working? An ecological genetic assessment

SP 2016-015

D Coates, M Byrne, M Millar, S Krauss, J Anthony

Context

The recognition of poorly defined success criteria and a lack of long term monitoring have highlighted the need for the development of post implementation empirical evaluations of the quality of restoration activities. This recognition has led to the hypothesis that the most ecologically and genetically viable restored populations will be those where reproductive outputs, plant pollinator interactions, levels of genetic diversity, mating systems and patterns of pollen dispersal most closely mimic those found in natural or undisturbed remnant vegetation. These populations are more likely to persist in the long term and contribute to effective ecosystem function through integration into the broader landscape. This project aims to assess the success of restoration in terms of ecological and genetic viability for plant species in the Fitzgerald River-Stirling Range region of Western Australia, where significant investment is being made in restoring connectivity at a landscape scale.

Aims

- Evaluate levels of genetic diversity for each of six target species, at each of the restoration sites at which they occur and in equivalent remnant reference sites.
- Evaluate mating system parameters for each of six target species, at each of the restoration sites at which they occur and in equivalent remnant reference sites.
- Evaluate patterns of pollen mediated gene dispersal in two proteaceous species.

Progress

- Restoration populations of *Acacia cyclops* have similar levels of genetic diversity and mating systems are not genetically differentiated from remnant populations. A manuscript entitled 'Assessment of genetic diversity and mating system of *Acacia cyclops* restoration and remnant populations' is in press in *Restoration Ecology*.
- Restoration populations of *Melaleuca acuminata* have similar levels of genetic diversity and mating systems and are not genetically differentiated from remnant populations. A manuscript entitled 'Genetic diversity, mating system, and reproductive output of restored *Melaleuca acuminata* populations are comparable to natural remnant populations' has been submitted to *Ecological Restoration*.
- Genetic diversity and mating systems are similar in restoration and remnant populations of *Banksia media*. Patterns of pollen dispersal vary across restoration populations, and proximity to remnant vegetation enhanced pollen immigration into restoration populations. Seed weights varied among sites and were greater for remnant populations. A manuscript reporting this work is being finalised.
- Genetic diversity and the mating system were largely equivalent among restoration and remnant populations of *Hakea nitida*, although divergence was surprisingly high. Random patterns of pollen dispersal were found, although pollen immigration was low in the restoration sites. A manuscript reporting this work is in preparation.
- Work on *H. laurina* has shown that genetic diversity is maintained in restoration populations. A lower outcrossing rate was observed at one restoration site, with greater inbreeding in restoration populations. Invertebrate floral visitor abundance varied at sites but richness did not. A draft manuscript on this work is in preparation.
- This work was presented at the 12th Australasian Plant Conservation Conference in November 2018.

Management implications

- Comparable genetic diversity in restored and remnant populations of all species indicate that restoration practices have been effective in establishing initial genetic viability in restoration populations.
- Restoration populations appear to have been established with local provenance material. The cause and effects of genetic divergence among the restoration and remnant population of *H. nitida* are unknown.
- General equivalency in mating systems among restoration and remnant populations suggest the presence of biotic pollinators in restoration sites of varying ages.
- The enhancement of pollen immigration with proximity of restoration populations to remnants should be considered in targeting future restoration sites.

Future directions

- Papers on each of the study species will be finalised.



Interactive key and taxonomic studies of Myrtaceae tribe Chamelaucieae

SP 2013-052

B Rye

Context

Taxonomic revision is required in various plant groups to facilitate appropriate determination of their conservation status. The main group of plants under study, Myrtaceae tribe Chamelaucieae, comprises over 800 species of shrubs, including over 200 unnamed species and subspecies. The lack of an adequate taxonomy continues to impede their conservation, study (in fields other than taxonomy) and commercial utilisation.

Aims

- Publish a series of taxonomic papers describing many new species, most of which have conservation priority, and in some cases also describe new genera or sections.
- Maintain a draft *Flora of Australia* treatment of tribe Chamelaucieae of the Myrtaceae.
- Produce and continually update an interactive key to members of this tribe.

Progress

- Short communications on *Babingtonia*, *Darwinia* and *Verticordia* (Myrtaceae) have been submitted to *Nuytsia*.
- A Paper on *Scholtzia* (Myrtaceae) has been published in *Nuytsia* and a paper on a new subtribal classification of Myrtaceae tribe Chamelaucieae has been submitted to *Australian Systematic Botany*.
- Papers on *Hypocalymma* and new generic boundaries in the subtribe Chamelauciinae are in preparation.
- Updates have been made to the interactive key to Myrtaceae tribe Chamelaucieae and it has been installed on *FloraBase*.

Management implications

- An improved understanding of the numbers and status of taxa will facilitate their management and conservation. For the large tribe Chamelaucieae, in which generic boundaries are still far from clear, an interactive key provides the best practical means of identification of all its members.

Future directions

- Start investigation of generic boundaries in subtribe Chamelauciinae based on molecular and morphological evidence, making new combinations and new genera where required.
- Submit papers on *Hypocalymma*, *Scholtzia* and the new subtribal classification (Myrtaceae).
- Complete articles for a special issue of *Nuytsia* planned for 2020.



Strategic taxonomic studies in families including Amaranthaceae and Fabaceae (*Ptilotus*, *Gomphrena*, *Swainsona*) and other plant groups

SP 2012-006

R Davis

Context

Ptilotus, *Gomphrena* and *Swainsona* are important genera, particularly in arid and semi-arid areas of Western Australia, such as the Pilbara and Midwest Regions, where they are often dominant components of the vegetation. This project undertakes basic taxonomic studies in these three genera, including the description of new species and taxonomic assessments of existing taxa, and preparation of a *Flora of Australia* treatment for the family Amaranthaceae. Development of interactive keys to all Western Australian species in the three genera are being undertaken, as these keys will allow easier and more accurate identifications of all species.

Aims

- Publish new taxa and review infraspecific taxa in the genus *Ptilotus*.
- Create interactive keys to all Western Australian species of *Ptilotus*, *Gomphrena* and *Swainsona*.
- Publish new taxa in other genera.

Progress

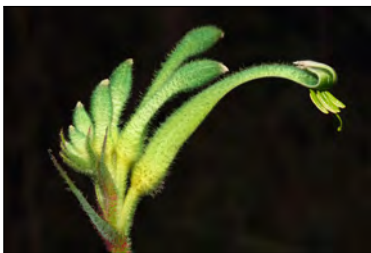
- Published descriptions of two new species of featherheads from the *Ptilotus macrocephalus* (Amaranthaceae) complex in *Australian Systematic Botany*.
- Published description of *Ptilotus actinocladius* (Amaranthaceae), a new and rare species from the Gascoyne bioregion, Western Australia in *Nuytsia*.
- Published description of *Ptilotus yapukaratja* (Amaranthaceae), a new species from the Gascoyne bioregion, Western Australia in *Nuytsia*.
- Published a key to *Ptilotus* (Amaranthaceae) in Western Australia in *Nuytsia*.
- Published descriptions of *Eremophila oldfieldii* subsp. *papula*, *E. sericea* and *E. xantholaema* (Scrophulariaceae), three new taxa from Western Australia in *Nuytsia*.

Management implications

- Clarifying the taxonomy and identification of *Ptilotus*, *Gomphrena* and *Swainsona* is important as these genera include indicator species and are significant for rangeland and arid land management and assessment. Many species are annuals, and *Swainsona* is a nitrogen-fixing legume. Some species of *Ptilotus* have been shown to have high phosphate uptake capabilities and are potentially useful in land restoration and rehabilitation programs. Several species within each genus are listed as threatened flora or are on the priority flora list. Having a sound taxonomic understanding of the species within these genera will enable the department to provide informed advice on the conservation status of the species and the communities they inhabit and how best they can be managed.

Future directions

- Preparation of further papers describing new taxa in *Ptilotus* and other genera.
- Further field studies to assist in the resolution of problematic groups within *Ptilotus*.
- Progress interactive keys to *Ptilotus*, *Gomphrena* and *Swainsona*.
- Finalise paper dealing with the synonymy of *Adenanthos pungens*.



The Western Australian Plant Census and Australian Plant Census

CF 2011-111

C Parker, J Percy-Bower, R Rees, M Falconer, E Wood-Ward, S Coffey, T Macfarlane, K Knight

Context

The Western Australian Plant Census (a component of WACensus) is the authoritative database of all names of plants in Western Australia, including synonyms created by taxonomic change. It is continually updated to reflect changes in our knowledge of the flora. The census constitutes the fundamental master list for many departmental processes and datasets, including the Threatened and Priority Flora databases maintained by the Species and Communities Program, the Herbarium's specimen database, Max, *FloraBase* and *NatureMap*.

The Australian Plant Census (APC) is a project of the Council of Heads of Australasian Herbaria, designed to provide a consensus view of all Australian plant taxa. Until now plant censuses have been only state-based, which has made it difficult to obtain authoritative information on what species occur in Australia as a whole, to obtain accurate national statistics, and to deal with differences in opinion and knowledge for taxa that cross state boundaries. In addition to working systematically through the vascular plant families, the APC process provides for updates as taxonomic changes or new findings are published. The consensus also extends from family and genus level to an overall classification of the plants that occur in Australia. As the APC project continues, the Western Australian Plant Census is updated to reflect the consensus view. The APC provides the key name list for the Atlas of Living Australia.

Aims

- Maintain an accurate and timely listing of all plants, algae and fungi in Western Australia, including both current names and synonyms, and integrate this with the national consensus.

Progress

- 423 plant names (363 formally published and 60 informal names) were added to WACensus.
- 1343 other edits were made to the WACensus.
- WACensus updates were regularly distributed to 262 registered Max users.
- Provided critical review of the final version of the list of all currently known taxa in the family Orchidaceae for Australia, which has resulted in nationally standardised names for Western Australian orchids.
- Contributed to discussions on taxonomy and nomenclature to assist in reaching national consensus for the National Species List (NSL), also known as Australian Plant Census.
- The State's contribution to maintenance of this national cooperative database continued with the addition of 168 new vascular plant names to the NSL database and creation of 931 new instances (data on synonymy and publications).

Management implications

- WACensus provides users with a single, authoritative official list of plants for Western Australia, with their currently accepted classification, scientific name, correct spelling and authority. Delivery of this information is through the *FloraBase* website, Max (departmental software for information based on taxonomic names) and other linked databases or websites.
- Users of plant names are able to access WACensus information to ensure that current information on names, taxonomic acceptance and occurrence in Western Australia is available for conservation status lists, publications, signage and legal requirements. Outdated names can be traced to their current status or updated name through WACensus.
- WACensus feeds Western Australian information to national biodiversity systems such as the Atlas of Living Australia, the Australian Plant Census (National Species List), e-flora of Australia and the Australasian Virtual Herbarium.

Future directions

- Continue to provide a comprehensive and up to date census across all plant groups.



The Western Australian Herbarium's specimen database

CF 2011-110

J Percy-Bower, K Knight, M Falconer, R Gillen, E Wood-Ward, S Coffey

Context

The Western Australian Herbarium's specimen database (WAHerb) allows staff at the Herbarium to manage and maintain the Herbarium's collections, and provides core data on the distribution, ecology and morphology of all taxa for the department and the community, through the *FloraBase* and *NatureMap* websites. Data from the specimen database is provided to researchers, consultants and community members on request, and to the Australasian Virtual Herbarium (AVH), Atlas of Living Australia (ALA) and the Global Biodiversity Information Facility (GBIF) on a regular basis.

Aims

- Capture, maintain and validate spatial, phenological, population and habitat data for all the Herbarium's collections, enabling curation of the collection and providing core data for *FloraBase* and departmental decision support systems and research.

Progress

- Addition of 10,862 records to WAHerb, including 972 priority flora, 159 threatened flora and four presumed extinct flora. The following projects and significant collections were databased: Fitzgerald River Flora Survey, Pilbara Inshore Islands Survey, Fortescue Valley Wetlands Survey, Mandora Marsh / Walyarta Survey, Central Ranges Expedition, South West Australian Transitional Transect, and collections from G Byrne, M Hislop, GJ Keighery and AN Start.
- Regularly provided customised specimen data requests (species lists and label data) to departmental officers, researchers and the public.
- 43,323 specimen records were edited as part of activities aimed at ensuring the collection is scientifically valid, up-to-date and aligned with the department's conservation codes.
- A significant task accomplished was the editing of ca. 1,500 fungi specimen records from the merge of the Manjimup Herbarium fungi collection.

Management implications

- WAHerb represents the most comprehensive database on Western Australian plants available and provides a source of information that managers can use for updates on biodiversity or conservation status, plant identification, clarification of plants in an area, and identification of knowledge gaps. This ensures that all research and management activities use up to date and valid plant species names.

Future directions

- Continue adding to, timely editing and validation of herbarium specimen records to maintain currency and connectivity between the Herbarium collection, the Western Australian Plant Census (WACensus) and external databases, including AVH and ALA.



Herbarium collections management

CF 2011-105

K Knight, C Parker, J Huisman, J Percy-Bower, R Rees, S Coffey, M Falconer, E Wood-Ward, M Hislop, R Davis

Context

The Western Australian Herbarium collection provides the core resource for knowledge of the State's plants, algae and fungi. The collection is growing constantly, through addition of new specimens representing new taxa and new records of existing taxa. The collection is maintained to a high standard, and provides the department and the community with the fundamental resource that provides knowledge of the diversity, distribution and abundance of plants throughout Western Australia.

Aims

- Fully document and audit the diversity of Western Australia's plants, algae and fungi.
- Maintain in perpetuity a comprehensive, adequate and representative research and archive collection of specimens of all taxa in these groups occurring in Western Australia.
- Contribute to, support and service the research, conservation and decision-making activities of the department.
- Contribute to, support and service taxonomic research by the world's scientific community.

Progress

- Addition of 10,862 specimens (including 972 priority flora, 159 threatened flora and four presumed extinct flora specimens) to the collection, which now stands at 802,107, a 1.37% increase in holdings.
- Loans and exchanges: loans outward - 20 loans consisting of 398 specimens; loans inward - 6 loans consisting of 436 specimens; loans returned to the Herbarium - 29 loans consisting of 1,683 specimens;

loans returned to their home institutions - 33 loans consisting of 1,965 specimens; exchanges inwards - 708 specimens; exchanges outwards - 1,308 specimens including 18 external requests for destructive sampling.

- The most significant achievements were databasing the 800,000th specimen, preparing specimens for the *Nuytsia* 2020 special edition and the curation of the Inocybaceae Fungi of Australia treatment.
- Tasks managed by collections staff with the assistance of volunteers were as follows: mounting and labelling 7,492 specimens; validating the name and occurrence of 1,088 incoming specimens for lodgement; labelling and incorporating ca. 1,500 fungi specimens; incorporating 8,190 specimens; added printed collection information to 801 accessioned specimen backlogs; entering data for 1,071 specimens into Max database format.
- Volunteer participation was significant, totalling 10,198 hours, which is equivalent to ca. 5.8 full time employees. Eleven volunteers were recruited bringing the total working at the Herbarium to 60.
- Maintained the Reference Herbarium facility, which has 14,715 specimens representing 11,871 taxa as well as adding or replacing 136 specimens and removing ca. 340 replicated *Verticordia* specimens. This resource was used by ca. 1,600 visitors to identify plant specimens during 2018-19.
- Research collection was accessed by ca. 800 visitors to study taxa or help with flora identification.
- Provided 40 high resolution scans of Herbarium specimens to departmental staff and industry consultants to aid in the identification and location of known and new populations of priority and threatened taxa, and to scientists for research purposes.
- Scanned 160 Types for the Global Plants Initiative, where Western Australian Herbarium Type specimens are now accessible to the world's scientific community for study.
- Significant collections lodged included industry surveys, departmental regional surveys, Herbarium staff and Research Associates, Ausplot Vouchers, Nimalarragan Survey, Fortescue Valley Wetlands Survey, Kimberley Mound Springs Survey, and collections from SD Hopper.
- The Herbarium Identification Program provided identifications to a range of clients and specialises in taxa and specimens that clients find challenging. Our most significant clients included departmental staff, other government agencies, environmental consultancies, regional herbaria and the public.
- Educational role continued with staff providing tours of the Herbarium for departmental staff, tertiary institutions, environmental consultancies, community groups and the media.

Management implications

- Maintenance and curation of the Herbarium collections provides an authoritative inventory of the plant biodiversity of Western Australia underpinning flora conservation and research programs. The collections are drawn upon constantly by department staff, consultants and others for validating specimen records from biological surveys and for assessing the conservation status of native taxa.

Future directions

- Continue to maintain the collection to an authoritative standard for all users.
- Continue to review and document collections management policy and procedures, to effect efficiencies and reflect modern herbarium practices, and where applicable make these available on the Herbarium webpage.
- Recruit a sustainable number (ca. 20 per year) of volunteers to assist in key Herbarium functions.
- Align the collection and datasets with the recently published *Algae of Australia: Marine Benthic Algae of North-western Australia, 2. Red Algae*.
- Curate the Myxomycete collection.



Biodiversity informatics at the Western Australian Herbarium

CF 2011-104

B Richardson

Context

FloraBase, the web information system for the Western Australian flora, is the department's main means of communicating botanical taxonomic information. *FloraBase* draws from three corporate datasets maintained by the Herbarium, dealing with names (WACensus), specimens (WAHerb) and images (Imagebank). Managing the currency, authority, data quality and linkages between these datasets is an important task, both for the maintenance of *FloraBase* and for Western Australia's contributions to national and global plant information resources such as the Atlas of Living Australia (ALA) and the Global Biodiversity Information Facility (GBIF). WAHerb is the Herbarium's specimen database, currently holding data on over 792,000 specimens. It is the sole source of specimen data used by *FloraBase*. Imagebank is the Herbarium's image collection, currently containing data and files for nearly 74,000 images.

Aims

- Deliver authoritative taxon, specimen and image information on all Western Australian vascular plants, algae, fungi, lichens, mosses and slime moulds to a wide audience, using efficient, effective and rigorous web-based technologies.
- Deliver the department's biodiversity data to the internet using standards-compliant web services and data structures.

Progress

- Maintenance of the *FloraBase* application and content continued, including upgraded infrastructure, regular *Nuytsia* sub-site updates to support ongoing journal releases, and six other bug fixes for *FloraBase*.
- Maintenance of Imagebank continued, including a fix for auditing processes, corrections to the way the application interacts with WAHerb specimens and better download options.
- Maintenance of WAHerb continued, including a major refresh of the management of comment data, both for the specimen as a whole, and specifically for identifications, and eight other bug fixes for WAHerb.
- Maintenance of the publishing system continued with 24 bug fixes supporting changes to WAHerb, WACensus, Office of Information Management infrastructure, and flora statistics handling.

Management implications

- *FloraBase* allows the community and department staff to retrieve the most recent information on the name, features, status and distribution of the 13,867 currently recognised native and naturalised Western Australian vascular plant taxa and 2,572 alga, fungus, lichen, moss and slime mould taxa. Species conservation and land management efforts across the state are made more effective by access to this authoritative information.
- WAHerb is the authoritative source of data for any application relying on Western Australian plant specimen data, and as such it is crucial to many applications, including *FloraBase*, Australasian Virtual Herbarium, the ALA and GBIF.
- Imagebank is the authoritative source of data for Western Australian vascular plant images, with full support for images of other taxon groups such as mammals, insects and fungi. It is also the source of data for other applications such as *FloraBase* and ALA.
- Involvement in national and international informatics collaborations enables Western Australia to participate fully in new developments in these areas, ensures that Western Australian data is made available to the broadest possible audience, and ensures that data from other sources can be integrated with local data for the more effective delivery of research outputs and outcomes.

Future directions

- Complete a review of the display of Imagebank images in *FloraBase*.
- Restart the maintenance of *FloraBase*'s search data, derived from the Descriptive Catalogue and enhanced to support algae, fungi, lichens, mosses and slime moulds, as part of *FloraBase* 3.
- Upgrade the mapping interface to make better use of modern mapping tools, and link to related tools, such as *NatureMap* and ALA.
- Implement a major revision of *FloraBase*, providing better decision-making support for tablets and phones and using ALA infrastructure, where suitable, to maximise the reuse of authoritative resources available across the Australian biodiversity information network.
- Add new content, including flora treatments from ALA's eFlora project.

- Commence a project to migrate WAHerb to a new collections management system.
- Develop further standards to facilitate and participate in national and international bio-infrastructure projects, such as ALA and GBIF, and common departmental online services.



Taxonomy of undescribed taxa in the Ericaceae subfamily Styphelioideae, with an emphasis on those of conservation concern

SP 2011-015

M Hislop

Context

Recent phylogenetic studies have foreshadowed significant changes to the classification of the epacrids at the generic level. The major effect of this will be the transfer to a much expanded *Styphelia* of all taxa currently in *Astroloma* (27 taxa), *Coleanthera* (3) and *Croninia* (1), as well as 108 now placed in *Leucopogon*. A paper to be published in the second half of 2019 will formalise the transfer of all of the previously described species to *Styphelia*. This will facilitate the process of describing the many phrase name taxa of *Styphelia* (i.e. in the newly expanded sense) that are currently listed under *Leucopogon*, a significant number of these being short range endemics of conservation significance. In addition there are still many species of *Leucopogon* s. str. in need of formal names.

Aims

- Publish new taxa from the tribes *Styphelieae* and *Oligarrheneae*, prioritising those of high conservation significance.
- Continue a taxonomic assessment of species boundaries across the tribe *Styphelieae* (mainly in *Leucopogon* and *Styphelia*) with a view to identifying previously unrecognised taxa, especially those which may be geographically restricted.

Progress

- A collaborative nomenclatural paper formalising the transfer to *Styphelia* of species currently in *Leucopogon*, *Astroloma*, *Coleanthera* and *Croninia*, has been accepted by *Australian Systematic Botany*.
- A collaborative paper dealing with the taxonomy of the *Styphelia xerophylla* species group has been accepted by *Nuytsia*. This includes four new species, all of which are of conservation significance.
- A paper describing two anomalous and geographically restricted new species of *Styphelia* has been submitted to *Nuytsia*.
- Two single species papers have been prepared for the *Nuytsia* special anniversary edition, describing a new species of *Leucopogon* and a new *Stenanthera*. Both are of high conservation significance.
- Four new phrase-name taxa, *Styphelia* sp. Tarin Rock, *S.* sp. Wandoo, *Leucopogon* sp. Cascades and *L.* sp. Kirup were added to the census. All are of high conservation significance.

Management implications

- The epacrids, of which *Styphelia* (in the newly expanded sense) and *Leucopogon* are by far the largest genera, have a major centre of diversity in south-west Western Australia. An authoritative source of current information is fundamental to correctly managing the conservation taxa and the lands on which they occur for this taxonomically difficult group that is also very susceptible to a number of major threatening processes, including salinity and *Phytophthora* dieback.

Future directions

- Preparation of further papers describing new taxa mostly in *Styphelia* and *Leucopogon*.
- Further field studies to assist in the taxonomic resolution of potentially new taxa in the tribe *Styphelieae*.



Resolving the systematics and taxonomy of *Tephrosia* in Western Australia

SP 2011-002

R Butcher, T Macfarlane

Context

Tephrosia is a large, pantropical legume genus comprising c. 400 species of herbs and shrubs. Sixty-three taxa are currently recognised in the Eremaean and Northern Botanical Provinces of Western Australia; including 28 phrase-named taxa, with a number of species complexes requiring further study. *Tephrosia* specimens are frequently collected during vegetation surveys for proposed mining developments in northern Western Australia; however, many of them cannot be adequately identified as they belong to poorly-known, undescribed taxa or to species complexes. Their identification is further hindered by the absence of up-to-date taxonomic keys and of comparable specimens, as many species of *Tephrosia* grow in remote areas and are poorly collected. Identification difficulties inhibit the accurate assessment of each taxon's distribution and hence its conservation status.

Aims

- Resolve the taxonomy of *Tephrosia* in Western Australia and the Northern Territory using morphological and molecular approaches.
- Assess the conservation status of all Western Australian taxa.
- Prepare an electronic Flora treatment of the genus in Western Australia and the Northern Territory (for the *eFlora of Australia*).
- Prepare identification tools, including an electronic key to the genus Australia-wide.
- Contribute to international phylogenetic research on *Tephrosia* and allied genera.

Progress

- Two species descriptions were published in *Nuytsia* and a paper was submitted to *Nuytsia*.
- A series of papers describing new species of *Tephrosia* in Western Australia and the Northern Territory are in preparation.
- Four months were spent at the Northern Territory Herbarium studying specimens, curating the collection and preparing descriptions for new and revised taxa, as well as sampling specimens for molecular analysis.
- One new taxon (*T. sp.* Lake Nash) was recognised from central Australia.
- One newly recognised taxon (*T. sp.* Glenormiston) was found to also occur in the Northern Territory.
- 184 samples for molecular analysis were processed and sent to overseas collaborators. These represented 93 taxa, 77 being new additions to the study (37 from Western Australia (seven endemic), 21 from Northern Territory (13 endemic) and 19 from Queensland and other states), meaning the molecular phylogenetic study will include a high proportion of the Australian species.
- Ongoing curation of the Western Australian Herbarium's research and reference collections and ImageBank images was undertaken.

Management implications

- Providing names, scientific descriptions, illustrations and identification tools for the various *Tephrosia* in Western Australia will enable industry and conservation practitioners to accurately identify taxa, thereby improving their management and the assessment of their conservation status. If it is found that the individual *Tephrosia* taxa can be identified through DNA barcoding, this method will enable sterile or poor specimens, often collected during botanical surveys, to be accurately identified.
- Collaborative research with *Tephrosia* experts in the Northern Territory and Queensland, will allow novel forms collected in Western Australia to be more readily and rapidly identified as either first records for the state of taxa occurring elsewhere in Australia, or as taxa truly new to science. This will prevent the proliferation of superfluous names on the vascular plant census, improve the accuracy and utility of the *Australasian Virtual Herbarium*, and increase certainty for stakeholders.

Future directions

- Review variation in existing named taxa occurring in Western Australia and the Northern Territory, revise descriptions where necessary, and publish papers describing new species.
- Conduct follow-up field work in the Northern Territory.
- Conduct a research visit to the Queensland Herbarium.
- Continue production of a revisionary treatment of *Tephrosia* in Western Australia and the Northern Territory for the *eFlora of Australia*, and a key to all *Tephrosia* taxa Australia-wide.



Taxonomy of selected families including legumes, grasses and lilies

SP 2011-001

T Macfarlane

Context

Successful conservation of the flora requires that the conservation units equate to properly defined, described and named taxa. There are numerous known and suspected unnamed taxa in the grass, legume and 'lily' (now Asparagaceae, Hemerocallidaceae) families, as well as numerous cases where keying problems or anomalous distributions indicate that taxonomic review is required. This is true of various parts of the families but the main current focus is on *Althenia* (formerly *Lepilaena*), *Thysanotus*, *Wurmbea*, *Lomandra*, *Neurachne* and *Trithuria*.

Aims

- Identify plant groups where there are taxonomic issues that need to be resolved, including apparently new species to be described and unsatisfactory taxonomy that requires clarification.
- Carry out taxonomic revisions using fieldwork, herbarium collections and laboratory work, resulting in published journal articles.

Progress

- *Althenia* (Potamogetonaceae; formerly *Lepilaena*): a genus of aquatic plants that have been difficult to identify has been studied from all Australian herbarium specimen holdings and species boundaries have been defined. A new Western Australian species, for which a draft description has been prepared, was sought in the field and a substantial range extension discovered, with additional research material obtained. New molecular phylogenetic results were obtained from international colleagues, for inclusion in a forthcoming paper.
- *Wurmbea* (Colchicaceae): continuing work on describing thirty new species, including preparation of plates of photographs. Recent progress includes field study of little-known taxa in the Wheatbelt and Esperance but otherwise limited by a dry season; processing of herbarium material; descriptive data collection and work on an identification key.
- Hydatellaceae: a paper on the molecular phylogeny and genetic variation in the *Trithuria australis* was published, including description of a new species, *T. fitzgeraldii*.
- Hydatellaceae: led field work with interstate collaborators to collect samples for preparation of a whole genome DNA sequence, considered important because of the exceptional scientific interest of the 'basal' phylogenetic position of this family (*Trithuria* is the only genus).
- *Thysanotus* (Asparagaceae): review of the taxonomy of the twining species, the *T. patersonii* group, continued with further field work, herbarium study and preparation of photographic plates towards preparation for publication. Herbarium studies continued on various non-twining species including adding to draft papers and registration of three new phrase-named species.
- *Lomandra* (Asparagaceae): paper being drafted on *L. suaveolens* group.
- *Corynotheca* (Asparagales): a taxonomic revision is in advanced draft.

- Asparagales: collaboration continued on a wider, phylogenetic study of the Asparagales order of families and the DNA sequence data obtained is currently being analysed.
- Poaceae: continuing research collaboration on *Neurachne* and the evolution of C₄ photosynthesis. Contributions were made to a paper in preparation concerning the phylogenetic origins of C₄ photosynthesis in *Neurachne*. Field work was carried out in the Northern Territory to obtain live plants of two species for the living collection.
- Poaceae: an invitation to participate in the Plant and Fungi Tree of Life project at the Royal Botanic Gardens, Kew, UK led to a contribution of samples of grasses sourced from field and herbarium for DNA analysis. Contributions from other Australian grass specialists were coordinated. This project is expected to achieve a phylogeny with coverage of most genera in this very large family.
- Anarthriaceae: This poorly known WA endemic family is closely related to the economically important grass family. A paper was published in *Botanical Journal of the Linnean Society* with international colleagues on the development of female reproductive morphology of Western Australian endemic plants in *Hopkinsia*, *Lyginia* and *Anarthria* and a second paper submitted dealing with male reproductive development.
- Priority conservation species: a set of papers is being written, describing species for a special series of the Herbarium journal *Nuytsia* in 2020.

Management implications

- Identification of species known or suspected to have a restricted distribution will enable re-assessment of the conservation status and improve management effectiveness. Improved identification tools will enable more effective and reliable identification of species and the subsequent assessment of their conservation status.

Future directions

- Complete and submit papers describing new species of *Wurmbea*, *Thysanotus*, *Lepilaena* and *Lomandra*.
- Conduct appropriate field searches for species or populations of relevant families that are insufficiently known.
- Continue to revise plant groups and investigate via field and herbarium studies various putatively new species in order to improve knowledge of the flora, provide stable plant names, and provide a means of identifying species. Current focus is on the special 2020 *Nuytsia* series.
- Publish information on selected plant groups for general audiences.



Systematics of the triggerplant genus *Stylidium*

SP 2010-001

J Wege

Context

With more than 300 known taxa, the triggerplant genus *Stylidium* is one of the most abundant and diversified genera in Australia. While substantial progress has been made over the past 20 years in documenting Australia's *Stylidium* diversity, our knowledge of the genus remains insufficient for scientific and conservation needs. There are new taxa awaiting formal description, species complexes that remain poorly understood, and a number of nomenclature and typification issues that require resolution. Perhaps the most significant issue at this point in time is the lack of an overarching flora treatment for the family Stylidiaceae, which hinders accurate identification by conservation personnel, botanical consultants and other stakeholders. This is concerning given the high proportion of taxa that require further survey to understand the full extent of their distribution and their conservation requirements.

Aims

- Improve the underlying taxonomic knowledge necessary for effective biodiversity management of the triggerplant family Stylidiaceae and make this information readily accessible to stakeholders.
- Investigate phylogenetic relationships within *Stylidium* and use these data to inform taxonomic research and conservation management.

Progress

- A paper describing a newly discovered species of *Stylidium* from the Mallee bioregion was accepted for publication in next year's special issue of *Nuytsia*.
- A taxonomic revision of the Australian endemic genus *Levenhookia* is near completion. This research has included taxonomic verification of more than 1,500 diminutive specimens at herbaria in Perth, Darwin, Adelaide, Melbourne and Canberra, and has resulted in the discovery of a new Western Australian species.
- Targeted field work was conducted in south-western Australia to help resolve outstanding taxonomic issues: 27 herbarium collections were acquired along with photographs for use on *FloraBase* and the digital *Flora of Australia* platform.
- A month-long research visit to the Northern Territory Herbarium was conducted to advance the *Flora of Australia* account of the triggerplants from northern Australia. Data were obtained by examining spirit collections and associated pressed material, with more than 300 collections annotated (about a third of which were corrections to misidentifications). At least one novel species endemic to the Northern Territory was discovered along with a number of new records of poorly known species.
- A collaborative paper on detecting canalization and intra-floral modularity in *Stylidium* was published in *Annals of Botany*.

Management implications

- Taxonomic research continues to improve our knowledge of Australia's triggerplant flora, with baseline data on the distribution, habitat requirements and conservation status of each species informing on-ground conservation efforts.

Future directions

- Continue writing species profiles for the *Flora of Australia*.
- Continue taxonomic validation of specimens housed at Australian herbaria.
- Conduct targeted field work to advance research publications and the *Flora of Australia* treatment.
- Prepare publications describing novel taxa, resolving typification issues, and documenting evolutionary relationships.



Taxonomic review and floristic studies of the benthic marine algae of north-western Australian and floristic surveys of Western Australian marine benthic algae

SP 2009-009

J Huisman, C Parker

Context

This project involves systematic research into a poorly known group of Western Australian plants and is directly relevant to the department's nature conservation programs. It includes floristic studies of the marine plants of several existing/proposed marine parks and also areas of commercial interest (Shoalwater, Marmion, Ningaloo, Dampier Archipelago, Barrow Island, Montebello Islands, Rowley Shoals, Scott Reef, Maret Islands, etc.) to provide baseline information that will enable a more comprehensive assessment of the Western Australian marine biodiversity.

Aims

- Collect, curate and establish a collection of marine plants representative of the Western Australian marine flora, supplementing the existing Western Australian Herbarium collection.
- Assess the biodiversity of the marine flora of Western Australia, concentrating initially on the poorly-known flora of the tropics.
- Prepare a marine flora for north-western Australia, documenting this biodiversity.

Progress

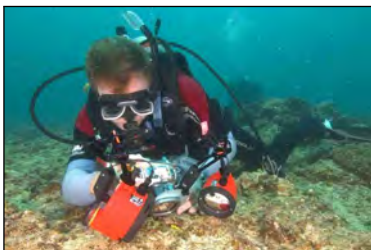
- Description of the new species *Champia patula* has been published and a new species of the red algal genus *Leptofauchea* was recognised in collections from the Houtman Abrolhos.
- A major monograph describing the genus *Caulerpa* in southern Australia was published, including several revised taxa and the new species *Caulerpa perplexa* from Rottnest Island.
- Addition of c. 40 new species of marine algae to WACensus and 580 new specimens of marine benthic algae to the Western Australia Herbarium collection.

Management implications

- Easier identification of marine plant species leads to a more comprehensive understanding of their conservation status, recognition of regions with high biodiversity and/or rare species, recognition of rare species, recognition of potentially introduced species, and discrimination of closely-related native species.
- Enhanced knowledge of marine plant species allows a more accurate assessment of management needs and potential impacts of environmental change, including change conferred by resource developments, biosecurity breaches and climate change.

Future directions

- Further surveys of the marine algae of Western Australia including at Coral Bay, the Capes region in the south-west of Western Australia, and sites in the Perth region including Cape Peron and Rottnest Island.
- Publication of papers describing new and existing genera, species and other categories.
- Finalise a paper describing a new species of the red alga *Leptofauchea*, collected from the Houtman Abrolhos.



The Western Australian marine benthic algae online and an interactive key to the genera of Australian marine benthic algae

SP 2009-008

J Huisman, C Parker

Context

This project is a direct successor to the 'Western Australian Marine Plants Online' and will provide descriptions of the entire Western Australian marine flora as currently known, accessible through *FloraBase*. Interactive keys enable positive identification of specimens and provide a user-friendly resource that enables the identification of marine plants by non-experts. It will be of great value in systematic research, teaching, environmental and ecological research, and additionally in environmental monitoring and quarantine procedures.

Aims

- Prepare an interactive key to the approximately 600 genera of Australian marine macroalgae.
- Provide online descriptions of the Western Australian marine flora, including morphological and reproductive features, to enable easy comparison between species.
- Provide online descriptions of higher taxa (genus and above).
- Incorporate descriptions and images of newly described or recorded taxa of marine flora into *FloraBase*.

Progress

- Descriptions of over 600 genera have been compiled for use in the interactive key.
- Numerous additional *in situ* (particularly from the Perth region) and microscopic images of marine algae have been taken. Over 40 new images have been uploaded to ImageBank/*FloraBase*.
- Data for 580 algal specimens newly added to the Western Australia Herbarium collection are now available via *FloraBase*, significantly improving taxonomic and distribution knowledge concerning the Western Australian marine flora.
- Approximately 40 new species of marine algae have been added to WACensus and c. 600 existing WAHerb records have been edited (associated with synonymy, cited specimens and family changes).

Management implications

- Easier identification of marine plant species will lead to a more accurate understanding of their conservation status, and enhanced knowledge of marine biodiversity that will permit a more accurate assessment of management proposals/practices and threats to biodiversity.
- Provision of a readily available web-based information system will facilitate easy access by managers, researchers, community and other marine stakeholders to marine plant species inventories and up-to-date names.

Future directions

- Finalise the interactive key.
- Continue collating existing species descriptions and write new descriptions for uploading to *FloraBase*.
- Upload additional marine plant images to ImageBank/*FloraBase*.



Taxonomic resolution and description of new plant species, particularly priority flora from those areas subject to mining in Western Australia

SP 2009-006

J Wege, K Shepherd, M Hislop, B Rye, T Macfarlane, R Davis, S Dillon, R Butcher, C Wilkins

Context

Western Australia has a rich flora that is far from fully known. New species continue to be discovered through the taxonomic assessment of herbarium collections, floristic surveys and the botanical assessment of mineral leases. There are 1,196 putatively new and undescribed taxa on Western Australia's vascular plant census, 578 of which are poorly known, geographically restricted and/or under threat (i.e. Threatened or Priority Flora). The lack of detailed information on these taxa makes accurate identification problematic and inevitably delays the Department's ability to survey and accurately assess their conservation status.

Aims

- Resolve the taxonomy and expedite the description of manuscript or phrase-named plant taxa, particularly threatened and priority flora and those taxa vulnerable to future mining activities.

Progress

- Twenty three new, rare or poorly known taxa in *Acacia*, *Eremophila*, *Lasiopetalum*, *Ptilotus* and *Scholtzia* were described in *Nuytsia*.
- An additional 14 papers describing assorted conservation-listed taxa were submitted for publication, of which 12 are contributions to a special issue of *Nuytsia* being planned for 2020.
- *Gastrolobium* Harvey (G.J. Keighery 16821) was shown to be synonymous with *G. capitatum* and was removed from WACensus and the Threatened and Priority Flora list.

- Targeted field work to obtain type material or resolve the taxonomy of 12 undescribed, conservation-listed taxa was successfully completed. This included the relocation of the only known population of *Arthropodium* sp. Yenyenning following a series of unsuccessful searches spanning many years. A new population of the potentially threatened species *Stylidium validum* was also discovered.
- A collaboration with regional staff to survey the threatened species *Trithuria occidentalis* has resulted in a recommendation to downgrade its status from Critically Endangered to Endangered.
- Team members discovered seven putative new taxa that were added to the State's vascular plant census and Threatened and Priority flora list.

Management implications

- The provision of names, scientific descriptions, illustrations and associated data will enhance the capacity of conservation and industry practitioners to identify new species, thereby improving species management, conservation assessments and land use planning.

Future directions

- Identify and formally describe new taxa of conservation significance.



Genetic and ecological viability of plant populations in remnant vegetation

SP 2002-001

M Byrne, C Yates, S McArthur

Context

A priority for long-term conservation of remnant vegetation is the maintenance of viable plant populations. However, little is currently known about what biological factors actually affect population persistence. This project quantifies genetic and ecological factors that influence the viability of plant populations in fragmented Western Australian agricultural landscapes and explores how these are affected by remnant vegetation characteristics such as size, shape, isolation, disturbance and landscape position.

Aims

- Identify and quantify the genetic and demographic factors that affect the viability of plant populations in vegetation remnants. The focus will be on the effects of genetic erosion, inbreeding and pollinator limitation on seed production and seedling fitness.
- Examine and model the relationships between key genetic and demographic factors affecting viability and remnant vegetation characteristics, such as size, disturbance and landscape position.
- Develop specific genetic and demographic guidelines for management of remnant populations of the target taxa and general landscape design principles for major plant life-history types that will maximise the probability of population persistence.
- Develop an understanding of the population biology, mating systems and gene flow of flora with distributions centred on the seasonally wet Busselton ironstone communities to inform management for long-term conservation in relation to population viability (population size and degree of connection) and appropriate fire frequency.

Progress

- A paper on pollen dispersal and mating system in *Banksia nivea* subsp. *uliginosa* has been published in *Biological Journal of the Linnean Society*, and a paper on reproductive biology and demography in *B. nivea* subsp. *uliginosa* is accepted in *Botanical Journal of the Linnean Society*.

Management implications

- The ability to rapidly and accurately assess the conservation value of a vegetation remnant is a critical step in landscape management aimed at integrating the goals of conservation and agricultural production. Currently much of this assessment is based on best guesses using anecdotal species-specific evidence, on the general principle that bigger is better, and on simple presence and absence data that take little account of long-term remnant trajectories. Improved accuracy of assessment of long-term persistence of broad classes of plant species will facilitate improved prioritisation of remnants for conservation and therefore better allocation of limited management resources.
- Establishment of realistic empirically-based goals for remnant size, shape and landscape configuration that maximise regional persistence of plant species will allow more efficient conservation efforts at the landscape level by facilitating cost-benefit analyses for remnant management and restoration work.
- Levels of secondary soil salinity should be assessed and monitored in high-value vegetation remnants in agricultural landscapes. A study of *Eucalyptus wandoo* revealed that low to moderate levels of soil salinity can have highly significant sub-lethal effects on reproductive output, which are likely to translate to reduced population viability.

Future directions

- Finalise a paper on mating system variation and reproductive output in *Eremaea pauciflora*.
- Finalise paper on genetic diversity in *B. nivea* subsp. *uliginosa*.



Translocation of critically endangered plants

SP 2001-004

L Monks, R Dillon, C Yates, M Byrne

Context

The contribution of translocations (augmentation, reintroductions, introductions) of threatened flora to the successful recovery of species requires development of best-practice techniques and a clear understanding of how to assess and predict translocation success.

Aims

- Develop appropriate translocation techniques for a range of Critically Endangered and other threatened flora considered a priority for translocation.
- Develop detailed protocols for assessing and predicting translocation success.
- Establish a translocation database for all threatened plant translocations in Western Australia.

Progress

- Completed infill planting for one translocation of the Critically Endangered *Banksia cuneata*.
- Assisted District and Regional staff plan and implemented flora translocations for a range of Critically Endangered flora (*Eucalyptus cuprea*, *Grevillea bracteosa* subsp. *howatharra*, *B. anatona*, *B. brownii*, *B. montana*, *Eremophila nivea*, *E. rostrata* subsp. *trifida* and *Verticordia spicata* subsp. *squamosa*).
- Co-authored and published a scientific review of flora translocations within Australia in *Biological Conservation*.
- Co-authored and edited five chapters in the recently published book *Guidelines for Translocation of Threatened Plants in Australia*.
- Finalised planning for experimental translocation of *Lambertia orbifolia* to assess fitness consequences of mixing genetically divergent lineages and the potential for increasing genetic diversity in translocated populations (genetic rescue).
- Commenced meta-analysis of flora translocation data from 22 years of plantings to examine factors that contribute to translocation success.

- Commenced analysis of demographic data from *Acacia cochlocarpa* subsp. *cochlocarpa* translocations for inclusion in a population model to assess the viability of translocated populations.

Management implications

- Translocations lead to improved probability of persistence for threatened flora, particularly Critically Endangered plant species. Ongoing monitoring of translocations is providing information on the success of methods used and the probability of long-term success. Close collaboration with District and Regional staff enables this information to be used immediately to inform other flora translocation projects.
- Further development of success criteria and methods for analysing long-term success, such as the use of Population Viability Analysis (PVA), mating system analysis and genetic variability analysis, will ensure completion criteria are adequately addressed and resources can confidently be re-allocated to new translocation projects.
- The improved awareness of best-practice translocation methods for departmental staff and community members undertaking such work, leads to greater translocation success.

Future directions

- Continue the planting of experimental translocations of Critically Endangered and other threatened flora where further translocations are deemed necessary, and continue monitoring translocations and evaluating success.
- Develop alternative criteria for evaluating success such as PVA, mating system and genetic variability analysis.
- Complete a review and meta-analysis on translocation methodologies, outcomes and success in Western Australia.
- Publish paper on *L. orbifolia* PVA study.
- Develop PVA model for translocated and natural populations of *A. cochlocarpa* subsp. *cochlocarpa* using demographic data collected over past five years.
- Establish an experimental admixed population of *L. orbifolia*.



Mating system variation, genetic diversity and viability of small fragmented populations of threatened flora, and other key plants of conservation importance

SP 2001-001

M Byrne, S McArthur, L Monks, R Dillon

Context

Understanding the interaction between mating systems, levels of inbreeding and patterns of genetic variation within populations of species is a key element in assessing the viability of plant populations, particularly rare and threatened taxa, and the development of management strategies that reduce the likelihood of local extinction and increase the probability of successful establishment of restored populations.

Aims

- Assess the relationship between effective population size and levels of genetic diversity, and the minimum effective population size for maintaining genetic diversity in natural and restored populations.
- Assess the effects of population size and habitat degradation on mating system parameters that indicate inbreeding or the potential for inbreeding.
- Assess whether reduction in population size, increased inbreeding and reduced genetic variation are associated with any reduction in fitness.
- Assess whether there are differences in the levels of genetic diversity and mating system parameters between rare and common congeners, which will provide a more general understanding of rarity in this flora and how it can be managed.

Progress

- Genotyping has been completed and data analysis underway for two translocated *Banksia brownii* populations and seven natural populations to assess mating system variation and genetic diversity, and benchmark mating system performance and genetic diversity in the translocated populations.
- Data collection is finalised for pollination studies on *B. brownii* at one montane and two lowland populations, and one translocated population, to assess pollination adequacy in the translocated population and suspected differences in pollinator type between montane and lowland populations.
- Assessment of fitness trait studies are ongoing in a common garden experiment involving 1,100 seedlings of *B. brownii* from montane and lowland populations, and a translocated population, to examine trait differences between montane and lowland populations, and implications for population mixing, and to benchmark the performance of the translocated population.
- Analysis of data from a genetic diversity study and crossing study on the Critically Endangered *Schoenia filifolia* subsp. *filifolia* and another subspecies is underway. These studies aim to evaluate the level of genetic differentiation between subspecies and whether genetic rescue involving crossing between subspecies is a feasible management option.
- Genotyping has commenced on leaf material collected from three translocated and seven natural populations of *Lambertia orbifolia*. Geneotyping will enable the assessment of mating system variation and genetic variability, and benchmark mating system performance and genetic diversity in translocated populations.
- Genotyping has been completed and data analysis underway for natural and translocated populations of *Acacia cochlocarpa* subsp. *cochlocarpa* and *A. cochlocarpa* subsp. *velutinos*. This study will benchmark genetic diversity in translocated and natural populations of *A. cochlocarpa* subsp. *cochlocarpa* and assess genetic structure across the range of both subspecies.
- Genotyping and mating system studies are underway for *B. anationa* to assess mating system performance and genetic diversity in a translocated population compared to natural populations.

Management implications

- Assessment of genetic variation and mating system parameters will inform prescriptions for the prevention of inbreeding and maintenance of genetic variation in small fragmented populations of rare and threatened plants, and will facilitate strategies for managing inbreeding and loss of genetic diversity during translocation programs involving species such as *B. brownii*, *L. orbifolia*, *A. cochlocarpa* and *S. filifolia*.

Future directions

- Finalise mating system and genetic diversity analyses on translocated and natural populations of *B. brownii*, *L. orbifolia*, *A. cochlocarpa* and *S. filifolia*.



The population ecology of critically endangered flora

SP 2000-015

C Yates, N Gibson, C Gosper

Context

South-west Western Australia is a global hotspot of plant diversity. Determining the relative importance of multiple threatening processes, including the interactions between fragmentation and small population processes, fire regimes, weed invasion and grazing regimes, is critical for conservation and management of threatened flora and threatened ecological communities.

Aims

- Determine the critical biological factors and the relative importance of contemporary ecological interactions and processes that limit population viability and persistence of threatened flora, particularly Critically Endangered species and other key plant species occurring in threatened ecological communities (TECs).

Progress

- Continued monitoring the demography of the Critically Endangered *Verticordia staminosa* subsp. *staminosa* in relation to a drying climate in south-west Western Australia.
- Resumed annual monitoring of the Eastern Stirling Range Montane Heath and Thicket TEC and associated threatened flora to assess the impacts of the May 2018 bushfire.
- Established an experiment investigating the impact of vertebrate grazing and fire interval on the recovery of the Critically Endangered *Banksia anaton* following the May 2018 bushfire in the Stirling Range National Park.
- Continued monitoring the demography of the Critically Endangered *Banksia verticillata* and the impact of fire in Torndirrup National Park.
- Reviewed, collated and analysed demographic data for *B. verticillata* and developed a population model for *B. verticillata* to investigate the impacts of canker disease, fire-interval and fire patchiness on the taxon's extinction risk.
- Continued monitoring an experiment investigating the impact of *Phytophthora* dieback and fire on the population dynamics of the Critically Endangered *Andersonia pinaster*.
- Commenced an experiment investigating the impact of environmental weed management on the population dynamics and recovery of the Critically Endangered *Ptilotus pyramidatus* on the Swan Coastal Plain.
- Commenced a regional analysis of the spatial distribution of threatened and priority flora and threatening processes for the Southwest Australian Floristic Region.

Management implications

- Demographic studies, models and experiments investigating the impact of fire regimes, plant disease and vertebrate grazing for the Montane Heath and Thicket TEC and threatened flora of the South Coast Region will provide critical information for defining ecologically acceptable fire return intervals and species recovery.
- Demographic studies and experiments investigating the impact of environmental weeds on *P. pyramidatus* will provide critical information for supporting species recovery.
- A regional analysis of the spatial distribution of threatened and priority flora and threatening processes in the SWAFR will identify hotspots and priorities for management.

Future directions

- Publish paper on the climate surfaces developed from the micro-climate sensor array in the Ravensthorpe Range.
- Continue demographic studies investigating fire regime, disease and vertebrate grazing impacts and recovery actions for threatened flora with South Coast Region.
- Continue demographic studies investigating environmental weed impacts and recovery actions for threatened flora with Swan Region.
- Complete population viability analysis for *B. verticillata* and write scientific paper.
- Complete spatial distribution and population sizes of threatened and priority flora, in relation to evolutionary history and contemporary land management.
- Complete a regional analysis of the spatial distribution of threatened and priority flora and threatening processes for the SWAFR and write scientific paper.



Seed biology, seedbank dynamics and collection and storage of seed of rare and threatened Western Australian taxa

SP 1999-010

A Crawford, A Monaghan

Context

Seed conservation is a specific and targeted action to conserve biodiversity and entails the banking of genetic material in the form of seed. Seed banking provides an important opportunity for assessing and utilising genetic

material for *in situ* recovery actions, and for seed research. Understanding the seed biology and ecology of plant species is important for the conservation and management of conservation-significant Western Australian taxa and for developing and implementing recovery plans for rare and threatened flora.

Aims

- Provide a cost effective and efficient interim solution to the loss of plant genetic diversity by collecting and storing seed of rare and threatened Western Australian plant species, and thereby provide a focus for flora recovery.
- Increase knowledge of seed biology, ecology and longevity.
- Incorporate all information into a corporate database and provide relevant information on seed availability, seed biology, storage requirements and viability of seed of rare and threatened taxa to assist the development of management prescriptions and preparation of interim recovery plans and translocation plans.

Progress

- A total of 150 seed collections (86 species) were banked at the Western Australia Seed Centre (Threatened Flora Seed Vault) during 2018–19; 97 of these collections (39 species) were listed as Critically Endangered, Endangered or Vulnerable (threatened flora). Nineteen of these collections (18 species) were listed as priority flora.
- Ninety eight germination tests were conducted.
- Seedlings of 10 threatened flora species were provided for translocation.
- The seed bank now contains 5,836 collections (1,904 taxa) representing 344 threatened flora, 733 priority flora and 827 key restoration species.

Management implications

- Seed conservation supports the survival of species in the wild by providing the genetic material for reintroduction; seed is provided for translocations of threatened flora and for departmental restoration projects.
- Provision of seed biology and ecology data increases the success of threatened flora recovery actions, particularly through knowledge of how pre-treatments may stimulate seed germination.

Future directions

- Ongoing collection of seed of threatened flora for long-term conservation and use in re-introductions.
- Ongoing processing and storage of collection backlog.
- Germination testing, storage and monitoring of existing collections.
- Ongoing research into seed biology and seed storage behaviour of threatened plant taxa.



Genetics and biosystematics for the conservation, circumscription and management of the Western Australian flora

SP 1998-003

M Byrne, R Binks, D Bradbury, B Macdonald, C Gosper, T Hopley, K Ottewell, N Gibson

Context

The flora of Western Australia is complex due to the antiquity of the landscape, and this can lead to obscurity in taxonomic identity, which impacts on conservation status of rare and threatened taxa. Genetic analysis can inform the conservation and biosystematics of these taxa.

Aims

- Provide genetic information for the conservation and management of Western Australian flora, especially rare flora.
- Determine the level of differentiation and association with environmental variables in *Calothamnus quadrifidus* to assist in the taxonomic revision of the group.
- Determine the genetic differentiation between geographically disjunct populations of *Banksia biterax*.
- Determine the phylogenetic relationships among populations of *Banksia densa*.
- Determine the phylogenetic and population genetic relationships among the disjunct populations of *Eucalyptus virginea* and related species.
- Determine the phylogenetic relationships among Western Australia *Leptospermum* species and examine the level of differentiation among several species complexes.
- Determine the potential for hybridisation and genetic differentiation among *Seringia exastia*, *S. katatona*, *S. elliptica* and *S. nephrosperma*.
- Determine the geographic range of two identified genetic lineages within *Eucalyptus salubris* and investigate genomic relationships among nine species within the gimlet complex.
- Investigate potential hybrid origins and parental sources of several *Eucalyptus* entities within the Stirling Ranges.
- Determine the genetic relationships among Australian *Arivela* species and the genetic relationships in two species complexes.
- Investigate the role of lignotuber loss or gain in the evolution and conservation of eucalypt diversity, through deriving phylogenetic relationships and quantifying genetic differentiation among a clade of eucalypts with obligate-seeder and lignotuber-resprouter taxa, using high density, genome-wide markers.
- Determine the genetic diversity and differentiation among sub populations of *Marianthus aquilonaris* in the Bremer Range.

Progress

- A paper detailing genomic variation across the *C. quadrifidus* species complex has been published in the *Journal of Biogeography*.
- A paper investigating differentiation across the disjunct distribution of *B. biterax* using genomics and cpDNA data has been published in *Biological Journal of the Linnean Society*.
- Sequencing and analysis of 14 populations of *B. densa* with cpDNA gene regions has been completed, and do not indicate historical differentiation of the Corrigin population that exhibits some morphological variation.
- Genomic analysis of *E. virginea*, *E. relictata*, *E. lane-poolei*, *E. phylacis* and *E. decipiens* has been completed, confirming the identification of a new, disjunct population of *E. virginea* in Meelup and that all existing plants of *E. phylacis* are a single clone that is an F1 hybrid between parents, *E. virginea* and *E. decipiens*.
- The first stage of phylogenomic analysis of *Leptospermum* taxa is complete, finding strong support for four clades that are polyphyletic with several other genera, including *Kunzea* and *Neofabricia*. This result is consistent with an early, poorly-supported phylogeny that was published using older molecular technologies in 2000.
- Field collections, DNA extractions and sequencing for the *L. nitens* species complex has been completed and genomic analysis will commence shortly.
- Genomic analysis of the *S. exastia* complex has been completed, confirming that *S. katatona* is a hybrid between parents *S. exastia* and *S. nephrosperma*, to be recognised taxonomically by re-naming as *S. xkatatona*. In addition, morphological overlap and a lack of genomic differentiation between *S. exastia* and *S. elliptica* requires their synonymisation under the older valid name of *S. exastia*. A paper combining the genomic analysis with subsequent taxonomic revisions has been submitted for publication in *Taxon*.
- Initial analysis identified two genetic lineages in *E. salubris* that also showed differences in specific leaf area. Analysis of 13 additional populations (22 in total) across the species' distribution has confirmed the presence of the two lineages with a south-west/north-east geographic orientation but with substantial overlap through the central area and geographically close populations belonging to different lineages. A paper is in preparation.
- Field collections, DNA extractions and sequencing for the nine species of the gimlet complex is complete and genomic analysis has commenced.
- Field collections, DNA extractions and sequencing for the putative *Eucalyptus* hybrid entities in the Stirling Ranges is complete and genomic analysis is underway.

- Relationships among *Arivela* spp. have been determined using cpDNA and ITS sequencing and a manuscript is in review in *Molecular Phylogenetics and Evolution*. Genomic sequencing of *A. viscosa* and *A. tetandra* has been carried out and analysis is being undertaken.
- A review of genetics and ecology of species that occur on Banded Iron Formations of the mid-west has been published in *Biological Reviews*. A special issue of *Australian Journal of Botany* was published on genetics and ecology of plant species on banded iron formations.
- Analysis of phylogenetic relationships and genetic differentiation in all terminal taxa of *Eucalyptus* sub-series *Levispermae* has been completed, showing that taxa that are morphologically identical except for differences in lignotuber state (obligate-seeder *c.f.* lignotuber-resprouter) formed discrete phylogenetic lineages. This work has been published in *Molecular Phylogenetics and Evolution*.
- Assessment of the genetic diversity present in each of the five sub-populations of *M. aquilonaris* and the spatial genetic structure present among the sub-populations showed the level of differentiation among the sub-populations to be high given the small geographical distance between them, indicating that gene flow and connectivity is limited between sub-populations.

Management implications

- Assessment of phylogeographic patterns and environmental associations in *C. quadrifidus* will inform taxonomic revision of the group.
- Identification of genetic differentiation between populations from three disjunct geographic regions of *B. biterax* confirms that populations in each region should be managed as separate lineages. Augmentation of the small Busselton populations should use seeds collected from the local populations only.
- Phylogenetic relationships among populations of *B. densa* suggest the morphologically different Corrigin population is possibly a distinct taxon, but this remains equivocal based on the cpDNA data.
- Population genetic analysis of relationships among disjunct populations of *E. virginea* will inform management of the populations, and will inform on the potential hybrid status of *E. phylacis* and its putative parental species.
- Assessment of the genetic relationships among *Leptospermum* species will inform taxonomic revision of the group, and define taxonomic entities to inform use of natural resources for honey production.
- Recognition of *S. xkatatona* as a hybrid and synonymisation of *S. exastia* and *S. elliptica* mean that neither taxon meets the criteria for needing protection and conservation listing of both can be reconsidered.
- Resolution of lineages in *E. salubris* and genetic relationships among all nine species in the gimlet complex will provide a basis for potential taxonomic revision.
- Analysis shows lignotuber state is an important taxonomic character in eucalypts, supporting recognition as separate taxa for populations that differ in this trait.
- Identifying putative hybridisation within several *Eucalyptus* entities, including *E. erectifolia*, within the Stirling Ranges will allow for potential taxonomic revision and reconsideration of conservation listings.
- Identifying genetic entities in *A. viscosa* and *A. tetandra* will provide a basis for taxonomic resolution of these species complexes.
- High genetic differentiation over very short distances in *M. aquilonaris* provides information for management of the species.

Future directions

- A paper investigating *E. virginea* and related species will be finalised.
- Phylogenomic analysis of *Leptospermum* will be undertaken.
- Fieldwork and population genomic analysis of several *Leptospermum* species complexes will be undertaken.
- Nominations for the delisting of *S. exastia* and *S. xkatatona* as species of conservation concern will be submitted.
- A paper detailing the genetic lineages in *E. salubris* will be finalised and genomic analysis of the gimlet complex will be completed.
- Genomic analysis of putative eucalypt hybrids in the Stirling Ranges will be completed.
- Analysis of genetic relationships in *A. viscosa* and *A. tetandra* will be completed.
- Taxonomic revision of *Eucalyptus* subseries *Levispermae* will be completed.



Ecosystem Science

Program Leader: Adrian Pinder Applied research undertaken by the Ecosystem Science Program seeks to understand the environmental, ecological and biogeographical processes that determine the conservation values, health and productivity of the lands and inland waters managed by the department. The program's research spans two broad themes: biogeography, and how ecosystems function and respond to threatening processes and management.

Biological surveys provide information on the composition of communities and distribution of the State's flora and fauna at scales relevant to management questions. Survey data provides the foundation for a range of management activities, including conservation estate planning, assessing the conservation status of species and communities and predicting the impacts of other land uses and threats.

The program investigates how ecosystems function and respond to water and land resource management practices and to broadscale threats including salinity, altered hydrology, climate change and habitat fragmentation. Projects include investigations into the nature of the threats through to monitoring associated ecological responses and effectiveness of mitigation strategies. The program also investigates genetic diversity, evolutionary history and ecological plasticity of plant populations in relation to guiding seed collection for restoration.

The program collaborates with other parts of the department, museums and herbaria, universities, cooperative research centres, natural resource management groups, CSIRO and other research providers. Partnerships also exist with traditional owners, resource companies and the environmental consulting industry.



Investigating the causes of change in forest condition

SP 2019-048

K Ruthrof, D Tarrant, R Van Dongen

Context

A decline in vegetation density in the northeast of the forest management plan area was noted in *Mid-term review of performance of the Forest Management Plan 2014-2023*. Forest die-off is particularly concerning, given the importance of the forest ecosystem for carbon sequestration, timber production, recreation, habitat, and a range of ecosystem services, including water. The decline is broadly consistent with climate change prediction models, although other factors may also be contributing. Previous research in the eastern part of the forest suggests that *Eucalyptus wandoo* has been undergoing a series of declines associated with drought and increasing temperatures. In addition, *E. wandoo* has been affected by a Buprestid beetle (*Cisseis fascigera*). An associated fungal pathogen is also suspected in the decline of this eucalypt but has not yet been identified and described. Other key canopy species, *Eucalyptus marginata* and *Corymbia calophylla*, have been reported to be susceptible to frost in certain sites, and vulnerable to acute drought and heatwave events at water-shedding

sites with shallow soils.

More information is needed about the landscape, site and stand characteristics that predispose forest to decline. Without this, we cannot predict how and where the forest will respond to a hotter and drier climate in the future. This project will build on the information available and investigate the contributing factors. This will provide a greater understanding of the vulnerability of the forest to climate change and assist in developing evidence-based management intervention techniques. The project has four key areas: 1) investigation of the decline trend maps; 2) forest validation via a forest survey; 3) investigating trajectories in recovery post-fire using satellite imagery; and 4) investigating climatic influences.

Aims

Investigate the cause of decline in vegetation density and further examine contributions by other factors.

Progress

- Examined the origins of the satellite imagery that indicated a decline in vegetation cover in the mid-term Forest Management Plan review, and discussed the underlying process of image creation.
- Field reconnaissance was undertaken to a number of the forest ecosystem types that were shown to be declining in cover to identify potential associations of decline.
- Developed a stratified decline map, highlighting areas with the highest level of decline.
- Designed a rapid field assessment technique to examine and capture the landscape, stand and tree level variables that could be associated with vegetation decline.
- Examined the wood boring insect and fungus that appears to be associated with *E. wandoo* decline.
- Examined image analysis methods to evaluate post-fire recovery.

Management implications

- Knowledge gained from this study will be incorporated into forest management policy and planning for biodiversity conservation, and also contribute to the mapping of forest health and reporting for the next Forest Management Plan (FMP).

Future directions

- Undertake field work in areas where decline is being shown by the satellite images and investigate landscape, stand and plant variables associated with the decline.
- Investigate the recovery of key forest ecosystem types from different levels of fire severity, using indices appropriate for use in the next FMP.
- Investigate climatic variables that are could be associated with vegetation decline.



Do hotter and drier regions harbour adaptive variation for climate change?

SP 2017-022

M Byrne, K Ruthrof, R Mazanec

Context

Understanding the capacity of trees to respond to climate change is essential for the maintenance of biodiversity, forest health and productivity. In south-west Australia, climate change has increased the frequency and intensity of droughts, which has resulted in tree death and negatively affected essential ecosystem services. Adaptive land management is required to mitigate the risk of large-scale drought mortality in a rapidly changing climate. Current forest regeneration practice provides for seed sourcing from land management units adjacent to the site based on a broad interpretation of local provenance in widespread semi-continuous species. Assisted gene migration has also been advocated as a tool for land managers and foresters in managing forests and

establishing plantations for future climates, and a scientific basis is required for land-managers to make informed decisions regarding the implementation of assisted gene migration.

Marri (*Corymbia calophylla*) is an important component of the forest ecosystem providing nesting hollows and a food source for threatened cockatoo species. In addition to being an important timber tree, the fruit, seeds, flowers, leaves and wood of marri are all important sources of food for native fauna. The seeds are a major food source for nationally listed threatened birds (Baudin's black cockatoo and Carnaby's black cockatoo) and the maintenance of habitat and food resources is a key factor in forest management practice. In each of the forest and woodland ecosystems where marri is present, it is an important and integral keystone species. Consequently, a decline in its overall health, now being experienced due to drought and disease, will have significant long-term detrimental impacts on ecosystem function. Management of keystone species within forest ecosystems needs to have a strong scientific basis. This project will deliver a scientific basis for consideration of adoption of assisted gene migration in south-west forests, through a detailed understanding of genetic adaptation and physiological tolerance in marri, and the capacity for enhanced drought-resilience under future hotter and drier climates.

Aims

- Characterise neutral and adaptive genetic variation to estimate demographic (population size, migration) and evolutionary (adaptation to climate) processes.
- Estimate the heritability of plant functional traits associated with growth and resilience, and correlated traits, to determine the propensity for genetic adaptation.
- Determine the physiological and molecular capacity to respond to drought to elucidate the mechanisms enabling plants to persist under climate change.

Progress

- A paper on genetic adaptation to climate in marri has been accepted for publication in *Molecular Ecology*. This genomic study of 23 populations across the range of marri, generating 10,000 SNP loci and showed low levels of genetic structure with isolation by distance in a north-south orientation. After controlling for population structure, analysis identified greatest variation explained by associations with temperature rather than rainfall or aridity. Variation occurred throughout the genome, and was found in gene coding and regulatory regions, including those known to regulate processes important in stressful climatic conditions, suggesting that both adaptive and plastic responses are involved in the response of marri to climate.
- A paper on variation in provenance trials has been accepted for publication in *Evolutionary Applications*. Analysis of 18 provenances and 170 families planted at Mt Barker and Margaret River has been undertaken for tree growth (height, basal diameter) and disease resistance (shoot blight). Growth and disease resistance both show moderate levels of genetic heritability. There were strong associations with the climate of origin (temperature, rainfall) showing high growth and disease resistance in southern coastal populations experiencing cool and wet climatic conditions.
- Analysis of seven traits related to climate was undertaken in plants in the provenance trials and significant differences were found between populations for all traits. Significant but low levels of narrow-sense heritability indicate that selection will differentially affect these traits. Climate was a significant predictor of trait values and generalised additive models predicted trait values across the landscape for current and future climatic conditions. Coordination among traits was predicted to break down in the future for some trait coordinations but not others. These findings suggest that trait coordination might be a hindrance to plant adaptation to novel climate conditions.
- Analysis of data from a drought experiment has been completed for seedlings from 12 provenances growing at 100% and 50% soil water holding capacity for four months over summer.
- Data analysis has been completed for a heatwave experiment where seedlings from eight provenances were grown under 'cool' (26 °C maximum) and 'warm' (32 °C maximum) growth conditions in a glasshouse and exposed to two consecutive five day heatwaves at either 40 or 46 °C in a fully factorial reciprocal temperature design. Leaf gas exchange, growth and leaf damage were monitored throughout the experiment under conditions where soil water content was maintained at field capacity. Results suggest that plants from cooler provenances exposed to the 46 °C heatwave experienced the most severe impacts on growth and had the highest levels of leaf damage.

Management implications

- Assisted gene migration has been suggested as a key climate change adaptation strategy for forests worldwide, and could be readily incorporated into current silvicultural practices in south-west forests through the inclusion of seed from dry adapted provenances in regeneration. This project will provide the scientific evidence required to determine effective assisted gene migration practices in south-west forests for resilience to changing climates, providing a basis for adoption of this practice by decision-makers and acceptance by the community and non-government organisations.
- Understanding of response of plant traits to changing climates will enable predictions and modelling of plant adaptation and strength of selection, and inform forest management in response to climate change.

Future directions

- Analysis of glasshouse heatwave and drought experiments will be completed and papers written.



Hydrological function of critical ecosystems

SP 2016-005

J Rutherford, G McGrath, L Bourke, B Huntley

Context

Biodiversity conservation requires an understanding of ecological processes that include balances and fluxes of water, energy and biogeochemistry. These processes are considered in a number of coarse scale ecological assessment and management frameworks, but these frameworks are difficult to apply at finer, or local, scales where an appreciation of hydrological variation is important. To increase confidence in applying coarse scale management frameworks at finer scales they need to be verified by results from targeted, critical, local scale ecosystem investigations. Critical ecosystem sites are selected where dominant processes driving their behaviour are complex, but not unique, so that frameworks for ecosystems with similar hydrological function and response to change can be assessed. The project will investigate the hydrological function of local scale critical water dependent ecosystems, determine and improve our understanding of dominant hydrological processes controlling their physico-chemical sensitivity and responses to change and feed the results back into coarser scale ecosystem management frameworks. Local scale sites will be selected where ecohydrological data can be collected and integrated with existing biophysical datasets and information to optimise the transferability of hydrological results and outcomes to other areas.

Aims

- Assess and determine the scales and dimensions of data required to map hydrological features being researched and measure change important for interpretation and management.
- Build suitable conceptual hydrological models within the bounds of available data and application requirements.
- Explore critical hydrological parameter/system sensitivities to resolve potential ecohydrological management zones.
- Construct conceptual hydrological models and review the need and uncertainties associated with numerical models.

Progress

- A DBCA science information sheet was published online for the Walyarta springs that highlighted the importance of collecting hydrogeochemical and environmental tracer data to fingerprint the dominant aquifer supporting the springs and the value of interpreting these in a 3D hydrogeological model. The major finding was that ascending springs (controlled by artesian pressures in the Wallal Aquifer) appear to be the dominant discharge mechanism.
- A surface water monitoring program was designed to collect data from three Walyarta mound spring moats. Preliminary results indicate that the moats contain limited/no measurable water during a below average

wet season, suggesting groundwater discharge rates are insensitive to seasonal changes in temperature and evaporation.

- A journal article is being prepared based on the Walyarta study, including an assessment of changes that could occur at spring sites with reductions in groundwater recharge, using information from remote sensing persistent vegetation/spring resilience mapping, spring water balances, and geochemical modelling.
- A report and journal article are being prepared for the Brixton Street Wetlands that discusses the seasonality and dynamics of the clay-pan hydro-periods.
- A hydrological study was designed for Ashfield Flats to assess the sources of contaminated groundwater and surface water discharging to the reserve and the Swan River as well as to assess surface water - groundwater interactions. Preliminary monitoring results suggest a significant influence from the Swan River on shallow groundwater recharge and strong tidal forcing of pressure heads deeper in the superficial aquifer at the site.

Management implications

- Identifying the aquifers that support the Walyarta mound springs and determining the direction of groundwater movement provides the basis to develop monitoring programs to improve understanding of the water requirements.
- The approach used to investigate and assess the Walyarta mound spring water balances and determine their resilience under changed water availability are transferable to other spring locations in Western Australia. This will help with the provision of advice on appropriate methods to investigate and assess other springs that host threatened ecological communities (TECs).
- Knowledge of hydrological functioning of the Brixton Street wetlands will increase the department's capacity to develop actions to reduce environmental impacts on TECs, other significant ephemeral wetlands and threatened flora on the Swan Coastal Plain. This will allow for the provision of more effective inter-agency advice on the potential environmental consequences of developing land within the Guildford Formation.
- Improved understanding of the Swan River - Ashfield Flats interactions will support the department's ability to develop strategies to manage the contaminated inflows at this site. More broadly, the study is developing methods to assess the hydrological functioning of estuarine salt flats which will support better planning to manage these TECs.

Future directions

- Continue the hydrological monitoring of Walyarta mound spring moats in order to collect baseline data to improve our understanding of the spring water balances under low groundwater demand conditions.
- Complete journal articles that discuss the approach in development of a three dimensional (3-D) conceptualisation of the Walyarta mound springs hydrology and how 3-D modelling helps develop more effective investigation and monitoring programs that improve spring management outcomes.
- Complete a report and a journal article on the spatial and temporal variation observed in groundwater and surface water interactions in the Brixton Street wetlands and recommend monitoring and management actions.
- Continue monitoring and conduct experiments at Ashfield Flats in order to establish the dominant processes responsible for surface water and groundwater storages and flows. This includes sampling and analysis of water chemistry to assist the development of a conceptual hydrological model.
- Write reports and articles describing the experiments conducted at Ashfield Flats to evaluate surface-water groundwater interactions and the mixing processes influencing water and contaminant transport.



Responses of aquatic invertebrate communities to changing hydrology and water quality in streams and significant wetlands of the south-west forests of Western Australia

SP 2015-017

A Pinder

Context

Aquatic habitats in the south-west of Western Australia are under increasing threat from changes in hydrology, water quality and fire as a result of the drying climate, historical and current land use and water resource development. The south-west of Western Australia has had a significant reduction in rainfall since the 1970s and it is predicted that by 2050 there will be little stream inflow into water supply dams. At present, there is an inadequate understanding of the responses of aquatic communities to these threats to inform the management of many aquatic systems in the Forest Management Plan (FMP) area, including the wetlands within the Muir-Byenup System Ramsar site.

This project has two components, 1) re-surveys of aquatic invertebrates in the Muir-Byenup System Ramsar site sampled in 1994 and 2004 and suites of wetlands further south sampled in 1993, addressing KPI3 of the 2014-23 FMP and, 2) periodic monitoring of high condition streams, with a focus on effects of the drying climate and forest management, addressing KPI1 of the 2014-23 FMP.

Aims

- Address KPI1 of the 2014-2023 FMP by monitoring the condition of currently healthy streams in relation to reduced rainfall and forest management practices.
- Address KPI3 of the 2014-2023 FMP by determining responses of fauna of high value Warren Region wetlands to changes in hydrology, water chemistry and fire over the last 10 to 20 years.
- Provide baseline data for some internationally significant wetlands.
- Use the above information to report on the current conservation significance of key departmental managed wetlands and their response and vulnerability to threats.

Progress

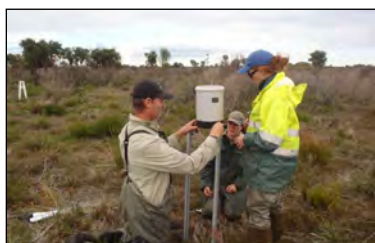
- Commenced writing a manuscript comparing aquatic invertebrates sampled in 1995/96, 2003/04 and 2014/16.
- Contributed a case-study on forest stream biodiversity to the South West Catchment Council's environmental snapshot website.

Management implications

- Re-surveying the Muir-Byenup System Ramsar site and other high value wetlands in the Warren region will provide the department with knowledge of how these wetlands and their fauna have responded to threats (especially altered hydrology and water quality arising from land-use change and climate change) over the last 20 years. Analyses are showing that aquatic invertebrates in some Muir-Byenup wetlands are being significantly affected by acidification. In conjunction with results from the peat wetlands project (SP 2014-24), this project will assist the department with making decisions about protecting remaining high conservation value wetlands versus taking remedial action at those where condition is declining.

Future directions

- Complete papers comparing invertebrate communities present in the Muir-Byenup wetlands.



South-west wetlands monitoring program

SP 2015-002

J Lane, M Lyons, A Pinder, A Clarke, Y Winchcombe

Context

Substantial decline in wetland condition has been observed across the south-west of Western Australia over the past 100 years, particularly in the Wheatbelt, almost certainly with ongoing loss of biodiversity. The most pronounced changes to wetlands have been associated with salinisation and altered hydrology following clearing of native vegetation in catchments. Broad-scale clearing has largely ceased but hydrological and fragmentation

processes will continue to be expressed for many decades. Changes in rainfall patterns are also resulting in significant changes to wetland hydrology, water chemistry and habitats.

While it is known that altered hydrological regimes and salinisation are major threats to wetland biodiversity, the relationships between physical expression and loss of biodiversity are poorly documented and poorly understood. Monitoring of wetland depth and water chemistry in the south-west began in 1977 to inform duck hunting management. After continuing at a reduced level following the ban on recreational duck hunting in 1992, the program was reinvigorated under the State Salinity Strategy in 1996, supplemented by intensive monitoring of fauna, flora, water chemistry and shallow groundwater at a subset of 25 wetlands. This project has delivered information on the long-term trends and variability in key determinants of wetland character and condition.

Aims

- Analyse long and short-term changes in surface water quantity and quality, shallow groundwater levels and biodiversity at representative south-west wetlands in relation to threatening processes (particularly dryland salinity and reduced rainfall).
- Assess the effectiveness of catchment and wetland management.

Progress

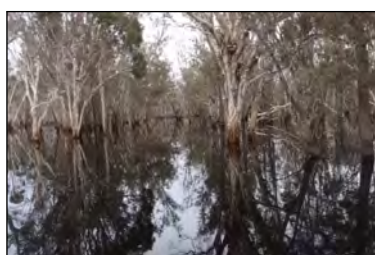
- Archiving of the water depth and water quality data, and supporting documentation (such as depth gauge maintenance records and maps, and project methodologies) was undertaken.
- Data from the fauna monitoring component have been uploaded to Data Catalogue.
- Water level monitoring of the Vasse and Wonnerup Estuaries and the Lower Vasse River wetlands continued.

Management implications

- The project has provided a long-term picture of trends in depth and key water quality parameters across south-western Australia, providing a context for assessing contemporary and future observations, especially in relation to climate change.
- Communities in most of the Wheatbelt wetlands where biological monitoring was carried out since 1996 are not undergoing strong directional change at present, but their responses to variation in rainfall revealed during this project suggests that longer-term shifts can be expected. These data provide a baseline for any future monitoring work.

Future directions

- Complete write-up of the 15 years of fauna and flora monitoring at the intensively monitored wetlands and archive data.



Advancing the hydrological understanding of key Wheatbelt catchments and wetlands to inform adaptive management

SP 2015-001

J Rutherford, L Bourke

Context

Changes in the hydrology of Toolibin Lake and the Lake Bryde catchments, due to land clearing, has resulted in these previously ephemeral fresh water wetlands developing a connection with deeper, saline groundwater and becoming degraded. A decline in average rainfall since the 1970s has seen a further decrease in wetland health as surface water flows and wetland hydroperiods decrease in quantity and quality. Robust management decisions require the main hydrological driver(s) of change to be identified and spatial and temporal fluxes (water and solutes) to be characterised. This project will significantly advance hydrological studies at Toolibin Lake and Lake Bryde by making full use of the data collection and analyses undertaken to date to produce practical tools for answering the key hydrological management questions.

Aims

- Produce quantitative conceptual hydrogeological model(s) for Toolibin Lake and Lake Bryde.
- Produce a numerical groundwater model to assess the Toolibin Lake water balance and determine the effectiveness of groundwater pumping (individual pumps) in returning the lake to a perched status.
- Evaluate catchment water and salt hydrodynamics (groundwater and surface water contributions/fluxes) tested using numerical modeling under different climate regimes at Toolibin Lake.
- Investigate the links between key ecological parameters (e.g. tree and understorey health, bird breeding, richness of aquatic invertebrates) and hydrological status of Toolibin Lake.
- Produce risk assessment framework(s) to prioritise conservation actions and assess the transferability of research outcomes.

Progress

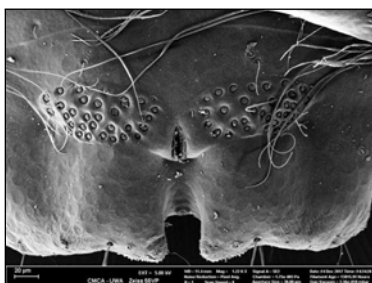
- Completed hydrological data analysis and reporting for the 2017 Toolibin Lake episodic rainfall/lake inundation event.
- Designed and undertook field investigations in Toolibin Lake to assess the changes in the root zone solute storage following the 2017 lake inundation. The investigations involved completing a repeat borehole geophysical (induction conductivity) survey to assess electrical conductivity changes in near-surface (0 to around 10 meters below ground level), and this was carried out in partnership with CSIRO. The second investigation involved partnering with ANSTO to develop the first study to characterise on the quality and age of groundwater within shallow aquifers beneath Toolibin Lake.

Management implications

- Understanding surface water and groundwater interactions following a significant lake inundation is a critical knowledge gap for the monitoring and management of Toolibin Lake. This was the first study to collect high frequency data to measure long term evaporation of the lake water body. The results provide valuable information on hydrological infrastructure and monitoring required to develop a lake water balance in these semi-arid zone ephemeral wetlands. The investigation design is transferable to other wetlands to help plan future wetland monitoring programs.
- Information gained from the hydrological investigations undertaken following the 2017 Toolibin Lake inundation have reduced uncertainty in data interpretations and allowed for the development of robust conceptual and numerical hydrological models. A flow on effect from this will be a scientific basis for the refinement of management actions, including the strategic placement of lake revegetation, the development of an optimised groundwater pumping program and an integrated platform for assessing the needs for current and future engineering works.

Future directions

- Complete the final internal report on hydrological conceptualisation of Toolibin Lake and catchment.
- Work with ANSTO on finalising groundwater quality and age interpretations and CyMod Systems by combining all results into a numerical model that can simulate Toolibin Lake hydrology.
- Present results from the conceptual and numerical model to the Wheatbelt Region and complete journal articles and DBCA science information sheets on Toolibin Lake hydrology.



Taxonomy, zoogeography and conservation status of aquatic invertebrates

SP 2014-025

A Pinder, K Quinlan

Context

Taxonomic knowledge underpins effective management of aquatic invertebrate biodiversity, including spatial patterning and trends over time in relation to threats. Over half of the species dealt with are not formally described, but they are consistently named across departmental projects through maintenance of a voucher specimen collection. As opportunities and skills allow, program staff undertake systematics studies (primarily species descriptions and genetic analyses), sometimes with specialist co-authors. This allows formal naming and description of Western Australian endemics that would not otherwise occur and allows species to be consistently identified by external research groups. Tools allowing consistent identification of aquatic invertebrates will also be produced.

Aims

- Undertake aquatic invertebrate systematics to improve description of Western Australian aquatic invertebrate biodiversity and allow more consistent identification of specimens by departmental and external researchers.

Progress

- Specimens of the ostracod *Lacrymicypris kumbar* were collected from the Type locality and three other wetlands to investigate cryptic diversity in this species.
- CO1 barcodes for 75 specimens, from 42 species, were entered onto the Aquatic Invertebrates of Australia database (a Barcoding of Life Database). External taxonomists were used to verify identifications and specimens prepared for deposition in the Western Australian Museum.

Management implications

- The description of new species and the production of taxonomic tools, will allow more routine and consistent identification of this group, including in environmental impact assessment.

Future directions

- Undertake similar taxonomic work opportunistically and as required.



Understanding peat wetland resilience: evaluating the impact of climate and landuse change on the hydrodynamics and hydrogeochemistry of peat wetlands in the Warren (Muir-Byenup) District

SP 2014-024

J Rutherford, L Bourke

Context

Peat wetlands are relatively rare in Western Australia but constitute an important habitat for biodiversity where they occur, especially in the far south-west of the State, providing refugia from seasonal and long-term drying for a range of restricted flora and fauna. Some peat wetlands in the Muir-Byenup System Ramsar site wetland suite are threatened by acidification and some have already acidified as a result of declining groundwater levels. Drying is also making these organic wetlands more prone to catastrophic fires. The peat also stores a range of toxic metals and metalloids that are released to the environment as they dry. The major aim of this project is to undertake a risk assessment of fire susceptibility and release of acidity and other contaminants. The project will deliver a map of the distribution of at-risk peat wetlands, combined with recommendations for fire management and maintaining water balance.

Aims

- Determine current hydrogeological and hydrochemical conditions of four representative peat wetlands, particularly water and chemical conditions and gradients.

- Map and quantify peat wetland carbon and acid stores.
- Identify and assess the transient behaviour of major threats to the health of the peat wetlands particularly the role of drying climate in changing water retention in peat sediments and the source and mobility of acidity and salinity.

Progress

- Continued development of a 3-D conceptual model that integrates hydrogeophysical and hydrogeochemical data and interpretations.
- Commenced using the 3-D conceptual model under development, to understand the role of periodic seismicity in modifying peat wetlands water, solute and acid balances.

Management implications

- The absence of bacteria that breakdown vegetation to form peat in disturbed peat wetlands confirms that these systems are under stress. The cause of the stress and likelihood of their recovery are factors that require consideration in management of peat wetlands.
- All peat wetlands have the potential to become acidic but they can be effectively managed if substrate geochemical gradients and discrete zones releasing acids are mapped and understood.
- Identifying the discrete zones within peat wetlands prone to acidification and drying allows management plans and actions to be developed and prioritised.

Future directions

- Complete work on the three dimensional understanding of the hydrogeology, water, salt and acid stores in order to understand spatial variability and identify wetlands where interventions are likely to be effective and the risk of peat fires reduced.
- Commence instrumenting and collecting hydrological and hydrogeochemical data to understand the extent and dynamics of the existing acidified peat wetland.
- Write a report, journal article and DCBA science information sheet that details the approach and application for management.
- Map and characterise peat wetlands in the Warren Region to better understand the likely distributions of threatened flora and fauna and risks of landscape threats (e.g. climate change, fire) to these systems.



Restoring natural riparian vegetation systems along the Warren and Donnelly Rivers

SP 2013-004

M Byrne, T Hopley

Context

Current practices of seed sourcing for revegetation projects focus on local seed, based on a premise of maximising adaptation to local conditions, but this may not be the most appropriate under changing climatic conditions. Identification of patterns of adaptive variation will enable more informed approaches to species selection and seed sourcing to maximise establishment and persistence of plants in revegetation programs.

This project will provide a climate change framework for revegetation of blackberry-decline sites on the Warren and Donnelly rivers by determining the scale of adaptation to climate along the river system and determining the best seed source strategies to maximise resilience to future changes in climate in the revegetated populations.

Aims

- Develop a climate change framework for revegetation of riparian vegetation along the Warren and Donnelly rivers.
- Determine seed sourcing strategies that account for climate adaptation to enable resilient restoration of riparian vegetation along the Warren and Donnelly rivers.

- Test adaptation to climate through experimental plantings under operational conditions of establishment.

Progress

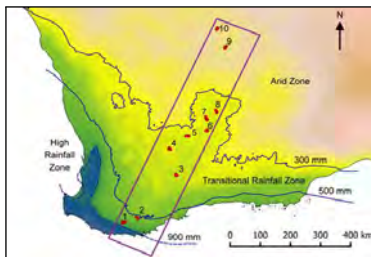
- Sequencing of *Astartea leptophylla* and *Callistachys lanceolata* using the DarTSeq method was completed and analysis of results undertaken.
- A manuscript detailing the new results from sequencing including genetic structure and association analysis outlining the number and scale of signals of selection for *A. leptophylla* and *C. lanceolata* has been submitted for publication.

Management implications

- Changing climates require a re-evaluation of appropriate seed sourcing strategies for revegetation and restoration of ecological function in degraded sites. Use of local seed will not provide adequate resilience to maintain ecological function under changing climates, and understanding of climate adaptation will provide a scientific basis to undertake best-practice restoration and facilitate establishment of biodiverse plantings that maximise ecological function for enhanced persistence and resilience. Development of a strategic revegetation program for the riparian areas of the Warren and Donnelly catchments has provided an integrated approach to habitat restoration and improved the knowledge and capacity of restoration practitioners and land managers.

Future directions

- Finalise paper on signals of selection for *A. leptophylla* and *C. lanceolata*.
- Analyse new sequencing results and complete and submit manuscript on *Taxandria linearifolia* genetic structure and signals of adaptation.



South-western Australia transitional transect

SP 2013-003

S van Leeuwen, N Gibson, M Byrne, M Langley

Context

The South-western Australia transitional transect (SWATT) is one of a series of national ecological transects or plot networks that traverse key Australian terrestrial ecosystems aligned along environmental gradients. The principal purpose of the transects is to measure selected biodiversity attributes along with biophysical processes, which will inform key ecosystem science questions and assist with the development and validation of ecosystem models. Transects will enable benchmarking and subsequent monitoring of trends in ecological condition in response to continental-scale biophysical processes such as climate change.

Aims

- Define, describe and understand the floristics and vegetation communities on deep sand plains across the transect to provide a baseline for monitoring change and impacts of disturbance e.g. fire.
- Identify sensitive, important or significant species and communities in the sand plain vegetation community and provide management recommendations.
- Determine whether soil community turnover reflects plant community turnover.
- Determine whether isotope analysis indicated species sensitivity to climate gradients.

Progress

- Twenty additional Ausplots have been established along the transect.
- Plant specimens associated with the AusPlots campaign have been identified with vouchers selected for retention and lodgement in the Western Australian Herbarium.

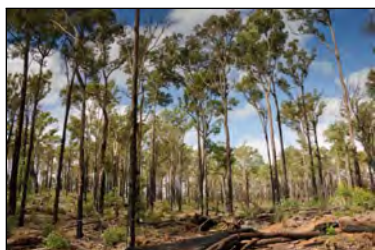
- Manuscript describing patterns of beta diversity in plant species across the Australian Transect Network published in *Acta Oecologica*.
- Manuscript describing the relationship between patterns of beta diversity in plants as determined from herbarium records in comparison of actual plot data published in *Ecography*.

Management implications

- A more detailed understanding of the beta-diversity patterns and vegetation structural attributes of the sand plains will enable improved assessment of impacts of development proposals on biodiversity values, assessment of effects of current fire management practices on biodiversity values, development of a more accurate assessment of the current reservation status of the sand plain vegetation types, better understanding of the conservation status of many species restricted to sand plain habitats, and greater understanding of the resilience of species and sand plain vegetation communities to impacts of climate change.

Future directions

- Complete isotopic signature data analysis and publish results.
- Establish additional climate gradient transects across transitional zones.



Responses of terrestrial vertebrates to timber harvesting in the jarrah forest

SP 2012-038

A Wayne, C Ward, M Maxwell

Context

Understanding the impacts of timber harvesting on the terrestrial vertebrates of the jarrah forest is necessary for biodiversity conservation and development of ecologically sustainable forest management.

Aims

- Investigate the impacts of current silvicultural practices on jarrah forest ecosystems.
- Determine what factors contribute to observed impacts.
- Develop or modify silvicultural prescriptions to ensure the ecologically sustainable management of timber harvesting in the jarrah forest.

Progress

- Spotlight monitoring on three standardised transects was maintained with three repeat surveys per transect. Ngwayir (western ringtail possum) populations in the greater Kingston area remain extremely low having declined to almost undetectable levels between 2001 and 2012. There was a slight increased trend in detections over the past two years, but this has not been sustained in the most recent surveys. Woylies and western grey kangaroos detections have also continued to decline following a peak in 2016.
- A digital data capture platform has been developed and will be trialled in the next spotlight surveys.

Management implications

- Identification of decline in the ngwayir numbers in the Upper Warren region (including greater Kingston area) contributed significantly to the recent elevation of its conservation status to Critically Endangered.
- Information on the impacts of timber harvesting on terrestrial vertebrates will lead to improved ecologically sustainable forest management practices and the conservation of biodiversity.
- Understanding the factors responsible for changes in populations of native mammals in the Upper Warren area provides critical context for informing management of fauna in areas subject to timber harvesting and other management activities.

Future directions

- Data on the responses to timber harvesting of terrestrial vertebrates will be analysed and prepared for publication.



Western Australian flora surveys

SP 2012-005

N Gibson, M Lyons, S van Leeuwen, A Markey, M Langley, M Collins

Context

Flora surveys of targeted areas provide knowledge of vegetation pattern and structure for conservation management. These surveys are undertaken for a variety of purposes and for, or in collaboration with, a number of partner organisations. Current projects include:

- Floristic survey and vegetation mapping of the mound springs and surrounding vegetation communities of Walyarta Conservation Park (Mandora Marsh) in collaboration with the West Kimberley District.
- Flora and vegetation survey of Fitzroy Valley in collaboration with the West Kimberley District and Traditional Owners.
- Floristic Survey of the Mound Springs of Dampier Peninsular and Carlton Hill Station in collaboration with the Kimberley Region and Traditional owners.

Aims

- Undertake targeted surveys aimed at providing specific management advice, monitoring long term change in vegetation at specific sites or in specific communities, or to fill specific data gaps.

Progress

- Material was collected from Western Australian Herbarium vouchers for 80 Pilbara weed species in preparation for DNA extraction.
- Plant vouchers were lodged in the Western Australian Herbarium for Kimberley Region mound springs surveys, vegetation map of Walyarta Conservation Park was completed and reporting is in preparation.
- Field program was completed for the survey of the Fitzroy Valley.
- Survey of flora of Nimalarragan wetland at Willie Creek was undertaken and is being written up.
- Report on flora component of a survey of Kimberley mound springs was completed.
- Charaphyte collection from the Pilbara and other wetland surveys was curated and is being prepared for herbarium lodgement.
- Manuscript describing the temporal changes to threatened ephemeral claypans over annual and decadal timescales in south-west Australia was published in *Australian Journal of Botany*.
- Wetland biodiversity patterning along the middle to upper Fortescue valley in the Pilbara was described to inform conservation planning.

Management implications

- A comprehensive DNA barcode library for Pilbara plants species will facilitate rapid plant identifications that will support traditional identification approaches while also clarifying the taxonomic status of many species and species complexes. This barcode library will also support the development of a proposed Pilbara eflora and relax restrictions on field sampling time for plant specimens as fertile vouchers, particularly for ephemeral species, will no longer be essential to confirm identification.
- Kimberley mound springs surveys (Dampier Peninsular and Carlton Hill) will provide the locations of significant weed occurrences (date palm) and priority taxa to guide mound spring management. Documentation of the floristic values of the springs provides important context for assessing possible future impacts of any proposed groundwater abstraction projects.

- Walyarta Conservation Park (Mandora Marsh) vegetation survey and mapping will enable identification of vulnerable vegetation communities for monitoring, and provide information for a monitoring plan to determine the effectiveness of feral herbivore exclusion or removal.
- The Fitzroy Valley survey will provide vegetation site descriptions and updated floristic information for a region that has been relatively unsurveyed and is under consideration for inclusion in the reserve system.

Future directions

- Continue collection of water depth data from claypans in Ellen Brook Nature Reserve to provide information on drying cycles.
- A manuscript on the Jurien coastal wetlands survey will be completed.



Long-term stand dynamics of regrowth forest in relation to site productivity and climate

SP 2011-020

L Mccaw, G Liddelow, R Mazanec

Context

This project provides information to underpin the management of karri and jarrah regrowth stands in the immature stage of development (25-120 years old). Regenerated stands have important values for future timber production, biodiversity conservation and as a store of terrestrial carbon. Immature karri stands regenerated following timber harvesting and bushfire comprise more than 50,000 hectares and represent around one third of the area of karri forest managed by the department. Large parts of the jarrah forest are also comprised predominantly of even-aged regrowth. There are a number of well-designed experiments that investigate the dynamics of naturally regenerated and planted stands managed at a range of stand densities. These experiments span a range of site productivity and climatic gradients and have been measured repeatedly over several decades, providing important information to support and improve management practices.

This project addresses emerging issues for the next decade of forest management including climate change and declining groundwater levels, interactions with pests and pathogens, and increased recognition of the role of forests in maintaining global carbon cycles. The scope of this project has been broadened to include thinning response of even-aged jarrah stands, with all thinning experiments now covered by a single project plan.

Aims

- Quantify the response of immature karri and jarrah stands to management practices that manipulate stand density at establishment or through intervention by thinning. Responses will be measured by tree and stand growth, tree health and other indicators as appropriate (e.g. leaf water potential, leaf area index).

Progress

- Two draft manuscripts analysing tree growth have been prepared and are close to submission.
- Second thinning was completed at the experimental site in 47 year-old regrowth karri forest at Warren block near Pemberton. Infrastructure is being re-established to maintain the integrity of the experiment for the longer term.

Management implications

- Thinning concentrates the growth potential of a site onto selected trees and provides forest managers with options to manage stands for particular structural characteristics that may be important for future yield of wood products, wildlife habitat or resilience to disturbance. Thinning is also an important tool for managing streamflow and groundwater levels in forested catchments in the face of a drying climate.
- Tree mortality associated with *Armillaria* root disease appears to reduce in older karri stands, and small gaps created by dead trees become less obvious as stands mature. Localised tree mortality can be regarded as a natural process and is likely to contribute to patchiness in the mature forest. However,

the extent of tree mortality in silviculturally managed stands should be monitored to ensure that stand productivity and other forest values remain within acceptable ranges.

Future directions

- Finalise and submit manuscripts analysing tree growth at Inglehope and Sutton thinning experiments.
- Evaluate the potential of existing thinning experiments to inform future management options for maintaining forest health and productivity in a drying climate.



Management of invertebrate pests in forests of south-west Western Australia

SP 2011-019

J Farr, A Wills

Context

Within the history of forest and natural landscape management in Western Australia, many invertebrates are known to utilise forest biomass for their survival and in doing so impart some form of damage to leaves, shoot, roots, stems or branches. There are 10 recognised invertebrate species with demonstrated significant impact on tree health, vitality and timber quality within our natural environment. Currently the most prevalent insect pests of concern in native forests are *Perthida glyphopa* (jarrah leafminer, JLM), *Phoracantha acanthocera* (bullseye borer, formerly known as *Tryphocaria acanthocera* BEB) and *Uraba lugens* (gumleaf skeletoniser, GLS). Both JLM and GLS have documented population outbreak periods, and BEB incidence appears to be responsive to drought stress and is likely to increase. However, Western Australian forests and woodlands also have a history of developing unexpected insect outbreaks with dramatic consequences for the ecosystem health and vitality. The decline in mean annual rainfall in south-west Western Australia since the 1970s and global climate model predictions of a warmer and drier environment mean conditions for invertebrate pests will alter significantly in the next decade as our environment shifts toward a new climatic regime. This project addresses both recognised and emerging/potential invertebrate forest pests, and is designed to augment forest health surveillance and management requirements by providing knowledge on the biological aspects of forest health threats from invertebrates in the south-west of Western Australia.

Aims

- Investigate aspects of pest organism biology, host requirements, pathology and environmental conditions (including climatic conditions) that influence populations.
- Determine distribution of the invertebrate pests, including outbreak boundaries and advancing outbreak fronts, using aerial mapping, remote sensing and road surveys.
- Measure relative abundance of invertebrate pests, including quantitative population surveys and host/environmental impact studies where appropriate and/or possible.

Progress

- Recurrence of Wandoo decline symptoms in the West Dale area was investigated on a field visit and presence of Buprestid larvae was confirmed along with unknown pathogens associated with the Buprestid galleries. These symptoms were common to the earlier decline syndrome.
- A paper is in preparation dealing with a historical *Cardiaspina jerramungae* outbreak, and the recurrence of rainfall conditions coincident with outbreak in the 1980s in the Great Southern.

Management implications

- Wandoo woodlands are of limited extent but of high biodiversity value because of the rare and threatened fauna they support. Understanding threats to the long-term health of Wandoo woodlands underpins their sustainable management.

- Integration of GLS population and impact data from two major outbreak events indicates a strong relationship between GLS outbreak and periods of below-normal rainfall at seasonal or longer timescales. Further outbreaks are likely given present declining trends in rainfall.

Future directions

- Respond to emergent problems with invertebrates affecting the health of woodlands and forest.



Western Australian wetland fauna surveys

SP 2011-018

A Pinder, K Quinlan, L Lewis, D Cale

Context

Regional biological surveys provide analyses of biodiversity patterning for conservation planning at broader scales but sites in these projects are usually too sparse for use at a more local scale, such as individual reserves, catchments or wetland complexes. This project is designed to fill gaps within and between the regional surveys by providing aquatic invertebrate biodiversity data and analyses at finer scales. Past examples of such projects are surveys of wetlands in the Drummond, Warden and Bryde Natural Diversity Recovery Catchments, the Hutt River/Hutt Lagoon catchments and the mound springs near Three Springs. This project runs on an 'as-needed' basis.

Aims

- Provide understanding of aquatic biodiversity patterning at the scale of individual wetlands to wetland complexes, catchments or regions to inform local conservation planning and as baselines for future monitoring.
- Provide better data on the distribution, ecological tolerances and conservation status of aquatic fauna species and communities.

Progress

- Produced a book chapter on aquatic invertebrates at springs on the west and east Kimberley coasts. Incorporated this into a report on biodiversity, mapping and conservation assessment of these springs.
- Reported on invertebrates at Nimalarragan wetland at the inland extent of Willie Creek.
- Commenced identifications of aquatic invertebrates from Dragon Tree Soak in the Great Sandy Desert.
- Processed aquatic invertebrate samples as a continuation of wetland survey work in the Goldfields.
- Identified and enumerated aquatic invertebrates from banded stilt gut samples and associated environment samples, collected from Lake Ballard in 1995.
- Refined identification of aquatic invertebrates collected for a western swamp tortoise translocation project for incorporation into a paper on aquatic invertebrate biodiversity of south-west vegetated claypans.
- Completed genetic barcoding analyses to enable more consistent identification of aquatic invertebrates and to contribute data to the Aquatic Invertebrates of Australia project on the Barcoding of Life Database.
- Reported on temporal patterns in biodiversity and water quality at Lake Pleasant View.
- Reported on aquatic invertebrates and waterbirds of the Lake Toolibin Ramsar site during the first major fill event in more than 20 years.
- Conducted and reported on a survey of waterbirds using the Parry Lagoons area of the Lower Ord Floodplain Ramsar site.
- Conducted and reported on two counts of waterbirds using the Lake Warden and Lake Gore Ramsar wetland systems. Commenced filling gaps in remote sensed wetland inundation for analyses of waterbird data from these wetlands.
- Survey and monitoring data was used to assess aquatic invertebrates for listing as priority species.

Management implications

- Priority ecological communities (Assemblages of the wetlands associated with the organic mound springs on the tidal mudflats of the Victoria-Bonaparte Bioregion) on Carlton Hill Station are threatened by changed hydrology as a result of planned irrigated agriculture. The survey conducted will more completely document these springs and their biota and help understand their vulnerability to altered hydrology that may arise as a consequence of agricultural diversification.
- Knowledge of the relative conservation values of other important Kimberley wetlands will allow land managers to prioritise actions for their management.
- Mining and pastoralism are ongoing threats to wetlands in the Goldfields Region and new knowledge of the biodiversity values of different types of wetlands will assist with environmental impact assessment.
- At Lake Toolibin, the period between the 2017 filling event and the previous major fill in 1996 may have been too long for the lake to retain its full complement of drought resistant propagules for freshwater species. The lower than expected richness of aquatic invertebrates may also be a function of there being few sources of aerial colonists nearby. Consideration may be given to the creation of artificial wetland habitats in the catchment. Waterbird community composition was similar to that documented in 1996 although abundance was below target populations for some species and the targets in the Toolibin Lake Recovery Plan may be too high.

Future directions

- Publish a paper on invertebrate diversity in vegetated claypans of south-west Western Australia.
- Complete report on the Dragon Tree Soak wetland survey.
- Write a paper on biodiversity patterning across Kimberley springs.
- Survey additional wetlands in the northern Wheatbelt for the brine shrimp *Parartemia extracta*.
- Complete processing of aquatic invertebrate samples collected from Goldfields wetlands surveys.
- Further assess the conservation status of south-western Australian aquatic invertebrates.
- Write journal article on the influence of regional versus local habitat availability for Warden and Gore system waterbirds.



Protecting the safe havens: will granite outcrop environments serve as refuges for flora threatened by climate change?

SP 2011-011

C Yates, M Byrne

Context

Many plant and animal species have survived previous climate change by contracting to dispersed refugia where local climate conditions ameliorate regional changes. Such refugia will likely contribute to the persistence of biodiversity under projected climate change. In south-west Western Australia, the old, highly weathered and flat landscape offers little scope for the biota to migrate to altitudinal refugia during climate change. However, the many granite outcrops (GOs) scattered across the region provide a suite of habitats and conditions not found in the wider landscape and these may ameliorate the impacts of regional climate change.

Aims

- Investigate the potential of GOs and their associated environments to act as refugia in the face of anthropogenic climate change across south-west Western Australia.
- Determine whether topographic and microhabitat features of GOs designate them as refugia.
- Use phylogeographic patterns to determine whether GOs have acted as refugia in the past and are important reservoirs of genetic diversity.
- Determine whether particular environments at the base of GOs are more productive, and whether individual plants in these environments are under less stress than those in the intervening matrix.

- Determine whether plant communities of GOs are more resilient to anthropogenic climate change disturbances than the communities of the surrounding landscape matrix.

Progress

- A paper on patterns of floristic composition in GO plant communities and their relationships with climate, topographic and microhabitat features on outcrops as been accepted for publication in *Ecology and Evolution*.

Management implications

- Identification of areas that can act as refugia under projected climate change enables adaptation and conservation activities to be focused where they will provide greatest benefit in facilitating species persistence and continued ecosystem function.

Future directions

- With the publication of the paper this project is now complete.



Identification of seed collection zones for rehabilitation

SP 2006-008

M Byrne, H Nistelberger, S McArthur

Context

The Conservation and Ecosystem Management Division of the department provides guidelines to the Forest Products Commission on seed collection zones for forest rehabilitation. Rehabilitation of sites through revegetation requires knowledge of the genetic adaptation of species to sites in order to manage in an ecologically sustainable fashion. This requires an understanding of the genetic structure and local adaptation of species.

Aims

- Identify appropriate seed collection zones (provenances) for species being used for rehabilitation. Initial work is focused on species in the jarrah and karri forest where seed is used for rehabilitation after logging.

Progress

- Analysis of genetic relationships among *Corymbia calophylla*, *C. haematoxylon* and *C. ficifolia* shows distinct genetic separation in the nuclear genome and shared cpDNA haplotypes, consistent with shared evolutionary history. A paper is in preparation.
- Analysis of microsatellite variation and cpDNA variation in 28 populations of *Banksia sessilis* revealed two major genetic clades, one on the Darling Range and Plateau, and another on coastal limestone that exhibited both higher genetic diversity and greater structure. The patterns of genetic diversity and phylogeographic structure suggest the ancestor to these clades originated in the northern coastal environment and diversified through the Darling Plateau during the mid-Pleistocene.

Management implications

- Knowledge of genetic structure and local adaptation will enable identification of appropriate seed collection zones for rehabilitation of forest areas, in order to maintain the genetic integrity of the forest on a sustainable basis. Data from previous research on *Kennedia coccinea*, *Bossiaea ornata* and *Allocasuarina humilis* indicate that seed collected from the same landscape management unit as the area to be rehabilitated would be an acceptable seed-sourcing strategy. Alternatively, where seed is not readily available from the relevant landscape management unit then use of seed from nearby areas in adjacent landscape management units would also suffice. This information has been used to update seed collection zones for forest rehabilitation in the *Forest Management Plan 2014-2023*.

Future directions

- Complete publication of genetic analysis of phylogeographic patterns and genetic structure, and seed sourcing strategies for *B. sessilis*.
- Complete publication of genetic analysis of *Corymbia* species.



FORESTCHECK: Integrated site-based monitoring of the effects of timber harvesting and silviculture in the jarrah forest

SP 2006-003

J Farr, G Liddelow, V Tunsell, B Ward, A Wills, L Mccaw

Context

FORESTCHECK is a long-term monitoring program and results will be used by forest managers to report against Montreal Process criteria and indicators for ecologically sustainable forest management. Initiated as a Ministerial Condition on the *Forest Management Plan 1994-2003*, FORESTCHECK has continued to be incorporated in the *Forest Management Plan 2014-2023* as a strategy for increasing knowledge on the maintenance of biodiversity and management effectiveness in Western Australian forests.

Aims

- Quantify the effects of current timber harvesting and silvicultural practices in the jarrah forest (gap creation, shelterwood, post-harvest burning) on forest structural attributes, soil and foliar nutrients, soil compaction and the composition of the major biodiversity groups including: macrofungi, cryptogams, vascular plants, invertebrates, terrestrial vertebrates and birds.

Progress

- A paper examining the effects of historical timber harvesting and fire regimes on the volume and condition of coarse woody debris at 48 monitoring grids was published in *Australian Forestry*.
- Monthly inspections to document flowering activity continued at seven monitoring grids burnt by the Lower Hotham bushfire in February 2015, facilitating the development of a flowering calendar and confirmation of plant juvenile periods.
- Floristic composition following prescribed fires was compared between fenced grazing exclosures and unfenced areas on grids at Amphion block in Perth Hills District.
- Nine monitoring grids in the Jarrah Forest South ecosystem were remeasured for plant species composition, cover and vegetation structure. Remote camera surveys of vertebrate fauna were also undertaken.
- Information from FORESTCHECK monitoring was provided for inclusion as a case study in Australia's State of the Forests Report 2018.
- Post-burn assessments were undertaken on grids at Barlee and Winnejup blocks burnt by prescribed fire.

Management implications

- FORESTCHECK provides a systematic framework for evaluating the effects of current silvicultural practices across a range of forest types and provides a sound basis for adaptive management. Sixty seven monitoring grids have now been established, with 50 of these sampled at least twice.
- Findings from the project continue to inform a variety of forest management policies and practices and have been incorporated in periodic revision of silvicultural guidance documents. Monitoring data have been used to verify predictive models for forest growth and species occurrence.
- The network of FORESTCHECK grids also provides a framework for monitoring responses to random disturbance events such as bushfires and extreme droughts, and for examining the impacts of a changing climate over the longer term.

Future directions

- Publish findings from the 10-year monitoring period (2002-2012).
- Review monitoring protocols and incorporate new techniques where these will improve efficiency and quality of data collected.
- Prepare manuscript on responses of vascular plants, forest structure and invertebrates following the 2015 Lower Hotham bushfire.
- Remeasure selected attributes on monitoring grids in the Jarrah Forest Sandy Basins ecosystem.



Hydrological response to timber harvesting and associated silviculture in the intermediate rainfall zone of the northern jarrah forest

SP 2000-003

J Kinal, G Liddelow

Context

This is a long-term experiment established in 1999 to address part of Ministerial Condition 12-3 attached to the *Forest Management Plan 1994-2003*. Ministerial Condition 12-3 states that the department shall monitor and report on the status and effectiveness of silvicultural measures in the intermediate rainfall zone (900-1,100 mm/yr) of the jarrah forest to protect water quality.

Aims

- Investigate the hydrologic impacts of timber harvesting and associated silvicultural treatments in the intermediate rainfall zone of the jarrah forest in a changing hydroclimate.

Progress

- Monitoring of groundwater levels, streamflow, stream salinity and stream turbidity continued in Yarragil 4L, 4X, 6C, and Wuraming catchments in the Swan Region.
- Yarragil 4L catchment was thinned to a target 11m²/ha, 36 years after the first thinning.
- A paper examining the relative contribution to streamflow generation in jarrah forest streams has been submitted to *Hydrological Processes*.
- A paper reviewing the long-term hydrological response to thinning in Yarragil 4L is being redrafted.
- Groundwater bores were re-measured at experimental catchments in the Warren Region including Crowea, Iffley, Poole, March Road and April Road. More than 120 bores were measured, with 90 still being in contact with groundwater.

Management implications

- Experimental catchments provide a unique long-term record of the hydrological response of the jarrah forest to climate change and forest management practices.
- Monitoring in these catchments contributes to reporting on KPI 10 for the *Forest Management Plan 2014-23* that relates to stream condition and groundwater level within fully forested catchments.
- Monitoring of experimental catchments helps inform the effects of silviculture treatments on water balance.
- Re-thinning of Yarragil 4L provides an opportunity to examine the effects of the silvicultural treatments on the groundwater and surface water hydrology, biodiversity, and vegetation structure and composition of the catchment.

Future directions

- Continue monitoring of groundwater levels, streamflow and water quality in the Yarragil catchments.
- Remeasure post-thinning stand density in Yarragil 4L.



Genetic analysis for the development of vegetation services and sustainable environmental management

SP 1998-007

M Byrne, S van Leeuwen, R Binks, M Millar, B Macdonald, S McArthur

Context

Understanding the genetic structure and function of plants is important for their effective utilisation for revegetation, mine-site rehabilitation and provision of ecosystem services, such as hydrological balance, pollination and habitat connectivity.

Aims

- Provide genetic information for the conservation and utilisation of plant species for revegetation and rehabilitation. Current work aims to identify seed collection zones for species used in rehabilitation of minesites in the Pilbara and the Midwest.

Progress

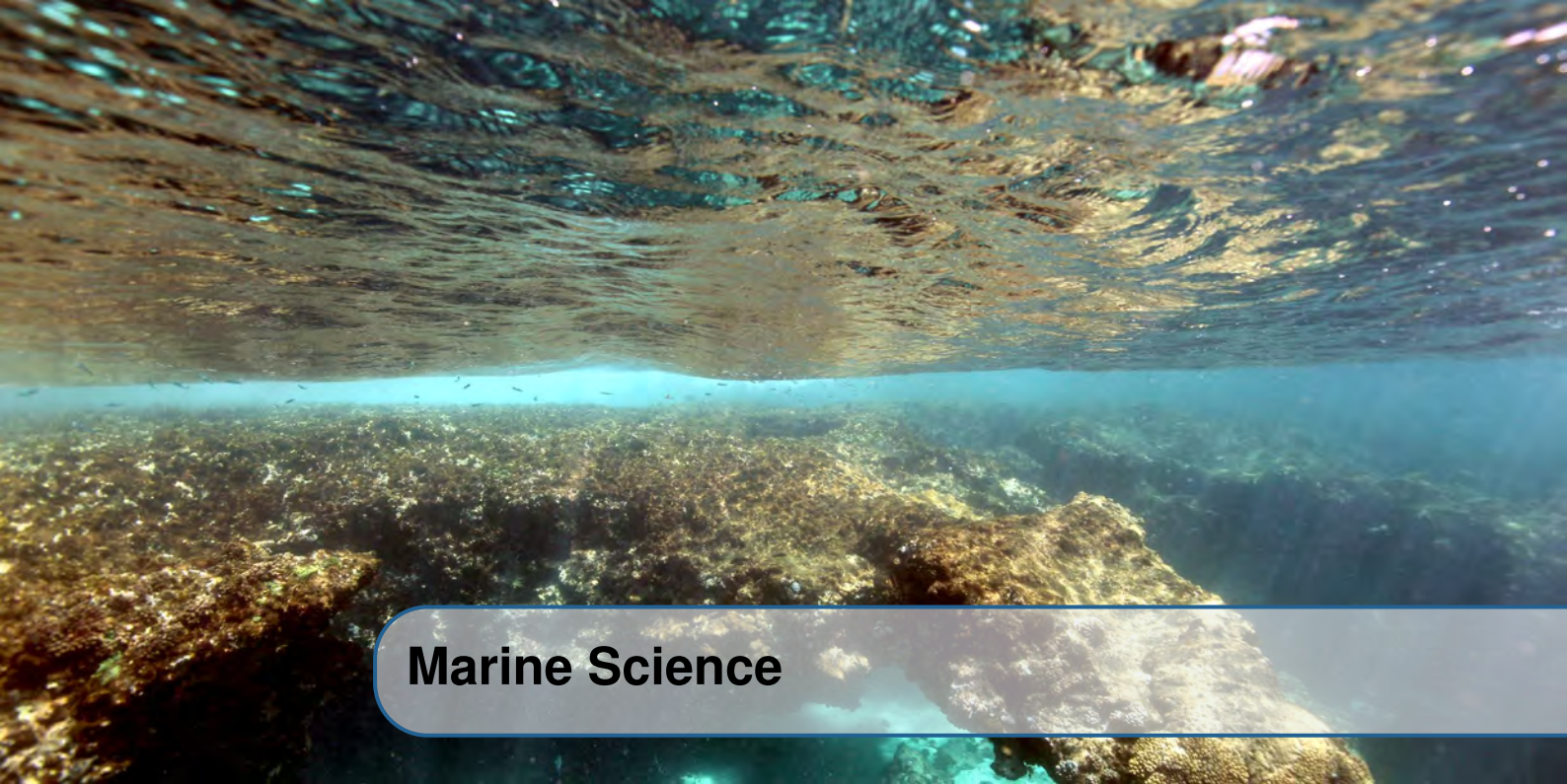
- Data analysis for both nuclear and cpDNA markers is complete for eight species in the Pilbara for the identification of seed collection zones, *Petalostylis labicheoides*, *Indigofera monophylla*, *Senna glutinosa*, *Corymbia hamersleyana*, *Acacia pruinocarpa*, *A. hilliana*, *A. spondylophylla* and *Mirbelia viminalis*. A paper on *C. hamersleyana* and *A. pruinocarpa* is in preparation.
- Further genomic analysis of *Aluta quadrata* was undertaken to investigate fine-scale genetic variation across the Western Range, the largest of the three locations for the species. Analysis is complete and a report has been written.
- A synthesis paper on modelling seed collection and restoration establishment scenarios for *Grevillea paradoxa*, *Melaleuca nematophylla*, *Mirbelia* sp. *bursarioides* and *G. globosa* has been published in *Australian Journal of Botany*.

Management implications

- Pilbara seed collection zones - Moderate levels of genetic diversity and lack of differentiation within *C. hamersleyana* and *Acacia pruinocarpa* imply that seed resources for land rehabilitation and mine-site revegetation programs for these species can be selected from a wide distributional range within the Pilbara. Low levels of differentiation across the ranges of *P. labicheoides* and *I. monophylla* allow for multiple, broad seed collection zones, while high genetic differentiation within the more restricted distributions of *A. hilliana*, *A. spondylophylla* and *M. viminalis* require more limited seed collection zones.
- *Aluta quadrata* - Range-wide genomic analysis supported the three conservation units that were previously identified with microsatellite data and re-iterate that seed collections for each location should be kept separate. Within the Western Range, individuals showed a clinal pattern of genetic variation, rather than discrete genetic clusters or widespread homogeneity. This indicates that gene flow is limited by distance and that connectivity across the Western Range is facilitated by stepping-stone dispersal.
- Midwest seed collection zones - Genetic analysis of four species has provided a basis for identification of seed collection zones for land rehabilitation and mine-site revegetation programs, with species wide collections for *M. nematophylla* (except for the divergent Murchison River gorge), *G. globosa* and *Mirbelia* sp. *bursarioides*, while three regional seed collection zones were identified for the bird-pollinated *G. paradoxa* that showed limited pollen dispersal.

Future directions

- Finalise papers reporting genetic results for eight Pilbara species with recommendations for seed collection zones.



Marine Science

Program Leader: Alan Kendrick The broad goal of the Marine Science Program is to ensure the department's marine biodiversity conservation and management programs are based on best practice science. Specifically, the program promotes and undertakes marine research and monitoring to improve the scientific basis for the conservation and management of Western Australia's state-wide system of marine protected areas, threatened marine fauna and marine biodiversity generally. The program also coordinates and manages external marine research programs, such as the current investigation into the bio-physical, social and cultural values of the Kimberley that is undertaken as part of the Western Australian Marine Science Institution (WAMSI). The research and monitoring programs undertaken by the Marine Science Program are based around the research and monitoring strategies identified in protected area management plans and threatened species recovery/management plans, ensuring that all activities are clearly linked to departmental priorities and programs.



Long-term monitoring in the area of the proposed Dampier Archipelago marine reserves

SP 2015-015

M Moustaka, T Holmes, S Wilson, A Kendrick, K Murray

Context

The Pluto LNG Project Offset D program includes the requirement to establish long-term monitoring reference sites in the proposed Dampier Archipelago marine reserves in accordance with the indicative management plan for the area. This task will require a prioritisation of ecological assets, the establishment of long-term monitoring sites to assess spatial and temporal distribution of key assets, and the provision of quantitative evidence on the status of these assets. This work will also help develop best practice monitoring techniques for assets and pressures where knowledge is lacking, and provide valuable information for marine planning and conservation initiatives.

Aims

- Develop and implement a monitoring, evaluation and reporting program of key biodiversity asset condition and their major pressures at key sites in the area of the proposed Dampier Archipelago marine reserves.

Progress

- A paper on coral assemblage was published in *Diversity*.

- Tropical seagrass article was written for publication in *Landscape*.
- Three field trips to monitor seagrass, coral (recruit/juvenile/adult), fish, macroinvertebrates, and water quality were undertaken.
- Development of tropical seagrass and macroinvertebrate monitoring methodologies.

Management implications

- An established monitoring program will inform managers of trends in asset condition and associated pressures that will facilitate long-term adaptive management for the proposed reserves, and promote environmental understanding for a range of stakeholders and the community. The latest field trips conducted will add a third data point to adult coral and fish datasets, a second data point to the seagrass dataset, and establish juvenile coral and macroinvertebrate datasets, further adding to the available baseline data for the region.
- New marine monitoring indicators and methods for seagrass and benthic invertebrates will provide a sound basis for assessing the condition of these ecological values in the Dampier Archipelago.

Future directions

- Undertake ground-truthing mangrove imagery with drones to utilise the higher resolution products available through new technology.
- Third seagrass and second macroalgae monitoring surveys will be completed.
- Coral settlement tiles will be deployed.
- Developing R scripts to expedite data analysis and reporting for ecological assets.
- Finalising Fit-to-Park and sampling methodology documentation for the Dampier Archipelago.



Habitat use, distribution and abundance of coastal dolphin species in the Pilbara

SP 2014-021

K Waples, H Raudino, C Douglas, R Douglas

Context

Australian snubfin (*Orcaella heinsohni*) and Australian humpback (*Sousa sahulensis*) dolphins inhabit Australia's north-western coastal waters, but little is known about the population sizes, distribution and residency patterns of these species. Current knowledge of these dolphin species in the Pilbara is poor and is limited to a dedicated study of humpback dolphins in Ningaloo Marine Park and Exmouth Gulf and opportunistic surveys and anecdotal sightings throughout the region. Although the presence of several coastal dolphin species is expected in nearshore Pilbara waters (humpback, snubfin and bottlenose dolphins), very little is currently known of their residency and habitat use patterns.

Human pressures on these species are increasing in the Pilbara through activities associated with expansion of the resources sector, including oil and gas exploration and production, coastal infrastructure development and shipping. While this is a key factor that proponents are required to address to secure State and Commonwealth environmental approvals, impact assessments for these species are complicated by the lack of best practice protocols and standards for survey design and data collection, which limits the comparison of different studies and study sites. This project will provide a better understanding of these species and their spatial and temporal use of Pilbara coastal waters and lead to greater certainty in assessing and managing impacts that relate to industrial developments. This project was designed to meet this priority need under the Wheatstone Offset C program.

Aims

- Determine habitat use, distribution, abundance, residency, and movement patterns of dolphins in coastal Pilbara waters.

- Identify the characteristics of habitats used by coastal dolphins, such as water depth, benthic substrate, and a range of environmental variables.

Progress

- Survey data from three aerial surveys of the coastal waters of the Pilbara extending offshore to the 20 metre depth contour, including the Montebello Islands has been used to produce estimates of dolphin abundance and density for the area.
- A manuscript is being prepared on minimum image resolution needed to differentiate between small coastal dolphin species from aerial survey.
- A boat based survey was conducted in the Dampier Archipelago in conjunction with Pluto Offset D project. This survey focussed on photo identification of bottlenose and humpback dolphins, collection of biopsy samples and trialling drop camera survey to characterise sponge habitat that may be important to the humpback dolphin population.
- A manuscript on alternative genetic sampling techniques using a drone has been submitted to *Ecosphere*.
- Data has been formatted and is being analysed using density surface modelling to better understand abundance estimation of coastal dolphins at a regional scale in the Pilbara.

Management implications

- This research will provide a baseline understanding of dolphin habitat use in the Pilbara region, which will inform the assessment of environmental impacts relating to future coastal developments, and will assist to determine the conservation status of coastal dolphin species in Pilbara waters.
- The research will establish baseline data and long-term monitoring protocols for coastal dolphin species in State waters.

Future directions

- Aerial survey data results will be prepared for publication.
- Species distribution models will be combined with other spatial data layers to assess risk to the target species (dugong, humpback and bottlenose dolphins) across the Pilbara region.
- A FinBook on bottlenose and humpback dolphins of the Dampier Archipelago will be prepared for the Murajugga Rangers, similar to the FinBook produced for the Yawuru Country Managers on snubfin dolphins of Roebuck Bay.
- A field trip will be undertaken to the Montebello Islands Marine Park to collect genetic samples and dolphin photoidentification.



Distribution and abundance estimate of Australian snubfin dolphins at a key site in the Kimberley region, Western Australia

SP 2014-018

K Waples, H Raudino

Context

The current lack of knowledge of the Australian snubfin dolphin (*Orcaella heinsohni*) meant that its conservation status could not be properly assessed in 2011 due to insufficient information on population dynamics and distribution. This species is known from tropical coastal waters of Australia and New Guinea, but tend to be shy, evasive and difficult to study. Although they range southwards to the the Pilbara region of Western Australia, there has been little Western Australian based research on this species and much of this remains unpublished. This project will compile existing data on snubfin dolphins across the Kimberley to gain a better understanding of their habitat use and distribution. The collation of data into a single database will also facilitate the study of population structure and demographics based on recognised individual animals. This project will assess dolphin distribution across the Kimberley region between 2004-2012.

Aims

- Provide a quantitative abundance estimate of snubfin dolphins for Roebuck Bay in Western Australia that will be used as a baseline for this population and will also enable comparison with abundance estimates of the species from sites at Cleveland Bay (Qld) and Port Essington (NT).
- Compare methods for abundance estimation (mark-recapture versus distance sampling) and the suitability of these methods for abundance estimation of this species.
- Map the extent of occurrence and area of occupancy of snubfin dolphins in the Kimberley by combining traditional knowledge and dolphin sightings from Indigenous sea rangers and scientific survey sightings.
- Refine and populate a purpose built and standardised database that will support long term data collection and curation in Western Australia and facilitate data-sharing between jurisdictions.

Progress

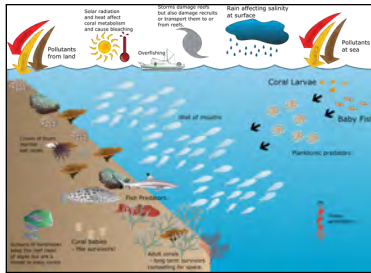
- A manuscript on snubfin dolphin abundance contrasting distance sampling and mark-recapture survey techniques in Roebuck Bay is being finalised.
- A manuscript on broadscale distribution of snubfin dolphins across the Kimberley region and implications for conservation status has been revised.
- A third training of community members in the use of the DolphinWatch app was held in Broome with the view of better understanding the habitat use of snubfin dolphins in the area and life history information at the individual level from dorsal fin images.
- A three day census of snubfin dolphins in Roebuck Bay was conducted, including participation from Parks and Wildlife Service staff, Yawuru Country Managers and commercial tour operators. A report on the outcomes of this survey is being prepared and will be shared with the community and participants.

Management implications

- Collation of scientific and traditional knowledge of a poorly understood marine mammal species of high conservation value means managers now have baseline knowledge of the abundance of snubfin dolphins in the proposed Yawuru Nagulagun / Roebuck Bay Marine Park.
- Establishment of a database for all dolphin research and monitoring where survey and photo-identification data is collected ensures that standardised data is available for assessing population abundance and distribution. It also provides the capacity to develop sighting histories for individual animals, thus providing a better understanding of population demographics and life history. This database can also be used for information sharing across jurisdictions and between research organisations.
- The broad-scale collation of information and modelling has provided relevant information on area of occupancy and extent of occurrence that can be used to more accurately assess the conservation status of snubfin dolphins.
- The research has enabled partnerships to be established with Indigenous sea ranger groups to develop survey methodologies, data storage and reporting structures that are consistent with healthy country and reserve management plans.
- The Dolphin Watch app and Finbook photo-identification guide will support ongoing monitoring of the snubfin dolphin population in Roebuck Bay and will be used to address the KPIs related to maintaining abundance and diversity of these dolphin species in the Yawuru Nagulagun / Roebuck Bay Marine Park.

Future directions

- Finalise paper on a population estimate of snubfin dolphins in Roebuck Bay.
- Re-submission of a manuscript on cross-cultural knowledge of the distribution of snubfin dolphins in the Kimberley to include species distribution modelling.
- Publication of the report describing the 2019 snubfin dolphin census.



Improving the understanding of West Pilbara marine habitats and associated taxa: their connectivity and recovery potential following natural and human induced disturbance

SP 2014-004

R Evans, S Wilson, M Byrne, R Douglas, R Binks, B Macdonald, K Murray, G Pitt

Context

The focus of work for Wheatstone Development Offset Project B will be to add to the understanding of west Pilbara marine habitats (including coral and seagrass communities) and associated taxa, including their level of connectivity and their recovery potential should they be impacted by natural and human induced disturbance. This research aims to build on existing knowledge and integrate with current and proposed connectivity projects on habitat-forming taxa and associated taxa in the tropical north-west of Australia. Broad-scale connectivity studies of flora and fauna within and between the offshore islands of the north-west continental shelf have shown varying levels of connectivity. Previous studies have also shown limited connectivity between inshore and offshore marine communities but there have been no studies looking at connectivity and recovery potential between locations within the Pilbara region, and their connections with the broader inshore locations of Ningaloo to the south-west, and the Kimberley to the north-east.

Aims

- Determine levels of population connectivity and assess the extent and spatial scales of local adaptation.
- Correlate genetic parameters with modelling of environmental variables to determine factors that have a significant influence on connectivity.
- Investigate coral demographics and recruitment to understand how the environment influences the corals in the Pilbara.

Progress

- Manuscripts are being prepared on genetic connectivity of seagrass and coral.
- A manuscript is being prepared on recovery of coral after multiple bleaching events in the Pilbara.
- A manuscript on mangrove population genomics and connectivity was published in the journal *Diversity and Distribution*.
- A manuscript on the genetic connectivity of the coral *Cyphastrea microphthalmia*, was published in the journal *Coral Reefs*.
- A manuscript on the state of Western Australia's coral reefs was published in *Coral Reefs*.

Management implications

- Mangrove propagule dispersal is spatially limited and significant gaps in mangrove distribution represent strong barriers to gene flow in this species. Thus effective management of these important ecosystem builders should prioritise restoring habitat continuity and minimise further fragmentation.
- Monitoring of Western Australian coral reefs shows that coral cover is low. Global issues drive this demise but management should consider local actions to enhance resilience.
- Barriers to genetic connectivity of corals exist between the Kimberley, the Pilbara and Shark Bay. There is also evidence to support further genetic structure within the Pilbara and Ningaloo that provides information for management of coral reefs.
- Analysis showed that oceanographic modelling of coral dispersal can predict genetic connectivity but using over-water distance is a better predictor of genetic dispersal. Therefore, oceanographic models require further refining before management can be confident in them.

Future directions

- Analyses of genetic data for the coral species *Turbinaria reniformis* will be completed.
- Analysis and preparation of a manuscript on coral recovery potential in the Onslow region will be completed.



The influence of macroalgal fields on coral reef fish

SP 2013-006

S Wilson, T Holmes, K Murray

Context

Macroalgae are a prominent component of tropical benthic communities along the north-west coast of Australia. Within the Ningaloo Reef lagoon, large fields of macroalgae are a distinct feature of the marine park, covering ~2,000 ha. These macroalgal fields are important habitat for fish targeted by recreational fishers and are a focal area for boating activity within the park. Moreover, large seasonal shifts in algal biomass on these and other tropical reefs suggest macroalgae play an important role in nutrient fluxes in Ningaloo and similar systems. Recent work at Ningaloo has quantitatively assessed seasonal variation in biomass and diversity of macroalgal communities. This project will build on the information gained from these initial studies to improve understanding of how macroalgae are distributed across the Ningaloo lagoon and better define the role of macroalgal fields as habitat for fish recruits and adults.

Aims

- Quantify spatial variance in macroalgal fields at Ningaloo Marine Park and determine the relative importance of physical and biological drivers of algal abundance and diversity.
- Identify attributes of macroalgal fields favoured by juvenile fish and examine the relative importance of habitat quality and predation on juvenile abundance.
- Assess the influence of juvenile fish on replenishment and future adult abundance.

Progress

- A review of the ecological services/processes provided by tropical macroalgal fields highlighted their high level of primary productivity and how this subsidises productivity in adjacent habitats. The influence of climate change on tropical macroalgae was also investigated, and a need for research on temperature thresholds of canopy forming taxa was identified. The review was published in *Functional Ecology*.
- Information on fish assemblages within tropical macroalgae fields was compiled from locations around the globe and meta-analysis used to characterise fish within this habitat. Initial results identify species unique to macroalgal habitats, that many fields are important nurseries, and that some of the fish which inhabit macroalgal fields are important to local fisheries. Moreover diversity of fish in macroalgal fields is comparable to that of other tropical marine habitats, such as seagrass. These findings are being prepared for publication.

Management implications

- Analyses of information from around the world emphasise the importance of macroalgal fields as nurseries, primary producers and habitat for fisheries target species. Canopy forming macroalgal fields are therefore habitat of high conservation value that should be considered for protection when planning marine reserves.

Future directions

- Submit meta-analyses results and associated review of fish assemblages in macroalgal habitats for publication.
- Undertake data analyses to understand links between juvenile and adult fish abundance.



Understanding movements and identifying important habitats of sea turtles in Western Australia

SP 2013-002

S Whiting, Tucker, S Fossette-Halot

Context

This project uses satellite telemetry to track turtles that are released to the wild with minimal and extensive rehabilitation. In addition, turtles are tracked to identify connectivity between different habitats in their life stages. Commonly, turtles are tracked from nesting beaches to identify interesting habitat, migration routes and resident foraging grounds. The tracking results identify the geographic range and preferred habitats and provide insight into the viability and survivorship of healthy and rehabilitated turtles in the wild. The identification of preferred habitat allows pressures to be identified and prioritised for different size classes. As tracking results will be broadcast live on the internet (updated daily via seaturtle.org) there is a direct link between the department's science activities and the community. The genetic information (derived from samples collected routinely across a range of projects) will provide another layer of information that helps to describe the spatial range of sea turtles in Western Australia.

Aims

- Determine the distribution and movement of sea turtles and investigate how components of sea turtle biology (including genetics) influence turtle distribution (including preferred sites), movement and foraging ranges.
- Investigate how environmental drivers, such as oceanographic factors, influence turtle distribution (including preferred sites), movement and foraging ranges.
- Investigate the viability and survivorship of rehabilitated turtles.
- Investigate connectivity of turtles between habitats across their life stages (commonly between nesting beaches and foraging grounds).

Progress

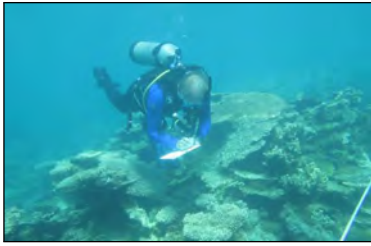
- Tracking studies continued in flatback turtle foraging grounds during the past year. More turtles were tracked at Roebuck Bay and new foraging areas were found along Eighty Mile Beach.
- Analysis of tracking revealed migratory paths to and from the nesting grounds providing new knowledge for this species and new potential mating grounds were identified.
- Data from this study is currently being integrated with animal borne cameras and other activity sensors to gain insights into foraging and diet.
- Movements of tracked turtles were displayed in real time on www.seaturtle.org.

Management implications

- Identifying the spatial and temporal distribution of any animal is critical to managing wildlife. This study has filled major gaps in understanding the life cycle of flatback turtles including foraging and migration components that allows critical habitats to be put in context with marine park boundaries and pressures.
- This project is conducted in partnership with Indigenous groups and knowledge is shared back to communities. Turtle information is directly used by Western Australian marine park planning in development assessment advice and to update information for the National Marine Turtle Recovery Plan.

Future directions

- Animal borne cameras and activity sensors will be evaluated for improvement on transmitter attachment methodology for flatback turtles.



Marine monitoring program

SP 2012-008

T Holmes, K Bancroft, C Ross, W Robbins, S Strydom, E D'Cruz, B French, M Moustaka, A Kendrick, K Murray, S Wilson, J Goetze

Context

A state-wide system of marine protected areas is continuing to be established in Western Australia as part of Australia's National Representative System of Marine Protected Areas. Long-term monitoring of the condition of ecological values and the pressures acting on them is seen as an integral aspect of adaptive management. The department's marine monitoring program is a state-wide, long-term, marine monitoring, evaluation and reporting program that is being implemented to increase the efficiency and effectiveness of marine reserve and threatened marine fauna conservation and management.

Aims

- Implement a long-term monitoring program of key ecological values, and the pressures acting on them, in Western Australia's marine parks and reserves.
- Develop and implement a long-term monitoring program of threatened/protected marine fauna, and the pressures acting on them in State waters.
- Report results and findings of the monitoring program to departmental managers, joint management partners, public, peers and other key stakeholders to facilitate effective management and conservation of Western Australia's marine values.
- Continually evaluate and review monitoring and reporting programs to ensure that best practice science is adopted and that communication methods are appropriate for the intended target audiences.

Progress

- Updated monitoring data was collected for fish, coral, seagrass, macroalgae, mangroves, macro-invertebrates, little penguins and water quality during fieldwork conducted across 13 marine reserves from Walpole and Nornalup Inlets Marine Park in the south to North Kimberley Marine Park in the north.
- Updated results and findings from the monitoring program were communicated to Marine Park Coordinators and regional managers via the annual Marine Park Performance Assessment process, written advice, and opportunistic presentations. This information included more detailed management implications and data interpretation for the Walpole and Nornalup Inlets, Rowley Shoals, Eighty Mile Beach and North Kimberley marine parks.
- The second document in the Marine Science Program monitoring report series was published as *Ecological monitoring in the Shark Bay marine reserves 2018*.
- Four scientific papers incorporating departmental monitoring data were published in the journals *Estuarine Coastal and Shelf Science*, *Coral Reefs*, *Marine Biology*, and *Diversity and Distributions*. A further seven scientific papers have been published in journals by monitoring staff incorporating external data sets.
- Significant scientific advice was provided as a part of the Ocean Reef Marina development proposal, the Harvest Road oyster farm proposal, and the ongoing planning process for a marine park in the Buccaneer Archipelago.
- Significant progress was made in the movement of monitoring data and metadata to the department's Data Catalogue and BioSys, and the automation of data cleaning and analysis processes through R-coding.

Management implications

- The long-term marine monitoring program provides data that informs the evidence-based adaptive management of Western Australia's marine parks and reserves and threatened and specially protected marine fauna.
- Monitoring data is collected on key ecological values, and the pressures acting on those values to guide management responses. This performance assessment and adaptive management framework allows conservation managers to respond appropriately to changes as they become apparent, and to refine approaches to managing ecological values based on rigorous scientific evidence.

Future directions

- Finalise and publish supporting documentation that describes the aims and structure of the marine monitoring program, including rationale for the selection of monitoring indicators and methods for key ecological values.
- Continue the implementation and periodic review of ecological value monitoring across the marine reserve system, including at recently created and proposed reserves in Western Australia's Kimberley region.
- Continue to provide marine park managers with evidence-based knowledge of the condition of key ecological values and the pressures acting on them to inform and assist the delivery of adaptive management.
- Continue to provide the scientific knowledge required for the department's marine parks and reserves reporting process.



North West Shelf Flatback Turtle Conservation Program

CF 2011-118

S Whiting, S Fossette-Halot, Tucker

Context

The Northwest Shelf Flatback Turtle Conservation Program (NWSFTCP) is one of four environmental additional undertakings for the Gorgon Gas project at Barrow Island. The purpose of the program is to increase the conservation and protection of the Northwest Shelf flatback turtle population through: surveying, monitoring and research; reducing interference to key breeding and feeding locations; and establishing information and education programs. The Marine Science Program coordinates the planning and implementation of works required for the NWSFTCP in addition to coordinating general research and monitoring of marine turtles in Western Australia. The NWSFTCP has a range of governance arrangements that include an advisory committee and a scientific panel.

Aims

Implement the scientific management and communication strategies of the the NWSFTCP Strategic Plan.

Progress

- One PhD project on climate change impacts was completed and three PhDs commenced in the fields of climate change, animal movement and program assessment.
- Studies on the foraging stage of flatback turtles were undertaken in Roebuck Bay and included determining distribution, size class structure movements and habitat use, diet identification, health assessment through blood chemistry and dive behaviour.
- Foxes were culled at a major flatback rookery in the Pilbara on Mundabullangana Station.
- Monitoring of nesting turtles was continued at two major rookeries.

Management implications

- The NWSFTCP Strategic Conservation Plan maps out the foundations of the program to establish a robust program of works within a strategic long-term framework.
- Knowledge from foraging ground studies has been used to assist planning and actions for the Roebuck Bay Marine Park and have been used in planning advice.
- The first major fox cull at Mundabullangana rookery in the Pilbara since the mid 1990s will increase hatchling production for the stock.
- Knowledge of turtle distribution and breeding sites provides information for marine park planners, healthy country plan custodians, managers of Indigenous land and sea country and regulatory authorities responsible for development assessments.
- Strong relationships through collaborative projects have been built between DBCA, Yawuru Rangers, traditional custodians and Indigenous Corporations and these will be integral for long term management.

Future directions

- Continue efforts to identify, understand and fill gaps in knowledge (sub-adult turtles, mating areas).
- Continue fox mitigation at major rookeries.
- Continue studies to investigate impacts of artificial light, climate change and feral animals.
- Continue efforts to jointly build Indigenous partnerships, engagement and employment opportunities.



WAMSI 2: Kimberley Marine Research Program

CF 2011-117

K Waples

Context

The Kimberley Marine Research Program (KMRP) is undertaking a program of marine research to support the management of the Great Kimberley Marine Park (which will include state marine parks at Camden Sound, Horizontal Falls, North Kimberley, Roebuck Bay and Eighty Mile Beach) and the coastal waters outside of these proposed marine parks. The KMRP was developed and is being implemented through the Western Australian Marine Science Institution (WAMSI), with DBCA as lead agency responsible for the direction, coordination and administration of the research program.

A science plan for the KMRP was developed to address priority research and information needs to support the management of ecological and social values in the Kimberley region through joint management of the Kimberley marine park network. The plan comprises a suite of multidisciplinary research projects focused around two themes: (1) biophysical and social characterisation, to provide the foundational datasets required for marine park and marine resource management, as well as better understanding and management of current human impacts; and (2) understanding key ecosystem processes, to provide the scientific understanding of ecosystem functioning and response to a range of potential human impacts that are likely to arise in the future, including climate change.

The research program will be undertaken between 2012 and 2017 and involve up to 80 scientists from eight research or management institutions in Western Australia working collaboratively on 25 research projects. Aboriginal involvement is a key component to the success of the research program and all projects are engaging with Aboriginal people and developing partnerships with the relevant traditional owners to include their participation and to ensure the research outcomes benefit local communities.

Aims

- Ensure the KMRP research projects are developed and delivered in line with the State's priority needs, and to meet DBCA and joint management strategies for the newly-formed and proposed marine parks and reserves in the Kimberley.
- Ensure integration of research projects within the KMRP, both in terms of field logistics and science findings, so that the program as a whole produces a clear understanding of Kimberley marine ecosystems and the interactions between them that is useful to management.
- Ensure that the KMRP is undertaken in a culturally appropriate way in partnership with local Aboriginal people and delivered in a way that will help their longer-term aspirations.
- Ensure that knowledge transfer and uptake occurs between scientists, joint managers and decision makers.

Progress

- The final synthesis report for the program has been completed and published.
- Knowledge exchange activities to highlight key findings, management implications and potential development of decision making tools has been initiated.
- Communication of the KMRP achievements and outcomes continues through a range of activities, including media engagement, updated project information on-line and presentations at conferences and to stakeholder groups.

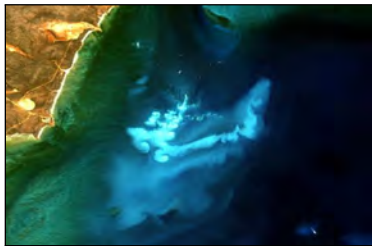
- A final project exploring the priority knowledge gaps that remain for the Kimberley and synergies between scientists and joint managers is underway.

Management implications

- The KMRP outputs will increase the capacity to manage human impacts in the Kimberley marine reserves and improve understanding of the ecological and socio-cultural significance of the biodiversity assets of the Kimberley for joint managers, industry and the community. The program also enhances the capacity of Indigenous rangers and working relationships with Indigenous communities, thereby increasing the opportunity for more productive and bipartisan joint management in the future. Findings are being used in the development of a monitoring program for key biodiversity assets across the Kimberley.

Future directions

- Complete remaining research project priorities for the Kimberley and share with key management staff.



Effects of Gorgon project dredging on the marine biodiversity of the Montebello/Barrow Islands marine reserves

SP 2010-008

A Kendrick, R Evans, G Shedrawi

Context

The Gorgon project on Barrow Island is the largest single-resource natural gas project ever developed in Australia. The plant includes three 5 million tonne per annum LNG trains, with domestic gas piped to the mainland, and a four kilometre long loading jetty for international shipping. The project included a dredging program that excavated and dumped approximately 7.6 million tonnes of marine sediment over a period of approximately 18 months. The Gorgon Dredging Offset Monitoring Evaluation and Reporting Project (Gorgon MER) investigated the impacts of the dredging and dumping activities on selected marine communities within the Montebello/Barrow Islands marine reserves. This monitoring will also help inform future environmental impact assessments by improving predictions of the spatial scale and nature of the likely impacts of dredging and dumping activities on sensitive marine communities. Additionally, this project will provide significant baseline data for long-term monitoring of key ecological values in the marine reserves.

Aims

- Assess the nature and extent of potential impacts of the Gorgon dredging program on the condition of coral, fish and other important ecological communities of the Barrow/Montebello islands marine reserves.
- Determine the cause/s of any changes in the condition of the above communities, with particular focus on dredging, dumping and re-suspension of spoil.
- Assess the effects of potential confounding natural (e.g. cyclones, disease, predation, bleaching) and other anthropogenic (e.g. fishing) pressures on the condition of coral communities of the Barrow/Montebello islands marine reserves.
- Assess the nature and extent of the impacts from the Gorgon dredging program on the social values of the Barrow/Montebello islands marine reserves.

Progress

- Final report is completed and awaiting final approval from Chevron before publishing in the library.

Management implications

- Phase One of the Gorgon MER project provides department managers and scientists with a relatively intensive baseline for assessing potential impacts on, and recovery of, coral communities within the MBIMPA, with a particular focus on potential impacts related to the dredging program for the Gorgon

Project. Information outputs include temporal condition and related pressure measures for biophysical assets (e.g. coral, finfish and macro-invertebrate communities) that aligns with the department's marine monitoring program for the MBIMPA.

- The data generated from this monitoring program complements Offset E of the Pluto Energy LNG program aimed at improving the capacity of government and industry to manage the impacts of dredging on tropical coral reef communities. The Gorgon MER project also strategically assists the planning for future environmental impact assessments by improving predictions of the spatial scale and nature of the likely impacts of dredging and dumping activities on sensitive marine communities.

Future directions

- This project is complete.



Spatial and temporal patterns in benthic invertebrate communities of the Walpole and Nornalup Inlets Marine Park

SP 2009-013

S Strydom, A Kendrick

Context

Walpole and Nornalup Inlets Marine Park (WNIMP) was created in 2009 to include the entrance channel, Walpole and Nornalup inlet basins and the tidal extent of the Frankland, Deep and Walpole rivers. Invertebrates are recognised as a significant ecological value of the marine park and a key performance indicator (KPI) of management effectiveness. Additionally, benthic invertebrates are a key food source for a range of fish species in WNIMP. The benthic invertebrate community of the inlets was initially described from surveys conducted in 1984 and 1987. The fauna was relatively diverse compared with most estuaries in the south-west of Western Australia because of the predominantly marine conditions that are sustained in the inlets. Few subsequent studies have examined this fauna, and the current knowledge of benthic invertebrates in the system is considered to be inadequate for marine reserve management. Furthermore, as there are strong recreational fishing values associated with the region, understanding trophic links between benthic invertebrates and fishes in the estuary is important for management of the marine park.

Aims

- Determine spatial patterns in the WNIMP benthic invertebrate community.
- Determine temporal variation in the WNIMP benthic invertebrate community, particularly in relation to seasonal changes in the hydrological cycle of the inlet system.
- Assist to develop methods for long-term monitoring of benthic invertebrates in WNIMP and more broadly across temperate estuarine marine protected areas.
- Determine whether there are spatial and temporal difference in fish community structure (i.e. species composition, abundance, age class) in WNIMP.

Progress

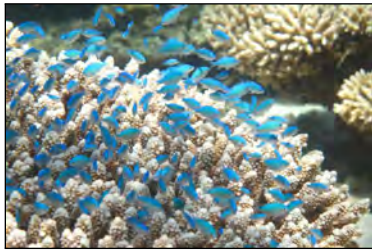
- A collaborative DBCA/Edith Cowan University (ECU) student camp was held at WNIMP in April 2019. Third year undergraduate students studying Coastal and Marine Management with Professor Paul Lavery collected data on fish within the estuary to examine broader ecosystem links with the invertebrate community.
- These data are now ready to be analysed together with the data collected from previous years.
- Local Parks and Wildlife Service rangers worked on the sampling with Marine Science Program staff and ECU researchers and students, which has provided educational opportunities to teach students about the values and management of WNIMP.

Management implications

- Benthic invertebrates are a KPI for this marine reserve. Understanding the relationship between invertebrates and finfish informs management of how changes to invertebrate communities can influence another KPI community within the reserve.
- Knowledge of spatial and temporal patterns of invertebrate distribution is important for understanding the condition of this community in relation to the influence of natural processes and possible anthropogenic impacts. As such, the study will assist the implementation of long-term benthic invertebrate community monitoring at WNIMP.

Future directions

- Continue sampling associated with the current ECU program in 2020.
- Analyse several large data sets and prepare reports and manuscripts for publication.



Interactive effects of fishing and climate change on coral reef fish populations

SP 2009-003

S Wilson, T Holmes

Context

Climate change and over-fishing are widely regarded as the major threats facing coral reef communities worldwide. Typically fishing has a 'top-down' effect on communities, through the removal of large predators, whilst climate change causes degradation of habitat, which affects fish that recruit, feed and shelter within corals. The independent impacts of these threats are well-studied; however, the interactive effects between fishing and climate change are yet to be examined. This interaction may be particularly important on reefs off the mid-western Western Australian coastline where per-capita boat ownership and recreational fishing pressure is extremely high.

Two critical processes that determine the community structure of coral reef fish are recruitment and early post-settlement predation. It is hypothesised that the degradation of coral-associated habitat due to climate change will cause a decline in recruit numbers. Conversely, fishing will reduce abundance of large predators and increase numbers of smaller habitat-associated predators, thereby increasing post-settlement predation. Examining how changes in habitat and predators interact and influence post-settlement survival of fish will be critical to understanding the impacts on biodiversity of fish communities and fish populations.

Aims

- Determine how habitat degradation instigated by climate change and changes in fishing pressures affect the composition of the fish communities on Western Australian coral reefs.
- Assess diet of predatory species targeted by fishers.
- Identify microhabitats preferentially used by juvenile fish.

Progress

- An assessment of marine heatwave and cyclone impacts on Western Australian coral reefs was published in *Coral Reefs*. The study shows that coral cover on some reefs is at the lowest levels recorded.
- The loss of coral due to heat stress can have flow on effects for reef fish assemblages. Evaluation of fish on reefs one year after the 2016 bleaching and seven years after the 1998 event to assess short and long term impacts, showed declines in small bodied fish a year after bleaching, primarily due to reduced cover of branching corals that provide refugia. The breakdown of coral skeletons seven years after bleaching is associated with lower abundance of both large and small fish. These findings were published in *Coral Reefs*.
- Assessment of 25 years of catch data from local fisheries in the Seychelles was undertaken to investigate the impact of the 1998 bleaching event on fisheries productivity. Encouragingly, catch per unit effort

had remained steady after the bleaching, primarily due to increased catch of species that associate with macroalgae rather than coral, although there was more variation in the size of the catch and reduced diversity of fish within the catch. The results of this study were published in *Nature Ecology and Evolution*.

Management implications

- These findings help identify the processes that drive fluctuations in fish diversity and abundance, making it easier to discern the human impacts that can be managed locally from natural and climate related sources of variation.
- Increased occurrence of fish associated with macroalgal habitats in tropical fisheries and reduced abundance of small bodied fish, are indicative of climate changes to coral reef habitats.
- Loss of habitat essential for fish, especially small bodied species and juveniles, may reduce diversity and abundance of fish in the future, emphasising the importance of identifying and managing climate resilient habitats.

Future directions

- Explore the changing role of marine reserves following regime shifts from coral to macroalgae.



Spatial and temporal patterns in the structure of intertidal reef communities in the marine parks of south-western Australia

SP 2009-002

S Strydom, M Rule, A Kendrick, J Huisman, B French

Context

Marmion Marine Park (MMP) and Shoalwater Islands Marine Park (SIMP) are located on the north and south Perth metropolitan coast, respectively, while Ngari Capes Marine Park (NCMP) is in Western Australia's south-west. These marine parks support a diverse range of marine conservation values ranging from various marine habitats to threatened marine fauna, and are dominated by sub-tidal and emergent limestone reefs and shallow sandy embayments. The marine parks are subject to high levels of recreational and commercial human activity due to their proximity to population centres. Significant areas of intertidal reef platform occur in both mainland and island shores and as isolated offshore patch reefs. While a number of local studies of intertidal communities provide a significant regional knowledge base, the broad spatial patterns of intertidal biodiversity across MMP, SIMP and NCMP are not adequately understood. Particular gaps exist in our knowledge of the intertidal communities of offshore platform reefs. This study will determine spatial and temporal patterns in the distribution of intertidal reef organisms in Western Australia's temperate marine reserves. Relationships between the composition of these communities and the physical structure and location of the reefs will also be examined.

Aims

- Determine spatial and temporal patterns in the composition of intertidal reef communities in MMP, SIMP and NCMP, including the proposed northern extension to SIMP.
- Determine if the intertidal reef communities in management zones protected from extractive activities differ from the intertidal reef communities of otherwise comparable reefs.
- Assist in the development of methods for long-term monitoring of intertidal communities in temperate marine reserves.

Progress

- Compilation and analysis of data sets from the three marine parks and nearby reefs outside of the park is continuing.
- A paper on algal cover and invertebrate species composition on intertidal reefs of Ngari Capes Marine Park was published in *Marine and Freshwater Research*.

Management implications

- As the first comprehensive spatial and temporal study of the biological communities associated with intertidal reefs of Western Australia's temperate marine parks and reserves, this work provides a baseline understanding of intertidal reef condition in the marine reserves in relation to natural processes and possible anthropogenic impacts. The results will assist with ascertaining the conservation significance of these habitats and assist the implementation of long-term intertidal reef monitoring and management.

Future directions

- Several additional papers will be completed.



Fire Science

Program Leader: Lachie Mccaw The Fire Science Program seeks to inform fire management and biodiversity conservation on lands managed by the department, which includes state forests, national parks and other conservation reserves. The strategic goal of the program is to ensure that the best available scientific information is used for integrated fire management to protect communities and natural values. Key themes for the program include developing and validating decision support tools for fire management, and understanding the effects of fire regimes on species, ecosystems and landscapes and how these interact with threatening processes including weeds, introduced predators and climate change. Monitoring and learning from the outcomes of prescribed burns and bushfire incidents is also an important activity for the program. Strong collaborative linkages exist with universities, cooperative research centres, CSIRO, the Bureau of Meteorology, other government agencies and private sector research providers.



Evaluation of synergies among fire and weed management in urban biodiversity and fire management

SP 2018-046

B Miller, R Miller

Context

The social and conservation values of remnant natural ecosystems in urban and peri-urban environments can be significant, particularly where they include threatened species and communities, such as the federally listed '*Banksia* Woodlands of the Swan Coastal Plain ecological community'. Fire management of these systems is particularly complex as they are often: very close to homes, businesses and infrastructure; exposed to high ignition likelihoods; fragmented; subject to a wide range of other threats and disturbances; and susceptible to invasion, or already supporting a number of pest plant and animal species. The spread of grassy weeds, in particular, can be enhanced by fire, and promotes changes in fire regime. Knowledge of interactions between fire regimes and weed invasion will provide a basis for synergies in fire and weed management that may deliver beneficial outcomes. The study design and replication, and its fuel, plant species and community response data, provide valuable research infrastructure that associated student projects and other studies can use (e.g. soil properties, invertebrate responses).

Aims

- Assess outcomes for prescribed and wild fire management, weed management and the persistence of native plant species in urban and peri-urban areas by testing a range of fire and weed management approaches.

Progress

- Baseline pre-treatment data have been collected from six sites - Kings Park, Bold Park, Jandakot and Beeliar Regional Parks, Murdoch bushland and Geraldton's Byrne Park.
- Burn implementation and follow-up weed management occurred at Byrne Park in 2019.
- Ongoing weed management was undertaken at Kings Park, Bold Park, Jandakot and Yangebup.
- Initial, early results confirm the positive response of grassy weeds in particular to burning, a negative consequence of high grass cover for native fire-ephemeral species, and the importance and efficacy of post-fire weed intervention.
- One study on fire and trapdoor spider persistence was published in *Austral Ecology*.
- A pilot project on the contribution of invasive grasses to banksia woodlands fuels was completed.

Management implications

- Identification of optimal combinations of weed and fire management treatments will provide a basis for recommendations for the management of peri-urban and urban bushlands.
- Initial results suggest poorer recovery of native species after fire when weeds are not controlled; however, post-burn weed management is also effective in maintaining low levels of weed cover.

Future directions

- Ongoing implementation of weed treatments and survey schedule.
- Implement first rotation burns in the oldest sites.
- Analysis of initial response data will be undertaken as a burn x weed treatment.
- Analysis of fuel and structure data with supplementary work including biomass harvesting and plant allometry.



Understanding the changing fire environment of south-west Western Australia

SP 2014-001

L Mccaw, V Densmore, B Ward

Context

Fire environment is the resultant effect of factors that influence the ignition, behaviour and extent of fires in a landscape. These factors include climate and weather, topography, vegetation and fuel, and ignition. The climate of south-west Western Australia is becoming drier and warmer, and reduced autumn and winter rainfall is causing the landscape to become drier, thereby extending the duration of the traditional fire season. A combination of land use, socio-economic and organisational factors has resulted in more widespread extent of lands unburnt for two decades or more, increasing the risk of high severity fires with adverse impacts on the community and the environment. Much of the science linking interactions between climate, fire weather and fire behaviour was established in the 1960s and 1970s, and there is a need to review and update baseline information that underpins bushfire risk management and the program of planned burning undertaken by the department. This project will draw upon data held by the department and other organisations with expertise in climate and bushfire science.

Aims

- Provide an objective basis to review and revise management guidelines and practices based on past research and experience during wetter climate phases.
- Provide contextual information for investigations of the role and effects of fire in the south-west Australian environment.

Progress

- Factors contributing to extreme fire behaviour during a prescribed burn at Table Hill forest block near Rocky Gully were investigated to understand the contributions of atmospheric instability, fuel conditions and ignition pattern. The Table Hill case study has been used to evaluate the applicability of a conceptual model for blow-up fire behaviour. The case study is also being included in training of duty officers and fire behaviour analysts.
- Trends in temporal and spatial patterns of lightning ignition across the Warren Region were reported in a paper published in the *Journal of Environmental Management*.
- Outcomes of prescribed burning undertaken in jarrah and karri regrowth forest at Poole and Gordon forest blocks were assessed using remote sensing and ground-based measurements as part of an adaptive management program undertaken jointly with Warren Region and Fire Management Services Branch.
- A paper examining the application of Synthetic Aperture Radar imagery for quantifying fire severity and post-fire tree recovery in jarrah and marri forest at Iffley forest block was published in *Remote Sensing of Environment*.
- A paper on the changing fire environment of south-west Western Australia was included in an e-book on *Advances in Forest Fire Research*.
- An initial evaluation of the Australian Soil Moisture Information System (JASMIN) was undertaken to compare trends in modelled soil moisture and deep litter fuels in tall open karri forest at Pemberton.

Management implications

- Understanding the factors that influence the location and timing of bushfire ignitions is important for developing effective management strategies to minimise the risks posed by unplanned fires, and to guide the level of resourcing required for bushfire suppression in different management areas. Lightning is an important cause of bushfire ignition in south-west Western Australia and the area burnt by lightning-caused fires has been disproportionately large relative to the number of ignitions during the past decade. Better understanding of the links between climatic patterns and lightning ignition could provide advance warning of above-normal activity and the opportunity for improved preparation and resource deployment.
- The increased occurrence of large and damaging bushfires in the past five years has led to a refocus on the importance of managing fuels with prescribed fire. In order to achieve a safe and effective prescribed burning program there is a need to understand how weather and climate influence opportunities for burning, and how these opportunities may be changing over time.

Future directions

- Investigate climatic drivers of inter-annual variation in lightning ignition activity in south-west Western Australia.
- Further evaluate and validate output from JASMIN to determine its ability to quantify the dryness and availability of fuels in a variety of vegetation types.
- Continue monitoring and reporting on outcomes of the adaptive management trial of prescribed burning in regrowth forest.



Long term response of jarrah forest understory and tree health to fire regimes

SP 2012-029

V Densmore, B Ward

Context

This study is a long term strategic research project to better understand the effects of fire regimes, including prescribed fire, on the floristic composition of jarrah forests. This knowledge is important for developing and implementing ecologically appropriate fire regimes and for managing fire to reduce risk to the community, biodiversity and other environmental values.

Aims

- Understand and quantify the long-term effects of various fire regimes on the floristic composition of jarrah forests.
- Determine the long-term effects of various fire regimes on tree health and growth rate.

Progress

- A paper examining fine-scale temporal turnover of jarrah forest understorey vegetation assemblages in relation to fire regimes over a 30 year period was published in *Fire Ecology*.
- Grazing exclosures at Yackelup were repaired to maintain the integrity of the experimental site into the future.
- Fire was applied to plots at McCorkhill and Yackelup blocks to maintain the schedule of experimental treatments.

Management implications

- Being one of a few long-term studies of its kind around the world, the findings of this study are important for guiding fire management policy and planning for community protection and biodiversity conservation.
- Knowledge and understanding gained from this long-term study have been incorporated into a fire ecology training program that is delivered to employees involved in fire management planning and operations.
- Within the fire frequency and intensity ranges investigated in this study, there was flexibility in the application of prescribed fire to achieve management goals without loss of plant diversity.

Future directions

- Maintain experimental burning treatments and post-burn assessments, and remeasure floristic composition at intervals of five years.



North Kimberley Landscape Conservation Initiative: monitoring and evaluation

SP 2012-027

I Radford, R Fairman

Context

This project is a biodiversity monitoring and evaluation program to inform adaptive management of fire and cattle in the north Kimberley. The adaptive management program that forms the Landscape Conservation Initiative (LCI) of the Kimberley Science and Conservation Strategy commenced in 2011 in response to perceived threats by cattle and fire to biodiversity conservation in the North Kimberley. This initiative is based on the hypothesis that large numbers of introduced herbivores and the impacts of current fire regimes are associated with declines of critical weight range mammals, contraction and degradation of rainforest patches, and degradation of vegetation structure and habitat condition in savannas. This monitoring and evaluation program will provide a report card on performance of landscape management initiatives in the north Kimberley, particularly prescribed burning and cattle culling, in maintaining and improving biodiversity status.

Aims

- Inform management of biodiversity status in representative areas after prescribed burning and cattle control programs have been applied.

- Provide warning when landscape ecological thresholds have been reached, for example decline of mammals to below 2% capture rate, or decline of mean shrub projected ground cover to <2%.
- Compare biodiversity outcomes in intensively managed and unmanaged areas to evaluate the effectiveness of management interventions in maintaining and improving conservation values.
- Investigate cane toad and predator interactions that may influence mammal abundance.
- Elucidate influence of different burning approaches to threatened plant taxa in the North Kimberley.
- Investigate interactions between fire and weed invasion.

Progress

- Monitoring continued and most study sites have at least five years of data. Work is progressing to evaluate the fire management factors that will provide the greatest conservation benefits for threatened mammals in the North Kimberley.
- The response of obligate seeder plants and other fire sensitive species (e.g. generalist rodents) to a systematic ignition approach to prescribed burning is being trialled in remote parks, including Prince Regent National Park, to reduce the annual extent of fire.

Management implications

- Monitoring demonstrates that increases in patchy early dry season prescribed burning benefited threatened species including the brush-tailed rabbit rat, northern quolls (in rocky habitats), the endemic Kimberley rock rat and the red cheeked dunnart.
- Conversely, some mammals including generalist rodents and northern quolls (in non-rocky habitats), respond negatively to increasing late dry season fire and positively to increases in large patches of long unburnt vegetation. This suggests that net reductions in annual burnt area will benefit these species.
- Rodent populations were more stable under prescribed burning, as fire extent is the main driver of populations and managed burning regimes are less chaotic than unmanaged wildfire dominated fire regimes.
- There is statistical evidence that the LCI has shifted fire regimes in the North Kimberley from a dominance by late dry season bushfires to predominantly early dry season prescribed burning with positive wildlife benefits.
- There is strong evidence that cattle have negative influences on critical weight range mammals, including threatened species such as the brush-tailed rabbit rat. Culling programs should be maintained and expanded in important conservation reserves.

Future directions

- Continue monitoring and evaluation to demonstrate management effectiveness.
- Evaluate factors influencing mammal abundance and richness between years using statistical modelling approaches.
- The impacts and management of cane toads, feral cats and other invasive animals and plants on savanna ecosystems will be investigated.



Fire regimes and impacts in transitional woodlands and shrublands

SP 2010-011

C Yates, C Gosper

Context

The Great Western Woodlands (GWW) is an internationally significant area with great biological and cultural richness. This 16 million hectare region of south-western Australia arguably contains the world's largest and most intact area of contiguous temperate woodland. The GWW Conservation Strategy and a review conducted by a wide range of scientists with expertise in the region each identified inappropriate fire regimes as a threat to

the woodlands and emphasised the need for a science-based fire management regime for the area. Critical gaps in the knowledge of fire ecology for GWW ecosystems are a major hindrance for ecological fire management in the region. The GWW supports eucalypt woodlands at very low mean annual rainfall (250-350 mm). Woodland eucalypt recruitment is stimulated by fire but individuals are very slow growing. In recent decades a large part of the GWW has been burnt and concern has been expressed over the ecological impacts of this. Fire ecology research already undertaken in eastern wheatbelt nature reserves will help resolve ecological fire management issues for mallee and mallee-heath communities in the GWW, but similar information for the dominant eucalypt woodlands is needed.

Aims

- Develop a method to robustly estimate stand time since fire in gimlet (*Eucalyptus salubris*) woodlands that have not been burnt during the period covered by remotely-sensed imagery, allowing the scale of recent extensive wildfires to be placed in a historical context.
- Investigate the effects of time since fire on the assembly and recovery of gimlet woodlands, including on plant and animal community composition and development of ecosystem structure.
- Measure fuel and carbon dynamics with time since fire in gimlet woodland.

Progress

- A conceptual model of vegetation dynamics for the unique obligate-seeder temperate eucalypt woodlands of southwestern Australia was developed and published in *Austral Ecology*.
- In collaboration with BirdLife Australia, the effect of time since fire on the abundance and composition of woodland bird communities and their habitat usage was assessed. One paper has been published in *Biological Conservation*, with another in review.
- Analysis of changes in coarse woody debris stocks showed strong responses to both time since fire and the length of the interval between the most recent fire and the previous fire.
- An article on how sampling ants on the chronosequence contributed to the discovery of a second extant population of the Critically Endangered Arid Bronze Azure butterfly was published in *Landscape*.

Management implications

- National-scale syntheses of temperate eucalypt woodland responses to disturbance revealed that many Western Australian woodlands are uniquely dominated by taxa that are obligate seeding, and have vegetation dynamics driven by rare, stand-replacing disturbances. These characteristics illustrate: (i) a putative vulnerability to decreases in intervals between fires; and (ii) potentially large fluxes in carbon after disturbances.
- Post-fire succession in plant composition and structure, which in turn determines successional patterns in animals, occurs over multi-century timescales, demonstrating the value of avoiding fire in mature woodlands to maximise future fire management options.
- Changes in vegetation structure and cover, and fire probability based on historical fire records, indicate maximum gimlet woodland flammability at intermediate times since fire, supporting the revision of fire behaviour ratings.
- Woodland bird species that have declined following habitat loss and fragmentation in the Western Australian wheatbelt are strongly associated with long-unburnt woodlands, providing information on appropriate woodland fire regimes to support persistence of these species.
- Knowledge generated through this project has been incorporated into fire ecology training and Fire Management Information Notes made available to departmental staff.

Future directions

- Finalise journal publications concerning revised estimates of time since fire of long-unburnt gimlet woodlands, and changes in bird communities, coarse woody debris and carbon stocks with time since fire.



Burning for biodiversity: Walpole fine-grain mosaic burning trial

SP 2004-004

N Burrows, J Farr, G Liddelow, B Ward, V Tunsell, A Wills

Context

Fire management based on sound science is fundamental to the conservation of biodiversity and the protection of life and property in fire-maintained ecosystems of south-west Western Australia. There is a substantial body of scientific evidence that, within ecologically circumscribed parameters, fire diversity can benefit biodiversity at the landscape scale. We hypothesise that a fine-grained mosaic of patches of vegetation representing a range of biologically-derived fire frequencies, seasons and intensities will provide diverse habitat opportunities and can also contribute to reducing the occurrence of large, damaging and homogenising wildfires.

Aims

- Determine whether a fine-scale mosaic of vegetation at different seral (post-fire) stages benefits biodiversity at the landscape scale.
- Develop the operational techniques to be able to use frequent and planned introduction of fire into the landscape (patch-burning) to create a fine-scale mosaic of patches of vegetation at different stages of post-fire development.

Progress

- Field work has been completed for this project. Data are compiled, fungi and invertebrate collections are sorted and documented. Data for invertebrates are compiled and analysis of epigaeic invertebrates is nearly complete.
- A manuscript describing effects of mosaics and responses to time since fire in bird assemblages has been submitted to *Fire Ecology*.
- A manuscript describing effects of mosaics and vegetation on epigaeic invertebrate richness has been submitted to *International Journal of Wildland Fire*.
- A draft manuscript describing the effects of mosaics and vegetation on epigaeic invertebrate trophic structure has been prepared.
- A paper describing the theory of fire-induced mosaics, how to describe and characterise mosaics, and operational challenges in creating fire mosaics is being prepared for publication.
- Preliminary analysis of vegetation data has been completed.

Management implications

- This study demonstrates that fine-grain patch-burning is operationally feasible in forest areas. Although data analysis is incomplete, benefits to biodiversity at the landscape scale, especially cryptogams, invertebrates, fungi, and birds through retention of patches of a range of vegetation ages are increasingly evident. Any benefits to higher order organisms may take longer to emerge.
- Large-scale implementation of mosaic burning by the frequent introduction of fire into the landscape is being considered as a strategy for increasing community protection while protecting biodiversity. The findings of this study will provide the underpinning science for this strategy.

Future directions

- Complete data analysis and publish papers.
- Develop recommendations for mosaic burning in forest areas.



Kings Park Science

Program Leader: Jason Stevens Kings Park Science undertakes research in native plant biology, underpinning the conservation and ecological restoration of Western Australia's unique biodiversity, and biodiversity generally. Research is focused in the key areas of restoration ecology and ecophysiology, seed science, conservation genetics, conservation biotechnology, ecosystem ecology, fire ecology and systematics. Research is prioritised to enhance practical outcomes in conservation and management, and sustainable development of the State's unique natural resources. The Program delivers science capacity underpinning the State's botanic garden and the lands managed by the Botanic Gardens and Parks Authority, as well as the horticultural development of the Western Australian flora. The Program has a long history of successful post-graduate student supervision in collaboration with Western Australian universities, and contributes to undergraduate teaching, predominantly in conservation biology and restoration ecology.



Seed science

SP 2018-085

D Merritt, T Erickson

Context

Seed science encompasses fundamental and applied research on the physiology and ecology of seed dormancy, germination, and longevity to facilitate the use of seeds for conservation and ecological restoration purposes. Seed science is integrated with the seed banking functions of the department to support and enhance the capacity for long-term storage of germplasm of Western Australia's flora.

The development of seed technologies to improve seed conservation, plant propagation and ecosystem restoration is a major emphasis of the research. Multi-disciplinary partnerships including those with soil scientists, plant physiologists, and engineers are fundamental to developing the capacity for seed-based restoration of biodiverse plant communities on degraded landscapes.

Aims

- Support and enhance the curation of *ex situ* collections of germplasm through resolving seed storage behaviour and longevity, and developing methods for assessing seed quality and predicting seed storage life.

- Develop reliable methods for seed-based propagation through determining seed dormancy-break and germination requirements.
- Develop seed enhancement technologies that improve seedling establishment for broad-scale restoration.
- Engineer efficient mechanised broad-scale delivery of diverse seed types to restoration sites, including sloped and rocky landforms.
- Inform the management of Western Australia's flora through the study of seed ecology in the natural environment.

Progress

- Automated and high-throughput closed system respirometry has been used to collect data on the metabolic rate of seeds of over 100 species in relation to other traits including seed mass, dormancy type, and germination temperature as part of developing seed respirometry to predict seed longevity and viability decline in storage.
- Clay-based seed pellets incorporating soil surfactants and activated carbon have been developed for *Banksia* woodland species, and field trials have been installed to test their effectiveness at protecting native seeds against herbicides used in restoration of weed-invaded sites following mining.
- Laboratory and glasshouse trials have been completed testing the effects of application of inorganic amendments to mine waste substrates on seedling establishment and growth, and substrate properties.
- Field trials in the Pilbara have been implemented across mine waste dumps examining the efficacy of seed treatments including flaming, coating, and dormancy-break, in relation to seed distribution through mechanical seeders and seedling establishment.

Management implications

- The metabolic rate of seeds of model species decreases predictably with age, and reduction in metabolic rate is detectable prior to the point at which germination testing can identify a decline in viability. Respirometry may prove an alternative technique for viability assessment with the potential to identify the early onset of seed ageing, prior to the loss of stored seed collections.
- The application of inorganic soil amendments to mine waste substrates for rehabilitation can improve some soil properties and increase plant growth, but water availability is the dominant determinant of their effectiveness. The timing of application of the amendments is important to avoid detrimental impacts on early stages of seedling recruitment.

Future directions

- Assess viability of seed collections in storage to inform and support management of conservation seed collections.
- Continue to develop seed dormancy-break and germination protocols for new species including for threatened species to support their conservation and management.
- Continue to develop and refine seed enhancement techniques that improve seed handling properties and increase germination and establishment potential under a range of environmental scenarios.
- Test new design modifications to direct seeders, incorporating new seed treatments and technologies, under field conditions through implementing seeding trials on rock waste dumps in the Pilbara.



Restoration science

SP 2018-077

J Stevens, S Krauss, W Lewandrowski, C Elliott, B Miller

Context

Restoration science is a multidisciplinary approach to provide a comprehensive scientific basis for restoration actions across the State. Overall, the research includes seed science, provenance, ecohydrology, ecophysiology, soil science, community ecology and plant-enabling technologies. Restoration science works across diverse systems including Pilbara grassland and savanna, mid-west shrublands, Swan Coastal Plain *Banksia* woodlands and shrublands, Jarrah forest, marine seagrass meadows, and arid coastal communities and collaborating with a variety of stakeholders. Restoration science is well placed to provide the applied scientific solutions required for all plant community restoration activities.

Aims

- Establish targets and success criteria for restoration success.
- Determine appropriate sourcing of biological materials for restoration.
- Optimise establishment of plants in restoration.
- Determine factors facilitating growth and survival of plants in restoration.
- Determine factors restoring resilience, sustainability and landscape integration.

Progress

- Contributed to a completion criteria framework document in collaboration with WABSI and other academic institutions to assist the mining sector in developing criteria associated with rehabilitation.
- Commenced an analysis of restoration trajectories in *Banksia* woodlands after mining, to understand the role of mining practices and plant traits in shaping rehabilitation outcomes.
- Established experiments examining the role of low water-use native grasses as substitutes or additions to traditional higher water-use pasture species (ryegrass and clover) in bauxite mining rehabilitation.
- Continued to assess indicators of plant water status and links to near surface remote sensing approaches to identify spectral indices associated with plant function.
- Investigated the role of biotic inoculants on drought stress tolerance of native species, with methods developed to understand hormonal signalling (e.g. cytokinin, salicylic acid) in response to drought and commercial inoculants.

Management implications

- Having a framework for completion criteria development paints a clearer picture for industry, the government regulators and the Western Australian community for what will be delivered in a post mining environment including standards of performance of rehabilitation and an increased understanding of risk and liabilities associated with decisions/strategies around mine rehabilitation.
- Monitoring rehabilitation programs to understand impacts of rehabilitation practice on plant function at the scale now required may mean introducing new technologies to complement traditional monitoring methods. Linkage rehabilitation outcomes to plant traits, as well as plant function to remote sensing spectral signatures will provide a valuable insight into the mechanisms underpinning successes in rehabilitation.
- Including native species into traditional pasture systems may not only improve biodiverse values of pasture systems but may improve performance in altered substrates and in more variable (drier) climates.

Future directions

- Continue to develop near surface remote sensing technologies and linking these to plant ecophysiological performance.
- Expand analytical methods for plant hormone analysis in native plant species to assess the role of biological inoculants in altering plant performance in rehabilitation systems.



Conservation genetics

SP 2018-068

S Krauss, J Anthony, E Sinclair

Context

The conservation and restoration of Western Australia's unique biodiversity is underpinned by genetics research that aims to understand the ecological requirements of native flora and their genetic vulnerabilities to threats, including mining activities. Such research provides information on genetic diversity, population and species relationships, mating system and pollen dispersal to support restoration, conservation, population management and taxonomy.

Aims

- Experimentally assess seed sourcing strategies for improved restoration outcomes.
- Assess the conservation and evolutionary consequences for plants pollinated by vertebrates.
- Assess reproductive functionality in restored plant communities.
- Experimentally assess the resilience of plant populations to environmental stressors.
- Assess responses of soil biota through ecological restoration.

Progress

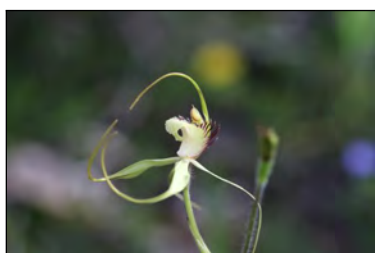
- Seed sourcing strategies for ecological restoration under current and future climates were assessed for *Banksia menziesii*, *B. attenuata* and *Eucalyptus todtiana* through large-scale field-based provenance trials across the Swan Coastal Plain.
- The restoration consequences of mixing seed source provenances was experimentally assessed for *Stylidium hispidum* in the northern jarrah forest. Life time reproductive output showed local inbreeding depression and outbreeding depression at a landscape scale, with an optimum at approximately 10km.
- The consequences of nectar-feeding birds as pollinators for eucalypts, banksias, kangaroo paws and catspaws continued to be assessed. Results show that while bird pollination typically causes high multiple paternity and wide outcrossing, this is impacted by the ecological properties of the local population. Some species assessed showed a highly specialised relationship with bird pollinators, such that introduced honeybees can have significant consequences for plant reproduction.
- Connectivity among old fragmented and newly restored populations of *Banksia menziesii* was demonstrated, showing that highly mobile bird pollinators move freely into restored *Banksia* populations.
- Results from reciprocal transplant experiments and stress-related gene expression analysis of seagrass in Shark Bay suggests adaptation and a resilience to climate change.
- The diversity and composition of soil microbial communities following post-impact rehabilitation in the Jarrah forest were assessed using eDNA. Although restored soil biota communities are returning towards the pre-disturbance state, even after 30-years key elements are still missing.

Management implications

- Seed sourcing guidelines developed for the Swan Coastal Plain improve restoration outcomes through the genetic delineation of locally adapted provenance zones for multiple species.
- Effectiveness of *in-situ* and *ex-situ* management can be improved through manipulating spatial genetic structure to maximise outcrossing and avoid genetic effects associated with inbreeding.
- Knowledge will guide the management and regulation of commercial and feral honeybees to minimise negative pollination impacts on native flora, especially in *Banksia* woodlands of the Swan Coastal Plain, a threatened ecological community.
- Enhanced knowledge of soil biota will improve guidance on restoration criteria.

Future directions

- Continue to assess conservation genetic consequences of vertebrate pollination through molecular and ecological studies.
- Continue to assess the resilience of seagrass to environmental stressors through reciprocal transplant trials in Shark Bay, population genomic analysis, and controlled manipulative experiments.
- Continue to assess seed sourcing for restoration strategies through large scale provenance trials, glasshouse trials, and seed germination trials for *Banksia menziesii*, *B. attenuata* and *Eucalyptus tottiana*, which are key species for ecological restoration on the Swan Coastal Plain.
- Assess delivery of vertebrate pollinator services as a measure of restoration success for *Lambertia multiflora* in ecologically restored plant communities.
- Assess the impact of introduced honeybees (*Apis mellifera*) on native flora and fauna.
- Assess the post-disturbance restoration of soil biota using eDNA, and above-ground/below-ground linkages.



Orchid conservation and recovery

SP 2018-060

B Davis, J Stevens, B Miller

Context

Western Australia is an orchid biodiversity hotspot of worldwide significance, with an estimated 400 species of orchid, many of which are endemic. There are currently 41 Western Australia orchid taxa listed as threatened, with the key threatening processes being habitat loss due to land clearance and fragmentation, loss of pollinators, weed invasion, illegal collection and habitat degradation. Orchids represent a conservation challenge as they have complex and sometimes highly specific ecological interactions with pollinators above ground and their mycorrhizal partners below ground. Overlaying the immediate needs of the orchid are the independent requirements of the pollinator (nectar sources, brood sites) and the mycorrhizal partner (carbon sources, soil attributes). *Ex-situ* conservation of Western Australia's orchids is undertaken through maintaining a large living collection of orchids, seed banking orchid seed and maintaining an orchid mycorrhizal library. This collection provides a basis for orchid translocations, through to propagation, outplanting and monitoring in the form of experimental research and species recovery.

Aims

- Determine and prioritise those orchid species most at threat and undertake *ex-situ* conservation actions leading to supplementation of natural populations, to ensure their ongoing persistence.
- Continue maintenance and growth of the *ex-situ* living collection, seed and fungal collections.
- Conduct integrated conservation research to provide management solutions to improve the conservation status of threatened orchid taxa.
- Make collections of seed and fungi from *Caladenia lodgeana*, *C. procera* (Critically Endangered) and *C. viridescens* (Endangered) to investigate the potential for supplementation of wild populations and *ex-situ* storage.

Progress

- Seven hundred *C. busselliana* seedlings were propagated and are currently in transition from laboratory to glasshouse.
- Ongoing monitoring of nine hundred *C. busselliana* seedlings emergence.
- Fungal isolates and seed sources were tracked for germination performance and survival in *C. busselliana*.
- One potential translocation site was selected for *C. busselliana* based on proximity to natural populations and site security.

- Eight hundred *C. lodgeana*, 150 *C. viridescens* and 350 *C. procera* seedlings have been successfully transferred from the laboratory to the glasshouse.
- Surveys across the extent of *C. lodgeana* provided updated numbers on population size.
- An audit of the long term fungal and seed collections has been completed and integration of isolates currently held on agar slopes has commenced.

Management implications

- The *ex-situ* collection of *C. busselliana* continues to grow and provides essential conservation support for this critically endangered species with total plant numbers and genetic diversity now increased many times over.
- The protocol for propagation of threatened orchids and maintenance of collections of associated mycorrhizal partners will demonstrate and improve capability transferable to other threatened orchid taxa.
- Growing *ex-situ* collections of other threatened orchids (*C. viridescens*, *C. lodgeana* and *C. procera*) of the Capes region provides conservation support for species with dwindling or singular populations that are at threat from stochastic events.

Future directions

- Optimise propagation protocols to increase supplementation success from laboratory to *in-situ* site.
- Design translocations to test survival of different aged seedlings and season of release.
- Identify potential translocation sites within the Blackwood region, taking into account pollinator presence and avoiding hybridisation risk.
- Develop protocols for cross-pollination, seed collection and fungal collection in small orchid populations.
- Increase the diversity of orchids and optimise growing conditions for plants from the living collection to be used as a seed orchard.



Conservation biotechnology

SP 2018-048

R Bunn

Context

Research into *in vitro* and cryogenic science is required to support *ex-situ* conservation and germplasm storage of threatened plants. The micropropagation of threatened taxa also provides a source of greenstock for plant translocation studies in cases where normal propagation is not possible. A range of species are kept in liquid nitrogen storage for conservation and research purposes, including many rare and threatened taxa, as well as seeds and mycorrhizal fungi of orchid species (including a number of rare taxa).

Aims

- Conduct research on micropropagation of rare and threatened plants for *ex-situ* conservation.
- Undertake research on development of cryopreservation protocols for *ex-situ* conservation of threatened plants and long-term storage of germplasm of selected species.

Progress

- Research continued into developing *in vitro* propagation and cryogenic protocols for a number of Western Australian threatened plants, including *Symonanthus bancroftii*, *Acacia leptoneura*, *A. subflexuosa* subsp. *capillata*, *Conospermum galeatum*, *Banksia montana*, *Lasiopetalum moulllean* and *Eucalyptus phylacis*.

- Threatened species cryo-banking research continued on the following rare species: *Philotheca basistyla*, *Synaphea quartzitica*, *S. stenoloba*, *C. galeatum*, *Styphelia longissima*, *Eremophila virens*, *B. serratuloides* subsp. *perissa*, *E. dolorosa*, *Allocasuarina fibrosa* and *L. moulleans*, with emphasis on cryo-banking multiple genotypes.
- A journal paper dealing with issues in cryopreservation and their importance for conserving threatened Australian native species was published in the *Australian Journal of Botany*.

Management implications

- In vitro propagation provides a 'safety net' for threatened species in dire need of protection off-site where seed is unavailable and conventional vegetative propagation does not work or is not possible. This approach creates a secure off-site repository of genetic material (storage at room temperature, 8-14 °C) for threatened plant populations that can later be utilised to provide plants for translocations to alternative *in-situ* sites or re-stock existing declining plant populations.
- Cryopreservation (storage in liquid nitrogen -196 °C) provides additional long term, stable and biosecure storage of shoot tips, protocorms, seeds and other material of threatened plant species, that can also be revived and utilised to produce plants for restoration purposes.

Future directions

- Continue *in vitro* and cryogenic research for *ex-situ* conservation.
- Continue to research and provide non-conventional solutions for the storage of germplasm for threatened species.



Perth Zoo Science

Program Leader: Peter Mawson Perth Zoo Science Program undertakes targeted research to support the Native Species Breeding Program and the breed-for-release efforts for seven threatened species. It also addresses knowledge gaps in our understanding of behaviour, reproductive biology and conservation medicine for the species in the Zoo's collection and smaller number of species in the wild. The research program involves projects dealing with our sustainable environment and environmental communication and socio-ecology.



Western ground parrot husbandry

SP 2018-137

A Ferguson

Context

The western ground parrot (*Pezoporus flaviventris*) is listed as Critically Endangered and is now restricted to a single population around Cape Arid. Less than 150 birds remain in the wild, and the parrots are threatened by foxes and feral cats, and habitat critical to the species survival is under threat from extensive wildfires. In July 2014, seven western ground parrots were transferred from departmental aviary facilities near Albany to the Perth Zoo to attempt successful breeding to help establish a captive insurance population and to investigate the potential for future breeding for release.

Aims

- To determine if the western ground parrot can successfully breed in captivity, as this knowledge will inform future recovery actions.
- To develop and document captive breeding techniques that maximise reproductive output for western ground parrots, while also taking the opportunity to learn as much as possible about the biology and behaviour of the species.

Progress

- Five new birds (two males and three females) were captured at separate locations within Cape Arid National Park and transported to Perth Zoo. These birds have transitioned very well to life in the captive

facility.

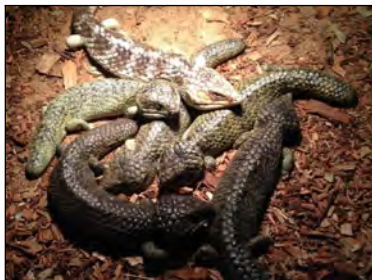
- Four breeding pairs have been established and settled into their respective aviaries in preparation for the spring breeding season.

Management implications

- Relatively little is known about this highly cryptic species and the information collected is valuable to those working with the species in the field.
- The successful breeding of western ground parrots in captivity will provide an insurance population from which birds can be used to supplement the extant population in Cape Arid National Park and provide a source of birds for reintroduction to former populations and localities in the Fitzgerald River National Park and areas west of Albany.

Future directions

- Establish successful breeding husbandry regimes to take advantage of the newly expanded genetic base to the colony.



Using dataloggers to determine the effects of handling and temperature on packages travelling along Australian postage routes used to illegally transport native fauna

SP 2018-128

P Mawson

Context

Veterinary staff at Perth Zoo are responsible for treating some of the native fauna (predominantly reptiles) recovered from wildlife seizures, including those that have been smuggled through the Australian domestic postal service. Knowledge of the forces and temperatures an animal is likely to have experienced will be beneficial in the assessment of the animals' health and welfare, and contribute to the decisions that inform the treatment plan.

Aims

- Use dataloggers to determine the temperatures and forces reptiles are likely to have experienced while being transported by post during illegal smuggling activities.

Progress

- Planning for deployment of the data loggers through the mail system was undertaken.

Management implications

- Gaining specific information regarding the temperature and forces applied to packages travelling along postage routes from remote Western Australian towns in the Kimberley, Pilbara and Goldfields that are known to be used by wildlife smugglers, will provide evidence as to the nature and extent of conditions animals are subjected to during transit. This knowledge will assist in the treatment of affected animals, and may also inform decisions related to prosecutions and potentially may influence sentencing of convicted offenders.

Future directions

- Dataloggers will be deployed during the summer.



Olfactory and auditory based behavioural enrichment for Perth Zoo's Asian elephants.

CF 2018-119

P Mawson, J Polla

Context

Keeping charismatic mega fauna such as Asian elephants is challenging. Elephants are intelligent, social and long-lived. Managing their welfare and ensuring that they are provided with the best standard of care requires a detailed knowledge of their behaviour. Despite a long history of domestication and keeping in captivity, little research has been conducted into the sensory and cognitive function in elephants. Examining the various components of their behaviour with carefully designed research programs allows us to understand the limits of their intelligence and to be able to modify husbandry and behavioural enrichment programs in order to provide optimal welfare conditions for the elephants.

Aims

- Investigate the sensory functions of Asian elephants.
- Use existing methods for auditory behavioural cure presentation to determine if Asian elephants will respond to an unfamiliar human voice.

Progress

- Data analysis of the olfactory trials to date reveals accurate target scent identification when a single scent was presented. However, target scent identification when multiple scents were present was not significantly different from chance.

Management implications

- Knowing the capacity of Asian elephants to identify and discriminate between scents or sounds will provide important information that can be incorporated into enrichment programs to maintain or improve the welfare of captive elephants.

Future directions

- Repeat the olfactory trials using a standard scent, rather than a varying one.
- Commence the auditory trials.



Memory of recent actions in large-brained mammals (*Elephas maximus*).

CF 2018-118

C Holland, P Mawson, J Polla

Context

Animals survival depends on how good, and timely the solutions to the problems are. Sometimes these problems are widely spaced in time so a problem-solving strategy that is not retained in their memory does not provide much of a cognitive economy to the individual. Among terrestrial mammals, elephants share the unique status, along with humans and great apes, of having large brains, being long-lived and having offspring that require long periods of dependency. Studying the memory of an Asian elephant may allow greater insights into the evolution of cognitive abilities in large brained animals.

Aims

- Determine if an Asian elephant is capable of understanding an abstract rule such as the 'repeat' command.
- Determine if an Asian elephant is capable of discriminating and identifying past actions and performing responses that clearly reveal the extent to which past actions were identified and remembered.
- Determine the ability of an Asian elephant to represent their own recently performed behaviours in working memory.
- Determine the ability of such representations to affect future behaviours.

Progress

- Control trials were completed, providing baseline data on the performance accuracy of individually cued behaviours. Basic analysis has been conducted on the control trial data.
- Experimental trials have begun to determine the capacity to remember and repeat recent behaviours and understand an abstract rule. During these trials, the elephant has remained calm and attentive and has shown motivation, choosing to participate in every trial.

Management implications

- Determining the extent of an Asian elephant's memory and the capacity to apply abstract rules will inform the types of training and enrichment that can be applied to this species in the zoo environment.

Future directions

- Undertake data analysis.
- Undertake trials involving behaviours that have never before been linked to the abstract rule to test the elephant's understanding of the abstract rule in an unfamiliar context.



Behavioural observations of Perth Zoo collection animals for animal welfare purposes and establishment of baseline data

SP 2018-115

P Mawson, J Polla

Context

Maintaining or improving animal welfare is a key consideration in operations at Perth Zoo, and behavioural observations of collection animals is a means of ensuring effective management approaches. Many observational studies conducted on Perth Zoo collection animals in the past have provided staff with insight into animal behaviour and generated recommendations on how to improve quality of life (e.g. through specific enrichment or modifications to enclosures or husbandry practices), as well as data to allow comparisons to be made for individual animals over time.

Aims

- Determine what behaviours are exhibited by certain individuals or species of Perth Zoo's animal collection, and at what frequency.
- Compare current data with past studies to see if animal behaviour has changed from what might be expected over time.
- Observe the effects of the current behavioural enrichment programs on behaviour in Perth Zoo's collection animals.
- Observe the effects of Perth Zoo visitors on the behaviour of Perth Zoo's collection animals.

Progress

- Analysis of observations of both Sumatran tigers revealed a relationship between exhibit swapping and behaviour, leading to the development of a revised exhibit swapping schedule that supports tiger welfare.

- The behaviour of the elderly solo lioness was recorded before and after the import of two younger lionesses to Perth Zoo, which are housed in the adjacent exhibit. The behaviour of the two younger lionesses was also monitored with a focus on animal interactions and the influence of Zoo visitors on lioness behaviour. The results suggest a positive welfare outcome for all three lionesses, with low levels of stereotypic behaviour and high frequencies of natural behaviours recorded.
- The nocturnal resting behaviour of Perth Zoo's elderly female elephant continues to be observed as she ages. The nocturnal behaviour of the Zoo's two other elephants is being recorded with a focus on the effects of provision of overnight enrichment on behaviour.
- Behavioural data has been collected and analysed for the three mother-offspring orangutan groups, informing food-based enrichment management practices and benefitting animal welfare.
- Observations have been made on a pair of golden lion tamarins with a focus on breeding behaviour and other affiliative behaviours.
- Data has been collected on Javan gibbon siblings after the passing of their mother. Results have been compared to previously collected behaviour data on the male sibling and reveal that positive interactive behaviours with other gibbons remained stable. The data collected from this study has created useful baseline data on the behaviour of the female Javan gibbon, which may be used to compare to data gathered in the future when she is housed in a new social grouping.
- The behaviour of the recently born female white cheeked gibbon is being monitored, along with the behaviour and interactions of mother and brother.
- Inter-species interactions between binturongs and otters living in a shared exhibit are being monitored. The breeding interactions and other affiliative interactions between the adult binturong pair are also being recorded.

Management implications

- Empirical behavioural data gathered through this project allow Perth Zoo staff to make informed decisions about animal welfare changes as animals age or respond to new or altered dietary regimes; monitor animals during introductions of new exhibit mates or breeding animals; validate enrichment programs; quantify animal use of exhibits before and after redesign; and measure visitor interaction with exhibited animals and the uptake of interpretation materials provided to visitors.

Future directions

- Monitor the spatial use of areas within the Australian Bushwalk exhibit at Perth Zoo by the four macropod species housed in the exhibit.



Geocrinia frog breed and rear for release program

SP 2018-102

P Mawson, C Lambert

Context

There are two species of Geocrinia frogs, *Geocrinia alba* and *G. vitellina*, that have a restricted distribution in south-west Western Australia and are listed as Critically Endangered and Vulnerable. Whilst these frogs lay large clutches of eggs, the survival rate to adult frogs is low. Captive rearing of eggs to metamorphs is an effective means of overcoming this constraint and providing supplementation of animals into the populations. Egg clutches of both species are collected from the wild at the request of the Recovery Team and metamorphs are raised and subsequently released to the wild. There is ongoing research and husbandry management to achieve regular and reliable captive breeding in both species.

Aims

- Breed and rear white-bellied and orange-bellied frogs for release to sites approved by the *Geocrinia* Frog Recovery Team in order to maintain or increase the current extent and viability of populations of these species.

Progress

- A captive breeding colony of *Geocrinia alba* and *G. vitellina* was maintained. Egg clutches of both species were collected from the wild and metamorphs raised to 11 months of age, at which point they were released to the wild.
- Laboratory experiments to determine the influence of temperature on the rate of larval development in *G. vitellina* have shown that juveniles incubated at higher temperatures developed at a slower rate than juveniles incubated at lower temperatures.

Management implications

- Captive-bred and reared frogs have provided the best, and in most cases the only, means of increasing the number of individuals in a sub-population, and bolstering the genetics of isolated populations.
- Knowing the upper thermal limits for successful larval development in the two *Geocrinia* species will allow much more informed decisions about which field sites are chosen for the release of juvenile frogs to augment existing, or create new populations.

Future directions

- Continue production of metamorphs for *G. alba* and *G. vitellina*.



Western swamp tortoise breed for release program

SP 2018-101

P Mawson, C Lambert

Context

Western swamp tortoises (*Pseudemydura umbrina*) are ranked as Critically Endangered and occur in only two natural populations at very low numbers. Establishing new populations entirely with wild caught tortoises is not feasible and captive breeding provides a source of animals for supplementation of wild populations and establishment of new populations. Captive-bred tortoises have enabled new populations to be established at Moore River Nature Reserve and Mogumber Nature Reserve. Two additional captive insurance populations have also been established at Adelaide Zoo and Monarto Zoo (South Australia) to reduce the risks associated with keeping half the global population of western swamp tortoises in a single facility.

Aims

- Produce a minimum of 30 hatchling tortoises (> 30 days of age) each year, that are grown on until they are three to four years of age, then reintroduced into sites approved by the Western Swamp Tortoise Recovery Team.

Progress

- Forty-seven western swamp tortoise juveniles were released into swamp habitat at Ellenbrook Nature Reserve (n=12), Moore River Nature Reserve (n=18) and Meerup in the D'Entrecasteaux National Park (n=17).
- A total of 89 eggs were produced in the captive breeding colony, 55 of which hatched.
- A research paper describing sexually dimorphic growth in western swamp tortoise was published in *Journal of Zoo and Aquarium Research*.

- Two diets (white-fleshed fish versus red meat) were investigated for captive tortoises. There was no significant difference in the growth rates of adult tortoises between the two diets.

Management implications

- The focus this year has been to compare the growth and survival of juvenile tortoises at the three release sites, one of which is 350 km south of the natural range of the species. Preliminary results indicate that growth was comparable between the three sites, and that the tortoises were able to find suitable summer aestivation sites. Only two mortality events were confirmed (both due to predation by foxes).

Future directions

- Continue to produce juvenile animals for release to sites approved by the Western Swamp Tortoise Recovery Team.
- Undertake a large release at Moore River Nature Reserve, involving 75-100 tortoises.



Dibbler breed for release program

SP 2018-099

P Mawson, C Lambert, A Friend

Context

Dibblers (*Parantechinus apicalis*) are ranked as Endangered and were formerly widely distributed along the west and southern coasts of Australia; however, now have a limited area of occupancy in the south west and on islands off the midwest coast. Establishing new populations entirely with wild caught dibblers is not feasible and captive breeding provides a source of animals for supplementation of wild populations and establishment of new populations. Dibblers are one of the species intended for reintroduction to Dirk Hartog Island following cat and goat eradication, and this will be achieved through captive breeding of animals sourced from the midwest islands.

Aims

- Maintain a captive breeding colony of dibblers to produce stock for translocation.
- Translocate captive-bred animals to establish further self-sustaining populations.
- Carry out genetic monitoring and management of reintroduced populations.

Progress

- Foundation breeding stock was increased by the capture of 15 juvenile and one adult dibbler from Whitlock and Escape Islands near Jurien Bay and transportation to Perth Zoo.
- These new animals were settled into captivity and paired for breeding. Twenty-eight pouch young were produced from those pairings and are developing normally.

Management implications

- The release of dibblers into Peniup Nature reserve will bolster this new mainland population.
- The progeny from this breeding program will be released onto Dirk Hartog Island National Park as part of the *Return to 1616* program to create a new wild population of the species.

Future directions

- Increase the size of the dibbler breeding colony to 10 pairs.
- Attempt to increase the reproductive output from the colony to expedite the release program.



Numbat breed for release program

SP 2018-098

P Mawson, C Lambert, A Friend

Context

Numbats (*Myrmecobius fasciatus*) are ranked as Endangered, and occur in only two natural populations at very low densities. Establishing new populations entirely with wild caught numbats is not feasible and captive breeding provides a source of animals for supplementation of wild populations and establishment of new populations. A captive breeding program for numbats at Perth Zoo has been in place since 1992. Captive-bred numbats have enabled new populations to be established at Boyagin Nature Reserve, Battaling Forest and fenced reserves at Perup, Dryandra, Mount Gibson Sanctuary in Western Australia, and at Yookamurra Sanctuary (South Australia) and Scotia Sanctuary (New South Wales).

Aims

- Produce yearling numbats in sufficient quantity to support proposed reintroductions to sites approved by the Numbat Recovery Team.

Progress

- Produced seven yearling numbats for release into the Australian Wildlife Conservancy's Mount Gibson Sanctuary. The numbats released at Mount Gibson represented the third and final years release into that facility.
- Seven yearling numbats were released into Dryandra Woodland to augment the population.
- One male and one female numbat were provided to the program from Dryandra Woodland to maintain the genetic integrity of the breeding program.
- A study of the genetic structure of all extant and captive/confined populations was completed. This study showed that there is merit in including genetics from the Perup/Upper Warren population in the the captive breeding program. Progeny derived from crossing Dryandra and Perup stock will only be used to establish new populations or to augment the genetics of the populations at Yookamurra, Scotia and Mount Gibson Sanctuaries.

Management implications

- Breeding of numbats provides animals to supplement existing numbat populations and establish new populations across the former range of the species. The program also aims to ensure the genetic viability of populations through monitoring genetic diversity and undertaking supplementary releases to enhance population genetic diversity.

Future directions

- Continue to produce numbats through captive breeding.



Survival and dispersal of black cockatoos in south-west Western Australia

SP 2018-025

P Mawson

Context

There are three taxa of black cockatoos (*Calyptorhynchus* spp.) endemic to south-west Western Australia. All three are listed as threatened (two Endangered, one Vulnerable), and all have national recovery plans. This project is designed to capture additional information on the ecology of all species and monitor recruitment in the wild. Monitoring survivorship of rehabilitated birds once released back into the wild is also undertaken.

This project has seen the successful release of 642 rehabilitated cockatoos from three species (335 Carnaby's cockatoo, 60 Baudin's cockatoo and 247 forest red-tailed black cockatoo). The total number of cockatoos banded (all species and all ages) is now 1,702 from 16 years of work. The rehabilitation techniques and release protocols currently in use provide very high survival rates. Confidence is supported by satellite telemetry of rehabilitated birds that have been released along with the continued sighting of banded rehabilitated birds in the field. Project success will be built on to investigate patterns of habitat usage and colonisation, to better understand distribution and further contribute to the management of black cockatoos on the Swan Coastal Plain.

Aims

- Monitor the recruitment of Carnaby's cockatoo at a number of sites across the species' range.
- Measure the health of nestlings of Carnaby's cockatoos at a number of sites across the species' range.
- Determine the availability of suitable nest hollows for Carnaby's cockatoo and investigate the value of artificial nest hollows to increase recruitment in the wild.
- Following veterinary treatment and rehabilitation, monitor the survival and dispersal of rehabilitated cockatoos (all three species) at release sites across their respective ranges.

Progress

- Banding was undertaken for 186 (133 as pullus, eight adults and 45 rehabilitated) Carnaby's cockatoos, along with 58 forest red-tailed black cockatoos (two as pullus, one as a yearling and 55 rehabilitated).
- Seventy Carnaby's cockatoos and nine forest red-tailed black cockatoo were either retrapped/recovered, had their bands/ colour bands photographed in the field and their band number read or inferred. Only three of those band recoveries involved birds that were dead.
- The first confirmed breeding of a known-age forest red-tailed black cockatoo was made of a bird that successfully fledged when only three years of age.
- A research paper on assessing flock integration of GPS tagged black cockatoos using behavioural change point analysis was published in *Journal of Wildlife Management*. A paper on factors affecting nestling condition and timing of egg-laying in Carnaby's cockatoo was published in *Pacific Conservation Biology*.
- Analyses of banding data for Carnaby's cockatoo to determine a more accurate annual survival estimate was commenced, along with annual survival estimates for rehabilitated Carnaby's and forest red-tailed black cockatoos. These data will help improve the previously published population viability analysis model for Carnaby's cockatoo and provide empirical evidence to support the rehabilitation program.
- Work has also commenced on an analysis of the costs of rehabilitating black cockatoos, relative to other types of conservation action.
- A paper is in preparation describing the utility and suitability of artificial nest hollows for Carnaby's cockatoo.

Management implications

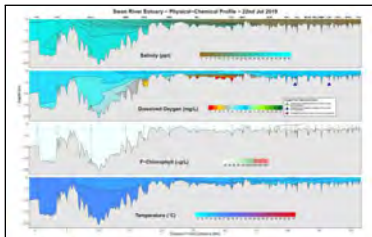
- The release of more than 600 rehabilitated black cockatoos provides a significant augmentation of adult numbers for all three species, and given the high survival rates indicates that this conservation action has an important role to play in the management of all species.
- The confirmation that GPS data can be reliably interpreted to determine when a rehabilitated black cockatoo has adjusted to life in the wild again, and that this occurs on average after only nine days, provides support for the future of the rehabilitation program.

Future directions

- Determine the costs-benefits associated with the rehabilitation of all three species of black cockatoos.
- Determine costs associated with the deployment of artificial nest hollows in comparison to the repair of degraded natural nest hollows.
- Use long-term banding data from rehabilitated birds to investigate historical and current survival estimates for Carnaby's cockatoo at a key breeding site, and determine the survival estimates for rehabilitated Carnaby's and forest red-tailed black cockatoos.

Rivers and Estuaries Science

Program Leader: Kerry Trayler The Rivers and Estuaries Science Program undertakes and supports research across a wide range of disciplines to address knowledge gaps and inform management of the Swan Canning Riverpark. Research is aligned with the Swan Canning Research Strategy and WAMSI estuarine research priorities. Strong collaborative linkages exist with universities, research centres and other government departments. Scientific advice and support is provided to the Rivers and Estuaries Branch in relation to waterway condition, management, and incident response including algal blooms, fish-kills, sewage overflows and dolphin deaths.



Incident investigations and response

CF 2018-095

K Trayler, J Cosgrove, B Huntley

Context

Rivers and Estuaries Science plays an important role in investigating issues as they arise in the Swan Canning Riverpark. This involves investigating events (such as harmful algal blooms, fish kills, and pollution discharge), examining causes, implications and control approaches.

Aims

- Monitor a toxic algal bloom of *Alexandrium* spp. and trial control approaches to inform a multi-agency incident response team, including DBCA Rivers and Estuaries Branch, Department of Primary Industries Resources and Development, and Department of Health.

Progress

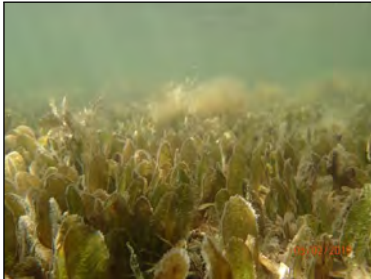
- Progress of bloom was tracked weekly and algal toxins were tested in biota (mussels, fish and crabs).
- Use of bentonite clay as a potential control option was tested in a laboratory trial, but not proven to be a viable option.
- Investigation updates were provided to the incident response team.

Management implications

- Monitoring of the algal bloom and toxin testing provided information to support Department of Health warnings to the public to avoid fishing in areas between Matilda Bay and Herne Hill between March and June 2019.

Future directions

- Response guidelines will be established for *Alexandrium* blooms and the management response will be reviewed.
- Other options for control of this harmful algae will be investigated.



Seagrass monitoring and evaluation

SP 2018-039

J Cosgrove, K Trayler, S Strydom, K Murray

Context

Seagrasses are a highly valued component of estuary ecosystems since they provide habitat, provide a food source for waterbirds and improve water quality by reducing sediment resuspension and removing nutrients. Seagrasses respond to changes in their physical and chemical environment, and worldwide human-impacts have unfortunately led to the loss of much seagrass habitat. Ensuring that seagrass communities remain viable and resilient is an important component of effective estuary management. Since 2011, the department has partnered with the Department of Water and Environmental Regulation (DWER) to develop and validate a seagrass-based index of estuarine health.

Aims

- Describe the natural variability of seagrass cover, species composition and other seagrass meadow characteristics as related to changes in key climatic conditions.
- Understand the sensitivity of seagrass metrics in response to anthropogenic stressors such as water quality and sediment stress.
- Periodically update seagrass habitat maps.
- Refine and validate the seagrass indicators proposed and provide protocols for the measurement and use of these indicators.

Progress

- A draft report prepared by DWER describing the refinement and validation of seagrass indicator was reviewed.
- DBCA completed the 2018/19 sampling season, including purchase and ground-truthing of new satellite images for seagrass habitat mapping.
- Processing is still continuing on thousands of geo-tagged benthic images. These will feed into and improve the accuracy of the final seagrass habitat map.

Management implications

- An updated map of seagrass community distribution in the Swan Canning Riverpark will aid accurate assessment of works proposals and necessary environmental considerations.
- The tested indices of seagrass health have already lead to a management response to investigate the cause of poor seagrass health in areas along the Attadale foreshore.

Future directions

- The department is currently integrating seagrass monitoring into its environmental monitoring program for the Swan Canning Riverpark and annual seagrass monitoring efforts will continue to expand our understanding of seagrass community dynamics in the Swan Canning and their response to stressors.
- The department continues to value add its monitoring program by engaging with university researchers and students.



Algal blooms: investigations and control

SP 2018-035

K Trayler, S Thompson

Context

Parts of the Swan and Canning rivers are affected by algal blooms, with the species effecting the blooms varying temporally and spatially. Blue-green algal blooms periodically occur in freshwater parts of the waterway during summer. 'Water Cleanser' is a product of the company Marine Easy Clean (MEC), promoted as means to improve water quality and control blue-green algal blooms. Curtin University investigations suggest the product provides a substrate, carbon and trace element source that supports Archaea microbes and particularly *Bacillus* and that, as these microbes accumulate, their biomass provides a catalyst to reset organic matter breakdown and facilitate the nitrogen cycle. Replicated tank trials in South America suggest improvements in water quality and anecdotal evidence of improved plankton communities in treated tanks. Many local governments in Western Australia have applied this product, with anecdotal evidence of effective bloom control in wetlands, but field trials have lacked adequate replication and evaluation.

Aims

- To test the product in a field setting and evaluate its effectiveness on improving water quality, algal composition and zooplankton abundance.

Progress

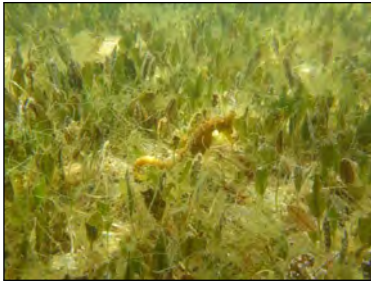
- A field trial of this product was undertaken.
- A before/after, control/impact (BACI) methodology was applied across six wetlands, with three selected for treatment and three as controls.
- Water quality, algal composition and zooplankton abundance were monitored at all six wetlands on three occasions prior to treatment and five occasions after treatment.
- A preliminary data report has been completed.

Management implications

- Preliminary results suggest that the 'Water Cleanser' did not have a significant impact on cyanobacterial abundance in a freshwater wetland setting. Further analyses is required to evaluate the impact on other water quality parameters, algal composition and zooplankton.

Future directions

- Further analyses of the water quality and phytoplankton dataset will be undertaken.
- Zooplankton samples will be processed.



Alfred Cove eutrophication investigation: gaining insights to apparent eutrophication-related stress exhibited by seagrass in the Swan Estuary Alfred Cove Marine Park

SP 2018-034

J Cosgrove

Context

The Alfred Cove Swan Estuary Marine Park (ACSEMP) is a 200 hectare area encompassing mudflats, seagrass meadows and intertidal vegetation, that provides habitats for a variety of animals including internationally important migratory wading birds. Previous seagrass monitoring and evaluation has suggested that seagrass meadows in the Alfred Cove area are in relatively poor condition compared to other areas of the Swan estuary.

Seagrasses play an important role in estuaries such as the Swan Canning Riverpark, by providing habitat, acting as a primary food source for black swans and stabilising sediments. Given the ecological services that seagrass meadows provide, it's imperative that we identify and understand drivers behind poor seagrass meadow health.

Aims

- Determine seagrass nutrient content in Alfred Cove and surrounding areas of the estuary.
- Investigate potential nitrogen sources and degree of eutrophication in Alfred Cove and compare this with seagrasses in surrounding areas of the estuary.
- Understand the roles of elevated eutrophication signals in influencing the productivity of seagrass.
- Investigate heavy metal concentration of seagrass tissue at Alfred Cove and determine if there is a relationship between seagrass standing stock and metal concentration.

Progress

- Fieldwork and data analyses have been completed and a draft report is undergoing review.

Management implications

- Results from the project will assist understanding and management of seagrasses in the ACSEMP and the wider Swan Canning Riverpark.
- Identification of key stressors may allow management to apply targeted mitigation measures.

Future directions

- Develop a strategic assessment of nutrient and non-nutrient contaminant sources and sinks.
- Conduct further local-scale characterisation of stressors that can be influenced through management and mitigation measures.



Investigating fish communities as an indicator of estuarine condition

SP 2018-033

K Trayler

Context

Fish communities exhibit predictable responses to ecosystem degradation/stress, and thus may be used as sensitive indicators of the ecological condition of these systems. Biotic indices, based on fish and other biological communities, are now used world-wide to quantify the ecological health of rivers, lakes, estuaries and many other environments. This project applies a Fish Community Index developed by Murdoch University in collaboration with government agencies (2007-2012) as a measure of the condition of the Swan Canning river system. This has been part of regular monitoring and reporting on the waterway since 2012 and a report on fish communities in the Swan Canning Riverpark is released to the public annually.

Aims

- To undertake the evaluation of the fish communities in the Swan Canning Riverpark for the purposes of applying the fish assemblage based index of estuarine condition and reporting.

Progress

- Fish communities were sampled at 48 sites and collected fish were identified, counted and returned to the water alive.
- Species abundances in each sample were used to derive values for core metrics including the numbers, diversity and identities of species, and the relative proportions of species with different feeding and habitat requirements. These underpinned the calculation of the nearshore and offshore fish community index. In turn these were used to calculate an overall index score for each zone.
- A report documenting the 2018 results was released. The report translates index scores to quantify ecological health and results are reported as a conceptually simple letter grade.

Management implications

- The Fish Community Index considers the fish community as a whole and provides a means to assess how the structure and function of fish communities in shallow nearshore and deeper offshore waters respond to a wide array of stressors affecting the ecosystem.
- In 2018, the shallow nearshore areas were assessed as being good to fair, and offshore waters of the system were assessed as fair - good. These results indicate slightly better ecological condition of both nearshore and offshore waters during 2018 compared with 2017.
- These results reflect the lack of any widespread or severe hypoxia during the 2018 monitoring period in contrast to the widespread impacts of a flood event that occurred in 2017.
- Across the estuary as a whole, the ecological condition based on fish communities has been assessed as generally good to fair in nearshore and offshore waters since 2008 and 2011, respectively.

Future directions

- A report documenting the results of the 2019 sampling is currently under review.



Assessment of multi-wavelength fluorometer technology for chlorophyll a and gross phytoplankton composition estimation

SP 2018-032

J Cosgrove

Context

Estimates of chlorophyll a (chl-a) concentration derived from fluorometers are currently considered qualitative to semi-quantitative and are not used in any reporting from the Swan Canning monitoring program. However, many national and international water quality monitoring programs use fluorescence-based estimates of chl-a quantitatively as a proxy for phytoplankton biomass. Prime benefits of this method are its low cost and near

real-time output. Most programs pair this method with limited pigment and phytoplankton measurements for calibration/verification of fluorescence data. New multi-wavelength instruments that use multiple LEDs of different spectral bands to both more accurately estimate chl-a and provide gross taxonomic characterisation (e.g. cyanobacteria, green, golden-brown (diatoms and dinoflagellates) and cryptophytes) are being applied in the field. This new fluorometer technology will be combined with machine learning techniques to draw the most from the data produced.

Aims

- Assess two multi-wavelength fluorometers for accuracy and precision of chl-a and gross phytoplankton composition estimation.
- Calibrate spectral settings to local species and apply novel machine learning techniques to improve chl-a and community composition estimates.
- Provide an assessment of instrumentation performance in the Swan Canning estuarine system and any potential benefits to environmental monitoring.

Progress

- A 6-channel fluorometer from BBE-Moldaenke (Fluoroprobe III) and a 9-channel fluorometer from JFE-Advantech (Multi-exciter Infinity) were trialled.
- Cyanobacteria, chlorophyte and diatom species representative of the local area were cultured and used in laboratory trials for chl-a calibration and determination of Specific Fluorescence Spectra.
- Potential impacts of prior light history and nutrient limitation on the fluorescence estimation of chl-a was also investigated within the laboratory setting.
- A short field trial was also conducted; however, delays in receipt and calibration of the equipment meant this was conducted during a period of low phytoplankton biomass and diversity.
- Both instruments had high accuracy for estimating total chl-a concentration, showing good agreement with traditional spectrophotometric methods.
- The final project report has been drafted and is under review.

Management implications

- The benefits of the technology are in review and will need to be weighed against the cost of the instruments and technical expertise required to ensure data accuracy.
- The analysis will provide information to assess cost versus strategic benefit of shifting from single- to multi-wavelength fluorometers for estimation of chl-a concentrations during routine water quality monitoring of the Swan Canning Riverpark.

Future directions

- A peer reviewed publication will be prepared.



Explaining foreshore vegetation die-off

SP 2018-030

K Trayler, B Huntley, A Okum

Context

At key locations in the Swan Canning Riverpark there is evidence of riparian decline. At Guildford, widespread die-off of *Eucalyptus rudis* has occurred and *Phytophthora* pathogens are suspected to play a role. However, this is a complex issue and a range of adverse environmental changes can influence the disease. There is potential to link LiDAR data, vegetation survey, information on plant water requirements, salinity tolerance and hydrodynamics in order to better understand the vegetation decline. The Swan Canning Estuary Response

Model, housed at UWA, will be used for this purpose. An associated study being undertaken by Murdoch University is exploring pathogen presence and soil influence on vegetation decline at Guildford. Together these investigations will work to understand what may be causing the decline in vegetation in that area.

Aims

- Use remote sensing to identify and map historic vegetation condition change.
- Combine field survey and model development to determine to what extent hydrodynamic changes (inundation extent, period and salinity) have contributed to the vegetation decline at agreed locations in the Swan-Canning.
- Investigate tree health by examining leaf nutrients, pathogen presence, soil moisture, nutrients and mycorrhiza.
- Trial phosphite injection as treatment option for trees impacted in the Guildford area.
- Predict where future change is likely to create heightened risk of tree decline, and make recommendations for remediation and revegetation approaches, and future research.

Progress

- The model has progressed well, with LiDAR data used to develop ultra-high resolution flood inundation maps for the agreed target location. An inundation extent and salinity dynamics model has been prepared using TUFLOW-FV and assessment of a range of flow events has been undertaken to identify salt sources and redistribution.
- Initial information from installed piezometers suggest a complex subsurface flow environment impacting on root-zone salinity with further analyses of summer / autumn piezometer data underway.
- Phosphite injection and nutrient implants to combat *Phytophthora* were trialled on trees at Guildford and involved community participation. A total of 120 trees were divided into 30 groups of four trees. Soil and roots from each group were screened for presence of *Phytophthora* species, and each group were then treated with either phosphite, a nutrient implant (Phoscap®), phosphite or Phoscap® combined or left untreated. None of the treatments for *Phytophthora* resulted in significant health responses in the tree canopies as determined by three different tree health measures. This indicates that the treatments were not effective over the 12 month monitoring.

Management implications

- Pre-emptive management approaches to protect existing vegetation may be an important management tool. The model development is expected to provide an exploratory tool to view the sensitivity of riparian zones under forecast hydrodynamic conditions.
- While *Phytophthora* treatments were not effective over 12 months, managing the riparian vegetation decline may require additional treatments. Repeat injections and extended monitoring will be considered.

Future directions

- Model simulations to forecast risk will be completed.
- Affected trees will be resurveyed for canopy health.



Application of FlowCAM® to biological monitoring in the Swan Canning Riverpark

SP 2018-029

J Cosgrove, K Trayler

Context

The department conducts weekly water quality monitoring of the Swan Canning Riverpark. Water-borne microscopic algae (microalgae or phytoplankton) are a key biological component of the estuarine ecology and

have been counted and characterised by trained taxonomists using microscopes since the inception of the monitoring program in 1994. Both monitoring technologies and data requirements have evolved since that time and this project will explore the potential of imaging flow cytometer technology to augment plankton monitoring in the Swan Canning Riverpark.

Aims

- Assess the use of a FlowCAM® imaging flow-cytometer in estuarine waters and compare results to traditional monitoring data.
- Highlight any additional data streams (e.g. zooplankton data, biovolume data) provided by the FlowCAM® and the quality of these data.
- Consolidate findings into management focussed recommendations for phytoplankton monitoring in the Swan Canning estuarine system.

Progress

- The FlowCAM® and supporting software were set up with classified images of phytoplankton that occur in the Swan Canning Estuary.
- The capacity of the FlowCAM® to replace or augment the existing microscopy-based regime was evaluated using preserved phytoplankton samples collected through the ongoing SCE monitoring.
- The accuracy of FlowCAM® auto-classifications was determined by manual checking of images, and FlowCAM® outputs have been compared to those of microscope-based taxonomists.
- Analysis suggests that accuracy of the FlowCAM® is poor when samples are from relatively turbid estuarine waters and preserved with Lugols Iodine solution (preventing use of chlorophyll fluorescence triggered mode).
- A draft project report has been prepared.

Management implications

- Technologies such as the FlowCAM imaging flowcytometer may provide other useful data streams such as cell biovolume estimates.
- Data collected during this technology assessment will be considered for other potential beneficial uses, such as cell biovolume estimates.

Future directions

- Project reporting will be finalised.



Stock enhancement of western school prawn: evaluation recruitment limitation, environment and release strategies

SP 2018-028

K Trayler

Context

The western school prawn (*Metapenaeus dalli*) was the focus of a small commercial and iconic recreational fishery in the Swan Canning Estuary. However, catches declined significantly through the 1950s and the commercial fishery closed in the mid-1970s. The popularity of the recreational fishery, which is estimated to have involved more than 50,000 people in the 1980s, also declined. Despite a reduction in fishing effort, stocks failed to recover. Restocking (i.e. releasing cultured individuals to rebuild stocks) was seen as a possible means of increasing the population of the western school prawn, improve understandings of the species and reinvigorate recreational prawning. Between 2013 and 2016, 4.5 million prawns were grown in aquaculture and released into the Swan Canning Estuary. Research and restocking, which was undertaken collaboratively with Murdoch University and the Australian Centre for Applied Aquaculture Research, was accompanied by a community education and engagement project, known as Prawn Watch, run by the River Guardians Program.

Aims

- Determine the biology and ecology of the western school prawn, and factors affecting their recruitment.
- Develop release strategies to maximise the survival of hatchery-reared prawns.

Progress

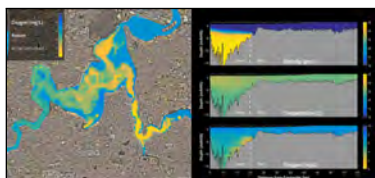
- Population dynamics for the western school prawn have been analysed over 5 years (2013-2018), covering a restocking period (2013-2016) and the impact of a flooding event in 2017. Data from ~1,240 hand trawls and 962 otter trawls were analysed.
- The abundance of the western school prawn increased over the first three years of the study, driven by the releases of ~4.65M hatchery-reared post-larval prawns, the persistence of marine-like salinities and normoxic conditions providing positive influences on density.
- A series of hypoxic events (April-June 2016) and a very cool over-wintering / spring period in 2016 had negative influences on the population.
- An aseasonal rainfall event (February 2017) caused widespread hypoxia during the breeding season of 2016/17. The spatial extent of this hypoxia impacted primary habitat of the western school prawn. Abundance in March 2018 was very low compared to pre-restocking levels.

Management implications

- The western school prawn is particularly vulnerable to changing conditions in the estuary, as it spends its entire life within the Swan-Canning and is unable to recruit from outside populations. This project indicates it is particularly sensitive to hypoxia across key habitat during the breeding period.
- Data indicates that the current abundance of the western school prawn in the Swan-Canning is currently very low, to the point where collecting enough broodstock for another restocking project would be difficult and not cost effective. Given the iconic nature of this species, there is value in monitoring the population in the future in association with management of the fishery.

Future directions

- Explore modelled oxygen data for the five years of this study to quantify the impact of hypoxia on key habitat for the western school prawn.



Model frameworks for estuarine reporting

SP 2018-027

K Trayler, J Cosgrove

Context

In the period spanning 2011-2016, the department and project partners at The University of Western Australia and Department of Water and Environmental Regulation invested considerable resources into the development of a spatially resolved coupled hydrodynamic-biogeochemical model, the Swan Canning Estuarine Response Model (SCERM). The model is a useful tool that can be used for predictive purposes as well as display. Elsewhere similar models have been developed to provide real-time evaluation of estuarine conditions. The SCERM model has the capacity to complement, but not replace, regular water quality monitoring and to simulate and display information on a wider spatial scale and over finer temporal resolution than the existing weekly water quality reporting. This could greatly enhance existing communications with the community about river conditions and create new opportunities to present 'interpreted' outputs of more relevance to management and outreach. This project aims to explore the capacity of a predictive model framework to rationalise water quality monitoring data and display information in a format that adds value through extension of information.

Aims

- Evaluate optimal water quality data requirements for predictive modelling of estuarine conditions.
- Develop a display portal for model outputs using near real-time data.

Progress

- SCERM was updated including: improved dinoflagellate motility coding; upgraded bathymetry to latest dataset available; model mesh refinement; new model zones with specific benthic properties; and machine-learning method to predict catchment nutrient inputs from rapidly available inflow data.
- The new generation of the model, Version 3, was compared with Version 2 performance.
- A web portal display has been created and is accessible to the public to view modelled water quality online. Key water quality variables (salinity, temperature, oxygen, nitrate, phosphate, total chlorophyll-a and turbidity) are included in the display.

Management implications

- Model accuracy is important in determining the level of confidence that can be placed in predictions. SCERM accurately reproduced physical conditions (salinity and temperature) of the estuary system, and effectively captured variations in dissolved oxygen and some of the nutrient pools (e.g. total phosphorus, ortho-phosphate and silicon). Reasonable accuracy was also obtained for other nutrient pools and chlorophyll a.
- The model is now suitable for assessing management scenarios associated with artificial oxygenation, nutrient and load management and/or climate change, bearing in mind some deficiencies that have been highlighted. Thus it is an important decision support tool for management of the waterway.

Future directions

- Utilise hindcast model outputs to correlate water quality and biological information on key populations / communities.
- Update model with improved oxygen metabolism coding.



Dolphin health - toxicogenomics and pathology investigations

SP 2018-023

K Trayler

Context

In 2009, following the deaths of six dolphins in one year in the Swan Canning Riverpark, a collaborative project with Murdoch University was established for on-going support in post-mortem investigations of individual strandings and unusual mortality events. That work was instrumental in understanding the underlying factors in the dolphin mortality event of 2009 and effort to understand dolphin health continues to be supported through the department and Murdoch University. Pathology investigations are linked with a university based research project examining toxicogenomics and contaminant exposure in live dolphins.

Aims

- Undertake post-mortem investigations of individual strandings and unusual mortality events in the Riverpark.
- Evaluate if there is any evidence of sub-lethal adverse effects on the immune, endocrine and nervous systems of the dolphins that use the Riverpark in comparison with dolphins in Shark Bay as a 'control' population.

Progress

- Necropsies have been undertaken on nine dolphins. Six of these were undertaken on dolphins found within the Swan Canning Riverpark and three were from the wider coastal area. Three of the dolphins died as a result of entanglements.

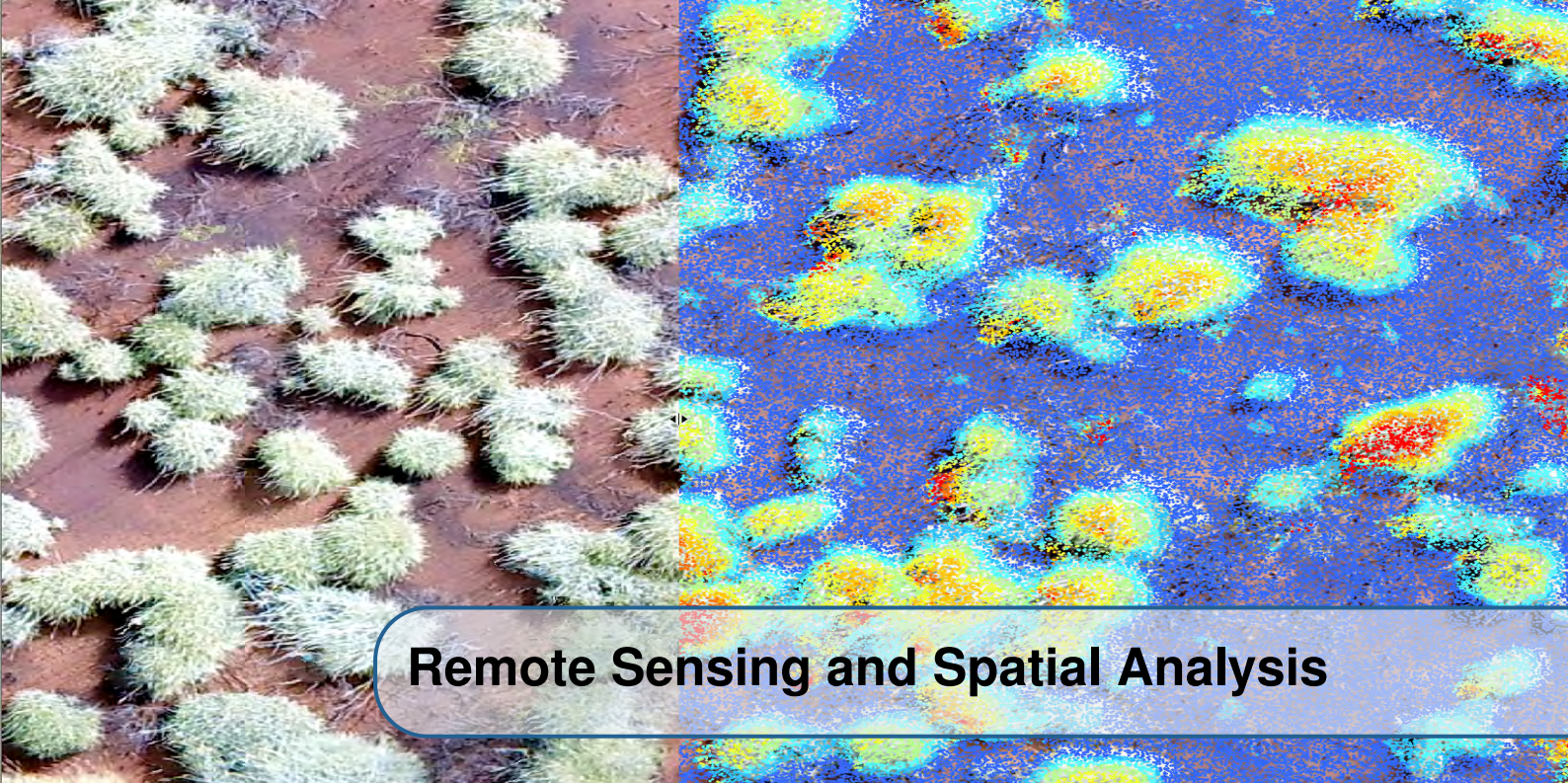
- Necropsy and pathology testing on five of the dolphins suggested an aetiology that is indicative of immune suppression with an underlying causal pathogen.
- Further testing for evidence of a viral pathogen using molecular techniques and immune-histochemistry were undertaken by Murdoch University.
- Results of molecular testing provide evidence of cetacean morbillivirus (CeMV) in three of the dolphins, including the two resident Riverpark dolphins. The two other dolphins showed some immune-histochemistry evidence of CeMV, but results were less conclusive.

Management implications

- The Swan Canning Riverpark dolphin sub-population is small and vulnerable to pressures associated with a habitat comprising a major industrial harbour and an urban estuary with high recreational usage and a large agricultural catchment.
- Identifying patterns in injury and disease provides valuable information on pressures affecting the dolphin subpopulation. The information is used in awareness raising and public information events.
- There are important implications of the presence of CeMV in the Riverpark subpopulation. The virus last affected the subpopulation in 2009, meaning that many resident individuals have not been previously exposed to this virus, most notably six calves and six juveniles. In addition, some of the adult dolphins may not have previously been exposed. Dolphin Watch and management groups in regional areas are being alerted to the potential impact of CeMV on cetacean populations.

Future directions

- Necropsy and pathology testing will include a wider area and range of species in order to understand the spread of this disease.

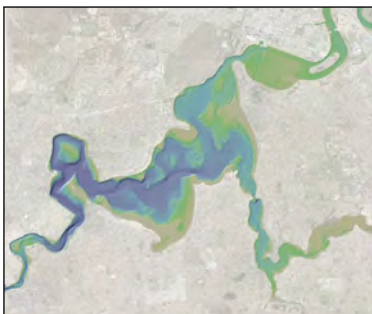


Remote Sensing and Spatial Analysis

Program Leader: Katherine Zdunic The Remote Sensing and Spatial Analysis Program seeks to integrate the science and application of remote sensing and spatial analysis into departmental programs. For a department that manages large tracts of terrestrial and marine conservation parks and reserves, the efficient use and analysis of spatial data is crucial for the understanding of natural processes and to inform management actions.

In recent times the availability of spatial data has increased dramatically. With this increase in data, the Program is continuing to develop sophisticated statistical analysis, interpretative and automation techniques to synthesise this data into a form where it directly assists departmental staff.

The program undertakes fire mapping over extensive areas of the state and has established monitoring programs in the forest, wetland, marine, coastal, rangeland and tropical savanna environments. Species and habitat modelling and spatially explicit assessments, such as risk assessments, allow managers to identify areas of concern and efficiently utilise resources. Program scientists collaborate with other parts of the department, universities, CSIRO, natural resource management groups, resource companies and other research providers.



Spatial data management

CF 2018-075

J Chapman, B Huntley, J Kinloch, G Loewenthal, K Murray, G Pitt, P Rampant, R Van Dongen, K Zdunic

Context

This core function manages spatial data sets by creating metadata, cleaning the data to a corporate standard and saving or migrating data in a secure and accessible corporate data repository - the Spatial Data Library. Many of the data sets in the Spatial Data Library are identified through departmental project requirements. Large data sets include imagery and digital elevation models captured for general use across the department or for specific projects and have multiple uses such as time series analysis, spatial analysis, modelling, and decision making for management, monitoring, planning and policy. Departmental collaborations also produce key data sets that are important but may not be ready to use or need a license arrangement in place to be utilised by the department. Making fundamental data sets accessible to all staff through corporate GIS software is an effective way of communicating what science is being undertaken and also assists with determining management priorities and actions.

Aims

- Identify and manage fundamental data sets created internally and externally that have value to the department and have multiple uses.
- Collate, clean and metadata final spatial data sets developed by science and science collaborations, and migrate this data into Corporate GIS applications and the Spatial Data Library.

Progress

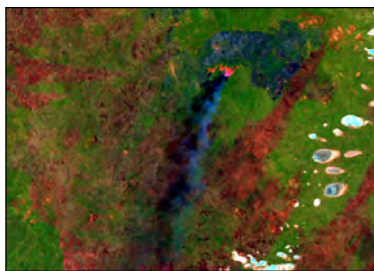
- The accessibility and discoverability of marine research datasets in the Kimberley region continued and 26 of the remaining Kimberley marine data sets generated through Western Australian Marine Science Institute (WAMSI) were processed. A video demonstrating the ease of access was created and sent to the Kimberley Marine Park Coordinators in addition to a report.
- Land Monitor products are now available through a web mapping service providing up to date state-wide imagery and vegetation classification information.
- The Terrain Data set (DEM/LiDAR) Index was updated to include new data sets available to the department on corporate systems.
- Scripts and functions were maintained to enable the download of data sources for satellite imagery and migration to storage infrastructure with Office of Information Management and Pawsey Supercomputing Centre.
- Provided feedback and advice to Landgate and the Office of Information Management to facilitate the future delivery of annual high-resolution imagery mosaics for regional Western Australia imagery as a replacement of aerial photography capture through the *Capture WA* program.
- Departmental bathymetric priorities were updated to contribute to state bathymetry priorities coordinated by the Department of Transport. Western Australian bathymetric priorities were submitted to the Australian Hydrographic Office and the HIPPS/SEA 2400 defence bathymetric capture program.

Management implications

- Appropriate access and curation of WAMSI data means that staff, particularly Kimberley Marine Park coordinators, are now able to use this data and knowledge to support management and monitoring for existing Kimberley Marine Parks and the current marine park planning process for the proposed Buccaneer Archipelago.
- Feedback to other state agencies such as Landgate and the Department of Transport, with regards to departmental requirements for high resolution imagery and bathymetry (respectively), is important to ensure future fundamental data sets provided to DBCA fill geographical or temporal gaps, are relevant, and can inform staff adequately to assist with our operational, monitoring, research and management needs.
- Continued development and migration of user-friendly spatial data sets will support the department's need to improve the discoverability and accessibility of science data for all staff.

Future directions

- Identify terrestrial and marine spatial data sets of corporate value to be migrated to the Corporate Data menu.
- Facilitate the delivery of web mapping service for Land Monitor products to the Corporate Data menu in ArcGIS and QGIS.
- Continue to update satellite imagery, LiDAR and DEM catalogues.
- Continue to maintain scripts and functions to download data sources for satellite imagery and migration to storage infrastructure with Office of Information Management and Pawsey Supercomputing Centre.
- Identify geographical or temporal gaps in aerial photography or high-resolution satellite imagery data and lodge requests with the *Capture WA* program.



Remote sensing and spatial analysis for fire management

CF 2018-074

J Chapman, B Huntley, G Pitt, P Rampant, K Zdunic

Context

The department's fire management, monitoring and reporting functions require knowledge of fire events that are effectively derived through fire scar mapping. The imagery used for this analysis is predominantly satellite imagery but also includes optical and thermal imagery from airborne platforms. Research areas include historical mapping which utilise the extensive archive record of satellite imagery and occasionally aerial imagery to build a fire history (or fuel age) for a location or to reconstruct the spread for major bush fire. This activity also includes monthly mapping during the prescribed burn season. The project also plays a key role in fire research and development, through research into fuel growth, fire spread and fire risk models. Internal and collaborative activities are carried out to further streamline and automate mapping techniques. General imagery support is also provided to Fire Management Services Branch and Regional staff. This includes roles such as incident mapping and predictions as required and advice in imagery and systems development.

Aims

- Improve processes of fire scar identification to enable historical fire regimes to be understood for safety and ecological applications.
- Improve burn security through the development of methodology to detect and communicate hotspot locations.
- Develop techniques to provide inputs for fire behaviour models to enable desktop assessments.
- Provide remotely-sensed spatial and temporal data streams to assist with bushfire investigations and reporting.

Progress

- Fire scar information for the Pilbara region, Kanyirninpa Jukurrpa, Desert Support Services and Bush Heritage Australia was supplied on a monthly and annual basis to inform and report on prescribed burning activities in the Western Desert and Pilbara region.
- Training was provided for the operational use of thermal camera to detect hotspots for burn security.
- Provided data to Fire Management Services Branch to inform fire recovery, fire chronology and new satellite technology/availability.
- Swan Region Fire Risk model for Autumn 2019 was completed.
- Provided Goldfields region with fire mapping to inform and report on prescribed burning activities and bushfires.
- Collaboration with Landgate in the development of appropriate automated state-level fortnightly burnt area map. The data for trial areas was validated and priority areas for further application were identified.
- A paper describing the relationship between spinifex fuel cover measured by remote piloted aircraft imagery and Landsat satellite imagery has been submitted to the *International Journal of Remote Sensing*.

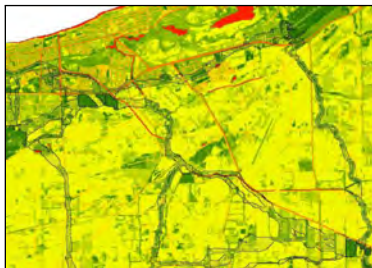
Management implications

- The information provided for fire management is designed to significantly increase the accuracy of reporting and decrease the risks of fire management activities. Delivering fire scar mapping and information allows practitioners to make informed decisions that lead to more efficient fuel reduction activities and successful completion of burn prescriptions.
- Developments in remotely piloted vehicle application together with satellite imagery will enable fire managers to more efficiently and accurately map fuel characteristics at a range of scales, greatly enhancing their ability to forecast fire danger and to predict fire behaviour without having to carry out costly ground-based field measurements.

- Consistent production and attribution of monthly fire scar mapping has resulted in the compilation of an annual fire scar mapping product with improved date, area and cause attribution. This product is suitable to analyse and provide spatial metrics that will aid in assessing the effectiveness of the fire management program over Millstream Chichester and Karijini National Parks.
- Security of burns is improved by the delivery of thermal imagery hotspots to on-ground staff.
- Updates to the Swan Region Fire Risk model informed prescribed burn planning.

Future directions

- Continued development and automation of fire scar detection methodology.
- Investigation and development of new data sources including new satellite data and aerial capture.
- Implementation and development of the spatial analysis of fire patterns and fuel loads.
- Further development of spinifex fuel cover from satellite imagery with greater field data inputs across the State.



Spatial analysis and modelling

SP 2018-073

J Kinloch, K Zdunic, G Pitt

Context

The spatial analysis and modelling project develops and utilises tools to assist in the evaluation, interpretation and prediction of conservation values, threatening processes and management actions. These tools generally integrate spatial data sets, expert knowledge and GIS modelling techniques to produce spatially explicit products that can be used to inform decision-making. Projects can be focused on species occurrence (e.g. species distribution models, habitat suitability modelling), animal movement (e.g. home range, identification of habitat linkages), landscape scale processes (e.g. assessment of habitat fragmentation) or assessments such as quantifying risk (e.g. risk presented by feral cattle to biodiversity values). Identification of areas of high conservation value for protection are also undertaken through combining numerous conservation value data sets and using software to evaluate possible conservation scenarios.

Aims

- Develop spatial models to describe ecological processes, thereby increasing the understanding and protection of biodiversity.
- Undertake spatial analysis tools to inform management and support decision making.
- Collate and summarise spatial information using statistical and documented methods to inform monitoring and management practices.

Progress

- A risk assessment for illegal sandalwood harvesting in the Goldfields Region was completed and future development of data sets to improve the model was identified.
- Spatial modelling methods were developed to identify removal locations of large feral herbivores using aerial tracklog data and the compilation of historical data has been initiated over the Martu Determination Lands.
- Satellite tracking of horses on the Fortescue Marsh and Upper Fortescue Catchment has continued, spatial metrics of animal movement have been produced and an annual report completed.
- A paper was published in *Wildlife Research* that reported on home range size and vegetation resource utilisation of tammar wallabies reintroduced into Kalbarri National Park.
- 2018 vegetation statistics (CAR Analyses) reports were completed. The South West Vegetation Complex report was expanded to report on the Perth and Peel Region Scheme areas.

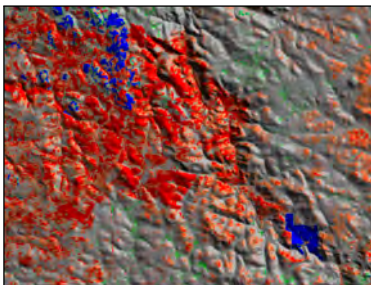
- Advice was provided on the feasibility of developing spatial distribution models for selected threatened flora species in areas where there are mining proposals.
- Advice was provided on the requirements to further develop a species distribution model for the sandhill dunnart.
- Progress was made on the development of an image segmentation and analysis methodology to discriminate Tuart woodland and forest areas using high resolution digital aerial imagery products from the Urban Monitor program.

Management implications

- Identification of areas at high risk of being targeted for illegal harvesting of sandalwood will inform surveillance strategies
- Information on feral herbivore hotspots and feral animal movement will inform the annual removal programs on the Martu Determination Lands and the development of feral herbivore management strategies for the Fortescue Marsh.
- CAR analyses contributed to the provision of advice on the reservation status of vegetation associations in various reservation and land acquisition proposals.

Future directions

- Continue work on standard methods and metrics to discriminate Tuart woodland and forest areas using Urban Monitor products.
- Produce and publish 2019 vegetation statistics reports.
- Complete spatial analysis and final report for the Fortescue Marsh Feral Herbivore project.
- Undertake further spatial modelling to support the planning of feral herbivore programs in the Pilbara and possibly other rangeland regions.
- Continue to provide advice on the development of species distribution models for threatened and priority species and develop models when appropriate.
- Further development of data sets and analysis of illegal harvesting to improve sandalwood risk assessment.
- Update data sets and refine spatial analysis methods to assist mapping and evaluation of wetlands data sets.



Remote sensing monitoring

SP 2018-072

J Chapman, B Huntley, G Loewenthal, K Murray, G Pitt, P Rampant, R Van Dongen, K Zdunic

Context

The measurement and analysis of change across terrestrial, wetland and marine environments using remote sensing provides essential historical and current information that can be used to understand the effects of management actions and natural events. The imagery used is predominantly satellite imagery, but also includes optical imagery from handheld and airborne platforms and LiDAR data. Field observations provide essential ground truth and calibration of remotely sensed data. Analysis techniques include an increasing number of sophisticated time series analysis tools and object orientated image classification. This work is underpinned by efficient and statistically rigorous analysis and batch processing techniques in the R programming environment. This function relies on repeatable and consistent source imagery and developing methods to produce reliable spatial and statistical products that can be used by the department for reporting on the state of the environment, managing the conservation estate and assessing threats to biodiversity.

Aims

- Undertake remote sensing monitoring and research projects at a range of temporal and spatial scales using technologies which include satellite imagery, digital cameras, remotely piloted aircraft and LiDAR data.

Progress

- A system to assess plantation stocking rates for Forest Management Branch was refined and validated.
- A satellite based vegetation cover change assessment over the Yarraloola and Red Hill pastoral leases was completed for Rio Tinto.
- The Millstream Chichester National Park riparian vegetation monitoring was continued.
- Input was provided to the Land Monitor project to develop satellite based rangeland vegetation monitoring.
- Landsat satellite imagery for the period 1988 to 2018 was analysed to quantify changes in vegetation cover and its relationship to rainfall and fauna numbers on Bernier and Dorre Islands.
- An assessment of satellite based vegetation cover change and its relationship to rainfall and tamar wallaby numbers on the North Island of the Abrolhos Islands was undertaken.
- Innovative techniques and high resolution imagery products from the Urban Monitor project were used to create up to date land cover and land use mapping of the Swan and Canning rivers catchments to provide inputs into modelling being carried out by Rivers and Estuaries Branch and the Department of Water and Environmental Regulation (DWER).
- Imagery report on suspected illegal clearing for DWER was completed.
- A report on the vegetation cover change in the *Plant assemblages of the Inering System* threatened ecological community was prepared.
- Identification of pine wilding density in the Gngangara region using digital aerial photography products from the Urban Monitor project was commenced.
- A remote piloted aircraft imagery capture for remote sensing applications training course was developed and five staff were trained.
- Remote piloted aircraft captured 65 mangrove field sites in the North Kimberley Marine Park for development of satellite derived mangrove vegetation cover and monitoring products.
- The ESRI collector app for capturing marine habitat types was altered to be compatible with Marine Science Program's EcoPass (photo and video habitat assessment tool). The app has since been used in the Swan River and the North Kimberley Marine Park.
- Shark Bay seagrass extent mapping was extended to the World Heritage Area for 2002, 2014 and 2016 and an additional year 2010. Analysis of the seagrass extent was conducted in relation to sea surface temperature and the marine heatwave of 2011.

Management implications

- The land cover and land use maps are used as input in hydrological and nutrient modelling and could be used to help identify areas with negative impacts on river systems.
- The *Plant assemblages of the Inering System* threatened ecological community assessment provides a template for a desk-top assessment of condition. The same method can be applied to other communities to identify those at most risk.
- The pine wilding mapping is required to ensure a pre-determined stocking rate is maintained. This stocking rate has implications on food availability and population viability of the Carnaby's Black Cockatoo.
- Stocking rate assessments for Forest Management Branch provide a cost effective and comprehensive process to assess stocking rates in south west plantations.
- The updated ESRI collector app for marine habitat types has increased opportunistic collection of field data to inform satellite image validation and management.
- Comprehensive information on the dynamics of seagrass extent in response to marine heat waves in the Shark Bay World Heritage area will inform management responses to the loss of habitat.

Future directions

- Implement the stocking rate assessment for Forest Management Branch as a production system.
- Improve the connection with field information obtained by the regions and remote sensing analysis for Forest Management Plan reporting.
- Continue to explore and develop cloud processing options with Geoscience Australia.

- Complete pine wilding mapping and develop a repeatable monitoring system.
- Commence investigating the cause of change in forest condition in the eastern jarrah forest and develop metrics for the Forest Management Plan reporting.
- Develop and refine the use of remotely piloted aircraft imagery for vegetation monitoring and mapping.
- Continuous development of mangrove monitoring methodology incorporating recent advances in field data capture and satellite imagery calibration.



Dirk Hartog Island vegetation monitoring

SP 2018-009

B Huntley, R Van Dongen

Context

In 2009 Dirk Hartog Island (DHI) was gazetted as a National Park and the process to remove introduced animals and reintroduce native mammals began. A vegetation monitoring program was developed that integrates detailed floristic surveys, repeated site photography and Landsat satellite imagery to provide a comprehensive picture of vegetation condition and how the island's ecology has changed since destocking.

Aims

- Monitor changes in the native vegetation cover following destocking of introduced herbivores.
- Monitor native vegetation cover changes with the recent reintroduction of native fauna.

Progress

- A manuscript on vegetation recovery using high temporal frequency Landsat imagery has been accepted for publication in *Ecological Management and Restoration*.
- Remotely piloted aircraft imagery and geographic positions of plant species were collected over several fauna exclusion plots.
- Vegetation cover change across the island was analysed with 38% experiencing a significant increase since destocking.
- The area of sand dune on the island has dramatically decreased by approximately 833 hectares in the period 2009 to 2019.
- Field data capture of small scale vegetation cover change has transitioned from using nadir photography (using a camera attached to a 4 m telescopic pole) to remote piloted aircraft imagery.

Management implications

- Results from the program demonstrate the benefit of the eradication program and provided management with evidence that, with the improvement in vegetation condition, the mammal reintroduction program has the best chance of success.
- The data collected and study of the fauna exclusion plots will help measure the impact of the reintroduced fauna.

Future directions

- Update the vegetation monitoring using Landsat imagery and carry out field validation of vegetation change.
- Update the sand dune area movement.
- Develop, refine and implement monitoring techniques using remote piloted aircraft imagery.



Species and Communities

Program Leader: Ken Atkins Species and Communities Program supports the delivery of the *Conserving Habitats, Species and Ecological Communities Service* through the provision of consistent and reliable products, information and advice regarding: legislation development and interpretation; policy development and interpretation; planning and setting priorities; implementing biodiversity conservation programs; maintenance of data and other information; and community engagement.

The program supports the department's operations in the areas of: threatened fauna, flora and ecological communities conservation; fauna and flora management; wetlands conservation; administering the departmental Animal Ethics Committee; and off-reserve conservation.



Wetland conservation

CF 2018-067

M Coote, F Felton

Context

Wetland conservation activities are conducted to improve the identification, protection, knowledge and management of wetlands on the conservation estate and off-reserve across Western Australia. The department partners with the Australian Government in implementing responsibilities under the Ramsar Convention of Wetlands to coordinate the protection and management of the listed sites in Western Australia. Maintaining wetland inventory across the State allows the department to provide accurate technical and scientific advice on high ecological value wetlands to decision makers in land use planning and environmental impact assessment processes. Many high ecological value wetlands are located on private property and the Healthy Wetland Habitats program provides an incentive for landowners to conserve and improve their wetlands.

Aims

- Coordinate the partnership responsibilities with the Australian Government for the implementation of the Ramsar Convention in Western Australia.
- Assist development of strategic policy for the conservation of high ecological value wetlands.
- Provide strategic technical advice in environmental impact assessment and land use planning processes for the protection of wetlands within the State's conservation reserve network and other high ecological value wetlands.
- Implement the off-reserve program for the conservation of high ecological value wetlands on privately owned land on the Swan Coastal Plain.

- Maintain the wetland mapping data sets for which the department is the custodian.

Progress

- Condition assessment of the Vasse-Wonnerup and Peel-Yalgorup Ramsar sites was undertaken.
- Analysis of extensions to Ramsar boundaries and updating the Ramsar information sheet for a number of sites was commenced.
- Review of the ecological character description and limits of acceptable change was progressed for the Peel-Yalgorup Ramsar site.
- The strategic management plan for the Fortescue Marshes has been completed.
- A wetland condition survey for Directory of Important Wetland Australia listed Lake Carnegie has commenced.
- Forty two requests to modify the *Geomorphic Wetlands Swan Coastal Plain* dataset were processed, including the Thornlie to Cockburn rail-link that identified 19 wetlands to be evaluated.
- As part of the mapping evaluations there have been five wetlands identified to be upgraded to Conservation category, including two sites confirmed to support migratory waders and endangered black striped minnow (*Galaxiella nigrostriata*).
- Contributed to development of the draft Wetlands Buffer Guideline as part of *State Planning Policy 2.9*.
- Technical advice was provided to departmental staff, other state and commonwealth agencies, land owners and their consultants for 32 land use planning issues.
- The Healthy Wetland Habitats program currently has 16 active participants receiving assistance for fencing, weed control and revegetation of wetlands.
- A review of wetlands mapping across the state has commenced.

Management implications

- The production of information sheets, mapping and condition reports for Ramsar wetlands will facilitate their ongoing management, and is a requirement for the Australian Government and the Ramsar Secretariat.
- The development of a climate change adaptation checklist for the Muir-Byenup System Ramsar site will facilitate a response strategy to major impacts of climate change.
- Management advice will provide for the protection and management of wetlands.
- Ongoing involvement of private land managers in the Healthy Wetland Habitats program promotes positive management of wetlands.
- Revised wetland mapping will facilitate targeted buffer guidance to be included with *State Planning Policy 2.9*.

Future directions

- Ecological character description of the Fortescue Marsh will be prepared.
- Condition survey for Lake Carnegie will be finalised.
- Evaluation of the status of wetlands will be undertaken.
- Technical advice on wetlands will be prepared to inform planning.



Ecological communities conservation and recovery

CF 2018-066

V English, C Harding, R Luu, S Martin, K Nilsson, J Pryde, P Robertson

Context

The ecological communities team collates and manages biodiversity information, and provides a range of science based support for the management, protection and recovery of threatened ecological communities (TECs) and priority ecological communities (PECs). Maintaining and managing the TEC database enables the department

to provide accurate technical and scientific advice on the protection and management of ecological communities to decision makers in land use planning and environmental impact assessment processes. Undertaking conservation status assessments, including nominations for listing/delisting and changes of status, ensures that the most recent ecological information is available to stakeholders. The team facilitates the Western Australian Threatened Ecological Communities Scientific Committee (TECSC) and coordinates recovery programs, including developing interim recovery plans and supporting recovery teams, to guide conservation activities for TECs and PECs.

Aims

- Provide evidence-based advice for the management, protection and recovery of TECs and PECs.
- Collate, manage and interpret information on the distribution, conservation status and recovery of TECs and PECs, and deliver a data provision service to ensure data are available within and outside of the department.
- Contribute to the assessment of environmental impact on TEC and PEC conservation values for development and vegetation clearing proposals in accordance with relevant policy and legislation.
- Undertake on-ground assessments to support conservation management and advice for environmental impact assessments and land use planning proposals affecting TECs and PECs.
- Guide strategic and coordinated recovery programs for TECs, including the preparation of recovery plans.
- Undertake assessments of conservation status based on all available data and prepare nominations for TECs and PECs for consideration by the TECSC.
- Implement the sections of the *Biodiversity Conservation Act 2016* (BC Act) that relate to TECs.

Progress

- At 30 June 2019, there are 65 ecological communities listed by the department as TECs (20 critically endangered, 17 endangered and 28 vulnerable) and four as 'collapsed'. Another 393 ecological communities are on the PEC list.
- One recovery plan for a TEC was adopted under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Interim recovery plans were drafted for two TECs.
- Three hundred and thirty two data search requests for TECs and PECs were processed for a range of stakeholders. Specialist TEC advice was also provided with a number of these requests.
- New occurrence information was added and edits to existing spatial information on the TEC and PEC database completed for 229 occurrences distributed across the state.
- On-ground survey and monitoring was undertaken for 33 occurrences of TECs and PECs throughout the state.
- Support and specialist input was provided, and meetings attended, for the Threatened Flora and Communities Recovery Teams in the Swan and Warren Regions, and the Albany, Esperance, Central Wheatbelt and Geraldton Districts.
- Environmental impact assessment advice was provided in relation to 109 clearing permit applications, land use planning, mining and development proposals.
- Specialist advice was provided to the Commonwealth Department of the Environment and Energy regarding their proposal to list a Western Australian TEC under the EPBC Act, and comment was provided on the draft Conservation Advice.
- Two meetings of the TECSC were held.
- Information and expert advice was provided for a Supreme Court case regarding a TEC occurrence.
- Preparation of TEC Notifications to Landholders under the BC Act was commenced.
- Field survey, and a draft report on the vegetation, threats and future management of the Nimalarragan wetland complex PEC near Broome were completed.
- A flora and vegetation report was completed for a coastal salt marsh TEC in Ashfield, to assist future management of the site.
- Draft assessments against the new ranking criteria, were prepared for 16 TECs.
- Documentation and processes were developed to support assessment of applications to modify TECs under the BC Act, and three preliminary applications were processed.

Management implications

- Enhanced data sets for TECs and PECs facilitate improved environmental impact assessments, land use planning, and conservation management.
- Maintenance of up to date data on the TEC and PEC database assists in resolving the status of ecological communities.
- Recovery plans, and management advice, assist the department and other land managers in maintaining the conservation values of TECs and PECs.

Future directions

- Continue to provide data and advice for the protection, conservation and management of TECs and PECs.
- Complete re-assessment of 65 existing TECs against the criteria, and prepare nominations for the TECSC.
- Prepare nominations for the TECSC for high priority ecological communities.
- Complete the two draft and one additional interim recovery plans for TECs.
- Continue to develop standard procedures and thresholds for 'Modification' of TECs, and process applications to modify TECs under the BC Act.
- Provide letters to owners and managers of private and public lands to notify them of their responsibilities under the BC Act regarding TECs on their land.



Off-reserve conservation

CF 2018-061

K Atkins, M Hunter, C Kemp, V Newbury, G Stack, L Zhang

Context

The department supports off-reserve programs to complement its conservation and management of the reserve system. The Nature Conservation Covenant program establishes covenants on land titles to formally protect the land's biodiversity conservation values. Technical and scientific advice is provided through the preparation of management guidelines, and funding is available for voluntary covenants. The Land for Wildlife program is a voluntary, non-binding scheme that provides technical and scientific advice for registered land managers to assist in managing their land for biodiversity conservation. The program is being delivered through a partnership with the Natural Resource Management (NRM) Western Australia regional organisations. The Roadside Conservation Committee has membership from other government agencies, road and rail managers, utility providers and community conservation organisations. An executive officer supports the committee and prepares technical and scientific advice for promoting road and railside vegetation, and promotes this through training programs and consultation. These programs work with other land managers and the community to assist in delivering biodiversity conservation outcomes on lands not managed by the department.

Aims

- Increase community awareness of biodiversity conservation and promote the department's biodiversity conservation activities through community and land manager consultation.
- Integrate science knowledge into technical biodiversity management advice.
- Improved conservation management on lands not managed primarily for nature conservation.
- Enhance the conservation estate through nature conservation covenants.

Progress

- Fifty two landowners applied for registration with Land for Wildlife during 2018/19, and a total of 1,945 properties are currently registered supporting 883,101 ha of bushland managed for conservation.

- Eleven property assessments were undertaken for Land for Wildlife by NRM partners, and 11 by the departmental coordinator during the year. Sixteen properties were added to the program as full members, one as an interim member and five were deemed unsuitable.
- Five regional NRM groups have been actively involved in Land for Wildlife activities. Funding has been obtained by the Peel Harvey Catchment Council for the development of an online data management system.
- An edition of the newsletter, *Western Wildlife*, was produced and emailed in digital format to most members.
- Thirteen new nature conservation covenants were registered covering 2,678 ha. Nature conservation covenants have been established on a total of 350 land titles, covering 27,273 ha, including habitat for threatened species and ecological communities, a Ramsar wetland and registered Aboriginal heritage sites.
- Advice was provided to land owners, local government and departmental planning staff on land use planning matters relating to covenants.
- Collaboration was progressed with the National Trust of WA and Department of Primary Industry and Regional Development to update joint publicity material, and represent the conservation covenant programs of the state at a NRM conference.
- Four meetings of the Roadside Conservation Committee were supported. Continued to develop education materials, and provide training to road and rail managers, to minimise potential impacts to adjacent vegetation.
- Training in roadside management was provided to five local governments, and a guidance document about how to manage roadside vegetation and minimise impacts of road works was prepared.
- Presentations were made to three WALGA road forums, and a rural Local Government Professional Association. Advice was provided to members of the community and road managers regarding roadside management issues.
- A discussion paper was prepared on the AusRoads Guide to Road Design (Part 6).
- A review of the Roadside Conservation Committee, Strategic Plan 2015-2020 was completed.

Management implications

- Off-reserve conservation plays an important role in achieving the conservation of the State's biodiversity. For example, 68% of threatened flora subpopulations (at 2017) occur on land not managed by the department, and 23% occur specifically on road and rail reserves. The encouragement of off-reserve conservation actions and the provision of technical support to enable effective management is important for achieving the biodiversity conservation objectives of the department and the State.
- Off-reserve lands are also often integrated with department-managed land, either by being adjacent to, or by providing linkages. Effective management of these lands, and the integration of management practices with those of the department, facilitate more effective management of the conservation estate to achieve biodiversity conservation outcomes.

Future directions

- Publish a technical guide on roadside pruning.
- Publish one electronic edition of the *Western Wildlife* newsletter.
- Develop a process for using spatial analysis to identify freehold land adjacent to the conservation estate for potential covenant sites.
- Establish all conditional covenants within the required planning approvals time frame.



Flora conservation and recovery

CF 2018-057

M Smith, A Jones, T Llorens, J Donaldson, K Griffiths, R Luu, W Thomas

Context

The flora conservation team collates and manages biodiversity information and provides a range of science based support for flora conservation and recovery. Maintaining and managing the Threatened and Priority Flora database (TPFL) allows the department to provide accurate technical and scientific advice on threatened and priority flora to decision makers in land use planning and environmental impact assessment processes. Undertaking conservation status assessments, including nominations for listing/delisting and change of status, ensures that the most recent biological and ecological information is available to stakeholders. The department facilitates the Threatened Species Scientific Committee (TSSC) and coordinates recovery programs, including developing interim recovery plans and supporting recovery teams, to guide translocations and conservation activities involving threatened and priority flora.

Aims

- Provide evidence-based advice for the management, protection and recovery of flora.
- Collate, manage and interpret information on the distribution, conservation status and recovery of threatened and priority flora.
- Provide a data provision service to ensure threatened and priority flora data is available within and outside of the department.
- Contribute to the assessment of environmental impact on flora conservation values for development and vegetation clearing proposals in accordance with relevant policy and legislation.
- Prepare permits to take threatened flora in a timely manner and within acceptable limits of impact to ensure the conservation of threatened flora.
- Guide strategic and coordinated recovery programs for threatened flora, including the preparation of interim recovery plans and threatened flora translocations.
- Undertake assessments of conservation status based on all available data and prepare nominations for the TSSC.
- Develop, inform and influence policy and strategic direction relating to flora.

Progress

- Preparation for the threatened species provisions of the *Biodiversity Conservation Act 2016* (BC Act) were made to ensure compliance with the new BC Act and Regulations, including transition from Declared Rare Flora (DRF) permits to threatened flora authorisations.
- 166 permits to take DRF/threatened flora authorisations were issued. Of these, 74 were issued for herbarium specimen collections for identification purposes, 20 were issued for scientific/research purposes and 72 were issued for land management and operational purposes.
- 556 new records were added to the TPFL database, of which 116 were records of new populations.
- 420 data search requests for threatened and priority flora were processed (15 internal, 70 other government departments, 313 consultants/mining sector, and 22 other organisations).
- Conservation status assessments resulted in 83 additions to the priority flora list, change in category of 35 taxa, and de-listing of 19 taxa after survey and taxonomic review clarified their conservation status.
- Administered changes to the Rare Flora Notice were published including one addition and the down grading of three species to a lower category of threat, criteria change for two species and ten name changes.
- Conservation status was reviewed for taxa described in 15 draft *Nuytsia* manuscripts.
- A recovery plan was published for one species, and interim recovery plans were published for another five species of threatened flora. Interim recovery plans were drafted for an additional ten species of threatened flora.
- Translocation proposals were approved for ten internal and three external projects.
- Impact assessment advice was provided in relation to 71 clearing permit applications, 31 other mining or development projects (73 separate advice requests) and nine land use planning proposals with the potential to affect threatened and priority flora.
- Support was provided for the meeting of Threatened Flora Recovery Teams representing the South Coast, Goldfields, Swan and Warren Regions, and the Albany, and Esperance Districts.
- Volunteers in the Swan, Wheatbelt and Warren regions, and Albany and Geraldton districts assisted in conducting surveys for many threatened and priority flora species. Volunteers from the department and the Western Australian Native Orchid Study and Conservation Group collaborated on the Adopt an Orchid

project to survey and monitor 36 threatened and priority orchid species, with 163 populations monitored and 34 new populations discovered.

- Information and advice was provided to the Department of the Environment and Energy to support threatened species listing and recovery plan decisions for flora taxa.
- Representation continued on the national working group for implementing the MoU on a Common Assessment Method for assessing threatened species. Nineteen flora species were endorsed by the Federal Minister for formal listing under the *Environment Protection and Biodiversity Conservation Act 1999* in 2019-2020.

Management implications

- Enhanced data sets and lists for threatened and priority flora facilitate improved assessment and conservation.
- Updates to the TPFL database assists in resolving the status of flora and provides improved information for land use planning and management.
- Management advice, and assessment of applications to take or translocate threatened flora, assists the department and other land managers to maintain the conservation status of threatened and priority flora.
- Industry management programs and threatened flora recovery plans guide conservation outcomes.
- Provision of input into the environmental impact assessment and land use planning processes maximises the potential for positive conservation outcomes.

Future directions

- Continue to assess the conservation status of flora and prepare six flora recovery plans.
- Make available the Threatened Flora Management Course for departmental staff.
- Transition to the new threatened species database and test the database for operational use, and train regional staff in the use of the new database.
- Continue to revise threatened flora operational procedures as required under the BC Act.



Fauna conservation and recovery

CF 2018-040

J Renwick, A Mutton, H Kilian, A Robey, K Rick

Context

The fauna conservation team collates and manages biodiversity information and provides a range of science based support for fauna conservation and recovery. Maintaining and managing the Threatened and Priority Fauna database allows the department to provide accurate technical and scientific advice on threatened and priority fauna to decision makers in land use planning and environmental impact assessment processes. Undertaking conservation status assessments, including nominations for listing/delisting and change of status, ensures that the most recent biological and ecological information is available to stakeholders. The department facilitates the Threatened Species Scientific Committee (TSSC) and coordinates recovery programs, including developing recovery plans and supporting recovery teams, to guide translocations and conservation activities involving threatened and priority fauna. The team facilitates the department's Animal Ethics Committee (AEC) to manage requirements for ethical consideration of animals in research projects.

Aims

- Provide evidence-based advice for the management, protection and recovery of threatened and priority fauna.
- Collate, manage and interpret information and data on the distribution, conservation status and recovery of threatened and priority fauna.

- Provide a data provision service to ensure threatened and priority fauna data are available within and outside the department.
- Guide strategic and coordinated recovery programs for threatened fauna, including translocations.
- Undertake assessments of conservation status based on all available data, and prepare nominations for the consideration of the TSSC.
- Inform policy and strategic direction relating to fauna, including animal welfare.
- Assess applications for Ministerial Authorisations to take or disturb threatened fauna under section 40 of the *Biodiversity Conservation Act 2016*, (BC Act) to ensure risks to individual animals and subpopulations are minimised during survey, monitoring and relocation activities.
- Provide technical advice on assessment of environmental impacts on fauna for development and vegetation clearing proposals, and licence applications to take fauna for relocation, scientific and other purposes, in accordance with relevant policy and legislation.
- Ensure that animals used for scientific purposes are cared for and used in an ethical and humane manner and that the department meets its commitments under the *Animal Welfare Act 2002*, its *Licence to use animals for scientific purposes*, and the *Australian Code for the Care and Use of Animals for Scientific Purposes*.

Progress

- As at 31 December 2018 a total of 382 fauna species were listed on the specially Protected Fauna notice, of which 249 were threatened fauna species (57 listed as critically endangered, 58 as endangered and 134 as vulnerable), 23 presumed extinct, seven conservation dependent, seven other specially protected and 96 migratory bird species that are protected under an international agreement. There were 217 species on the department's priority fauna list.
- Twelve fauna nominations were considered by the TSSC, resulting in two additions (due to taxonomic revision of *Perameles* species) and two deletions from the list of extinct fauna (one rediscovered species transferred to the threatened list as critically endangered (Douglas's broad-headed bee, *Hesperocolletes douglasi*), and re-identification of museum specimens of Gould's mouse (*Pseudomys gouldii*) as an extant species (Shark Bay mouse, *Pseudomys fieldi*) already on the threatened list). Seven threatened species had their status re-assessed and moved to a higher category of threat (all to align with the national status), and one species had a change to listing criteria only. One addition to the list of migratory birds was incurred, and nine nomenclature changes were implemented.
- A total of six fauna nominations were forwarded to the Australian Government for amendment of the threatened species listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Six additions, six increases in category of threat and two nomenclature changes under the EPBC Act occurred for Western Australian fauna species.
- Two thousand, six hundred and ninety records of sightings, captures or evidence of threatened and priority fauna were added to the Threatened and Priority Fauna database, bring the total number of records in the database to 66,385.
- Two hundred and sixty five threatened and priority fauna data searches and extract requests were performed and numerous responses were provided to fauna enquiries.
- Forty five applications were assessed for Ministerial Authorisation to take or disturb threatened fauna under section 40 of the BC Act, which was a new requirement that commenced on 1 January 2019.
- Two hundred and five applications were assessed for licences to take fauna for scientific, education, public and relocation purposes under the *Wildlife Conservation Regulations 1970* (regulation 15 or 17) or for fauna taking biological assessment, scientific or other purposes, and relocation licences under the BC Act.
- Seventy five formal written advice requests were provided in relation to assessment of environmental impacts associated with clearing permit applications, mining development projects and land use planning proposals, in addition to numerous informal requests for potential or hypothetical significance of impacts on threatened or priority fauna.
- A recovery plan was approved for the Australasian bittern (*Botaurus poiciloptilus*) in Western Australia and the *Wildlife Conservation Plan for Migratory Shorebirds* (Commonwealth of Australia 2015) was adopted as an interim recovery plan for eight species of threatened migratory shorebirds visiting Western Australia. Two multi-jurisdictional recovery plans prepared by the Northern Territory in consultation with DBCA, for fauna species listed as threatened in Western Australia (central rock-rat, *Zyomys pedunculatus*, and brush-tailed rabbit-rat, *Conilurus penicillatus*), were endorsed and adopted as national recovery plans under the EPBC Act.

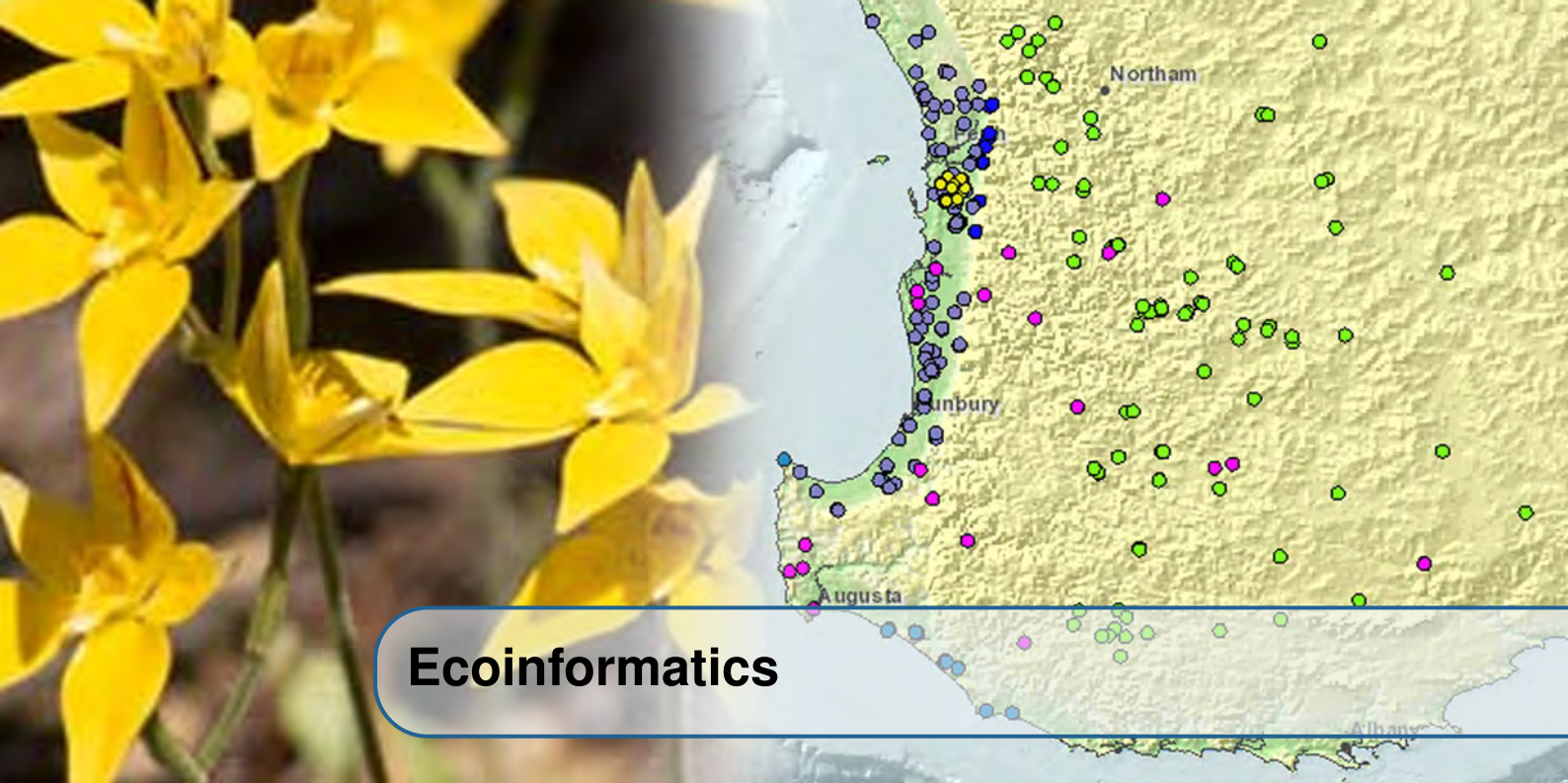
- Support was provided to 17 fauna recovery teams.
- Eighteen translocation and captive-bred releases occurred for banded hare-wallaby, bilby, bush stone curlew, black-flanked rock-wallaby, dibbler, Gilbert's potoroo, greater stick-nest rats, malleefowl, noisy scrub-bird, numbat, orange-bellied frog, red-tailed phascogale, rufous hare-wallaby, Shark Bay bandicoot, Shark Bay mouse, western swamp tortoise, white-bellied frog and woylie.
- The *Management Plan for the Commercial Harvest of Kangaroos in Western Australia 2019-2023* was approved by the Commonwealth Minister for the Environment.
- The AEC met six times, conducted a total of 334 assessments, approved 26 new projects and approved the renewal of 38 projects. There were 128 active projects that covered the following broad areas of research and monitoring: fauna monitoring, general fauna research, translocations, fauna surveys, education, feral animal control research and marine research.

Management implications

- Enhanced data sets and lists for threatened and priority fauna facilitate improved assessment and conservation.
- Updates to the threatened fauna database assists in resolving the conservation status of fauna and provides improved information for impact assessment, land use planning and management.
- Management advice, and assessment of applications for authorisations and licences to take and disturb fauna, or for the translocation of threatened fauna, assists the department and other land managers to maintain or improve the conservation status of threatened and priority fauna.
- Departmental animal welfare requirements are maintained through operation of the AEC.
- Industry management programs and threatened fauna recovery plans guide conservation outcomes.
- Provision of input into the environmental impact assessment and land use planning processes maximises the potential for positive conservation outcomes.

Future directions

- Continue to deliver strategic direction and coordination of the conservation, management, protection and recovery of fauna in an efficient manner.
- Transition to the new threatened species database, and test the new system to ensure it operates effectively.
- Prepare fauna conservation advice within requested time frames.
- Prepare one new threatened fauna recovery plan.
- Finalise the draft guideline for the survey and relocation of bilby, in relation to vegetation clearing and other significant disturbance activities.
- Continue to assist with the implementation of the BC Act and prepare additional guidelines, as required.



Ecoinformatics

Program Leader: Paul Gioia The Ecoinformatics Unit manages and make available the digital biodiversity assets of Biodiversity and Conservation Science. The unit compiles and maintains corporate databases and data warehouses. In particular, it develops and maintains the online portal *NatureMap* that publishes maps, lists and datasets of Western Australian species. The unit collaborates on projects involving complex information management and analysis, such as identifying broad-scale patterns of plant biodiversity. It also represents Biodiversity and Conservation Science, both internally and externally, on various forums that have a significant information management (IM) focus, and provides advice on a range of strategic IM issues. The Ecoinformatics Unit collaborates with various organisations in co-developing ecoinformatics tools (e.g. the NSW Office of Environment and Heritage) and data hosting (e.g. republishing fauna collections from the Western Australian Museum through *NatureMap*).



BioSys – the Western Australian Biological Survey Database

CF 2015-024

P Gioia, F Mayer

Context

A key strategy in conserving biodiversity is collecting field observation data that can be transformed into information, and then knowledge to inform decision-making. This biological survey is an important component of conservation programs, and because of Western Australia's size, and the remoteness and inaccessibility of many sites, data collection is typically expensive, and data sets are often irreplaceable. A corporately accessible database is required to capture biological survey data and ensure it is readily available. The Western Australian Biological Survey Database, BioSys, is a corporate application designed to load, curate and export complex ecological data. It aims to address the risks and issues described above by providing a secure, central, scalable, and accessible data repository based on modern, modular architecture.

Aims

- Build a corporate application for storing, curating and distributing ecological data, that allows users to manage their own data sets, and increases accessibility of ecological data to departmental users and systems.

Progress

- BioSys is the primary repository for new biodiversity data sets within Biodiversity and Conservation Science. It has been integrated into the data workflow supplying *NatureMap*. There are currently 30 major projects comprising 233 data sets and 836,594 records within the repository. Legacy data sets are being migrated to the new system, including important historical regional surveys, island flora and fauna, resource condition monitoring data, Carnaby's cockatoo, *Banksia* woodlands, Pilbara threatened fauna, Threatened Flora Seed Centre collections, many surveys from individual scientists, and a wide range of other datasets.
- Further collaboration with the NSW Department of Planning, Industry and Environment has been undertaken that further develops the workflow for the koala project to provide a second mobile application and BioSys instance for survey of endangered species.
- A proof of concept 'generic' data collection tool was also commissioned and completed. This proof of concept delivered a basic mobile application that requires further work to suit a range of customised workflows.

Management implications

- Reporting, research and analysis will be more effective and efficient through improved data consistency and availability. In turn, this will better inform decision-making and enhance conservation outcomes.
- Data will be better protected from loss arising from staff turnover or changing storage technologies, and will benefit from improved security and backup.
- Improved integration between systems will reduce the implementation cost on new projects through software re-use and more efficient data access.
- The system will facilitate improved compliance with government requirements for knowledge management and open data.
- Collaborations with external partners represents a major return on investment for the department that is building the functionality and utility of BioSys.

Future directions

- The data collection tool is being reviewed for customisation for use within the department. A variety of applications are under consideration internally.
- Other State jurisdictions, as well as the Commonwealth Department of the Environment and Energy, are evaluating the outcomes of this project. Further collaborations and potential investment will be explored to extend the capacity of BioSys for managing biodiversity data.
- The proposed Biodiversity Information Office initiative considers BioSys to be at the core of that technical architecture, and presents further collaboration opportunities to the department.



Provision of authoritative names of Western Australian taxa

CF 2011-108

P Gioia

Context

The department, academia and the community rely on authoritative species names to manage species databases. Without authoritative names, the ability to provide and integrate information is substantially impeded. WACensus, a database system, is the primary mechanism for managing those names. WACensus captures both current names and synonymies and information is disseminated widely throughout Western Australia. The department assumes a leadership role in providing authoritative names to assist in bio-inventory of both plants and animals, and the delivery of high quality information to a range of clients. There is a need to provide a standard mechanism for collection and management of plant species information. Max is a species database management system that substantially improves data accuracy through facilitating the correct use of names, and promotes a standard database design integrated with WAHerb, the Western Australian Herbarium's specimen database.

Aims

- Provide accurate and timely information on the names of Western Australian taxa to assist in management of species databases within the department and the wider community.
- Maintain updated species databases and provide facilities for entering specimen label information.

Progress

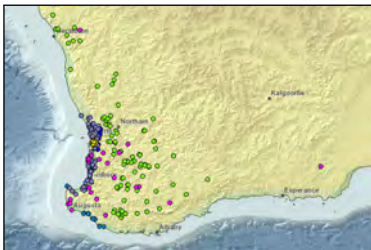
- WACensus data continues to provide both internal and public access to authoritative names data, and facilitating system integration.
- Annual statistics are now automatically generated and incorporated into *FloraBase*.
- Max continues to be maintained and enhanced to provide alignment with WAHerb, the most recent, authoritative species name information, and support for over 250 registered users within and external to the department.

Management implications

- The development of any database in the department that involves plant species names needs to be linked directly to WACensus data so that nomenclatural changes can be taken into account.
- Max provides a standard mechanism for entering specimen data, as well as the capacity to check species names against the most authoritative source, thus enabling better integration of floristic information.

Future directions

- Future refresh of WACensus to a modern architecture is being evaluated to integrate with other recently developed core systems.



Online GIS biodiversity mapping (*NatureMap*)

CF 2011-106

P Gioia

Context

A major challenge in managing the conservation estate in Western Australia, with its enormous biodiversity, is providing access to current and reliable information on species and their populations. Countless surveys and research projects have been undertaken within Western Australia over a long period of time, resulting in many data sets and reports that contain valuable and essential information for the ongoing management of this unique biota. Tools are required to enable conservation workers, industry and the public to more easily discover, assemble, analyse and report on biodiversity information that has been collected.

Aims

- Digital delivery of authoritative scientific information on the distribution and identity of major elements of the Western Australian biota from a single, online portal.

Progress

- Occurrence records now number over 5.3 million from 221 data sources.
- An additional 325 new registrations were recorded, bringing the total from 2,579 to 2,904, a 13% increase.
- Interactions between *NatureMap* and BioSys have been established providing integration of plot based data sets into *NatureMap*.

Management implications

- *NatureMap* provides a long-term repository for conserving and protecting the department's digital biodiversity data assets, so that knowledge can continue to be informed and improved through staff succession.
- *NatureMap* significantly reduces the time spent searching for point-based biodiversity data as well as easing the process of generating species lists for any area in Western Australia.

Future directions

- Continued incorporation of new and historical survey data into *NatureMap*.
- The proposed Biodiversity Information Office initiative is considering opportunities for the future development of *NatureMap*.



External Partnerships

Partners	Project Title	External Funding	Departmental Involvement
Atlas Iron, Fortescue Metals Group, Iron Ore Holdings, Roy Hill, Main Roads Western Australia	Ecology and management of the northern quoll in the Pilbara	\$195,000	J Dunlop, K Morris, S van Leeuwen, L Gibson
Atlas Iron, Main Roads Western Australia	Ecology and management of the Pilbara olive python	\$125,000	D Pearson, S van Leeuwen, K Morris, L Gibson, M Cowan
Atlas Iron, Rio Tinto, BHP, Kanyirrinpa Jukurrpa, BatCall WA	Ecology and management of the Pilbara leaf-nosed bat	\$320,000	S van Leeuwen, K Morris, K Ottevell
Atlas Iron, Roy Hill	Investigating the interactions between feral predators in the Pilbara	\$240,000	K Morris, S van Leeuwen, D Moro
Audelia Resources	Genetic assessment of sub-populations of <i>Marianthus aquilonaris</i>	\$130,000	M Byrne, T Hopley
Australian Biological Resources Study, Queensland Herbarium, Northern Territory Herbarium, University of the Western Cape (South Africa)	Towards an eFlora treatment of <i>Tephrosia</i> (Pers.) in Australia: taxonomic revision of the genus in Western Australia and the Northern Territory	\$515,000	R Butcher, T Macfarlane
Australian Institute of Marine Science, Australian National University	Coral reef fish recruitment study	\$13,000	S Wilson, T Holmes
Australian Institute of Marine Science, CSIRO	Mapping flatback turtle foraging areas in the Kimberley	\$1,000,000	Tucker, S Whiting
Australian Institute of Marine Science, The University of Western Australia	Understanding the early off-shore movement of flatback turtle hatchlings and the effects of anthropogenic light	\$400,000	S Whiting
Australian Institute of Marine Science	Potential anthropogenic impacts on Ningaloo whale sharks as determined through the tourism electronic monitoring system and scarring patterns	Nil	H Raudino, K Waples

Partners	Project Title	External Funding	Departmental Involvement
Australian Nuclear Science and Technology Organisation	Investigation of radionuclide contamination at Montebello Islands to understand implications for turtles and researchers	\$20,000	S Whiting
Australian Research Council, Australian National University, Western Australian Museum, South Australian Museum	Phylogenomic assessment of conservation priorities in two biodiversity hotspots: the Pilbara and the Kimberley	\$570,000	M Byrne, D Coates
Australian Research Council, Charles Darwin University, Save the Gouldian Fund, Balanggarra Aboriginal Corporation, World Wide Fund for Nature, Wild Spy Pty Ltd, National Drones Pty Ltd, The University of Auckland, Kimberley Land Council	Movement ecology of granivores: informing fire management of savannas	\$400,000	I Radford
Australian Research Council, Curtin University, Royal Botanic Gardens and Domain Trust (Mt Annan Botanic Gardens), The University of Western Australia, Australian Nuclear Science and Technology Organisation, United States Department of Agriculture, University of South Dakota (USA).	Advanced cryobanking for recalcitrant-seeded Australian rainforest plants	\$732,000	R Bunn
Australian Research Council, Murdoch University, Western Australian Museum, Roy Hill	Building resilience to change for mammals in a multi-use landscape	\$536,000	K Ottewell, L Gibson, M Byrne, S McArthur, R Shaw
Australian Research Council, Murdoch University	Optimising fire regimes for fire risk and conservation outcomes in <i>Banksia</i> woodlands in the Perth area	\$455,000	B Miller, K Ruthrof
Australian Research Council, The University of Western Australia, Australian National University	The evolution and conservation consequences of promiscuity in plants pollinated by vertebrates	\$1,400,000	S Krauss
Australian Research Council, The University of Western Australia, University of Adelaide, Australian Genome Research Facility	Seagrass adaptation and acclimation responses to extreme climatic events	\$525,000	S Krauss
Australian Research Council, University of Queensland, The University of Western Australia	Assessing the ecosystem-wide risks of threatened species translocation	\$311,377	M Byrne
Australian Research Council, University of Queensland, University of Western Australia, Perth Zoo, Melbourne Zoo, Taronga Zoo, Adelaide Zoo, Shedd Aquarium, Vancouver Aquarium, North Carolina Aquarium, St Louis Zoo, Denver Zoo, Oregon Zoo, Philadelphia Zoo, Brookfield Zoo, Oregon Zoo, Woodland Park Zoo.	Supporting family environmental learning and behaviour identifying, designing and testing transformative values-based education programs in zoos and aquariums	\$236,822	P Mawson
Australian Research Council, University of Sydney, Department of the Environment and Energy, Australian Reptile Park	Predicting the ecological impact of cane toads on native fauna of north western Australia	\$503,000	D Pearson

Partners	Project Title	External Funding	Departmental Involvement
Australian Research Council, University of Tasmania, Department of Primary Industry (NSW), Department of Environment, Water and Natural Resources (SA), Smithsonian Institute (USA).	Functional responses of rocky reef communities to effects of fishing and other anthropogenic stressors	\$900,000	T Holmes
Australian Research Council, University of Western Sydney, Murdoch University	Do hotter and drier regions harbour adaptive variation for climate change	\$281,505	M Byrne, R Mazanec
BHP, CyMod Systems, Australian Nuclear Science and Technology Organisation	Hydrogeochemistry of Walyarta Springs	\$120,000	J Rutherford
BioPlatforms Australia, Centre for Biodiversity Analysis, Western Australian Museum, Australian Museum, South Australia Museum, Museum of Victoria, University of Adelaide	Oz Mammals Genomics	\$1,112,000	M Byrne, K Ottewell
BioPlatforms Australia, Ian Potter Foundation, Royal Botanic Gardens Victoria, Centre for Australian Plant Diversity Research, Australian Tropical Herbarium, Royal Botanic Gardens and Domain Trust, Southern Cross University	Genomics for Australian plants	\$1,800,000	M Byrne, S Krauss, M Barrett
Biodiversity Fund, Warren Catchment Council, CSIRO	Restoring natural riparian vegetation systems previously infested by blackberry along the Warren and Donnelly Rivers	\$2,945,000	M Byrne, T Hopley
Birdlife WA	Shorebirds 2020 - capacity and information exchange	\$7,500	K Trayler
Bushfire and Natural Hazards CRC	Bushfire and Natural Hazards CRC	Nil	L Mccaw
CSIRO, Australian SuperSite Network, Terrestrial Ecosystem Research Network, National Research Infrastructure for Australia	Great Western Woodlands SuperSite	Nil	S van Leeuwen, M Byrne
CSIRO, National Environmental Science Program - Marine Biodiversity Hub	Dugong population and habitat survey - Shark Bay and Ningaloo	\$123,622	H Raudino, K Waples, K Murray
CSIRO, National Environmental Science Program - Northern Australia Environmental Resources Hub, Kimberley Land Council	Impacts and management of an invasive weed in the Fitzroy Catchment	\$140,000	S van Leeuwen
CSIRO, National Environmental Science Program - Threatened Species Recovery Hub, Australian Wildlife Conservancy, Bush Heritage Australia, Department of the Environment and Energy	Explaining and predicting the occurrence of night parrots (<i>Pezoporus occidentalis</i>) using GIS and ecological modelling	\$38,000	A Burbidge
CSIRO, The University of Western Australia	Marine turtle stable isotopes	Nil	Tucker, S Whiting

Partners	Project Title	External Funding	Departmental Involvement
CSIRO, The University of Western Australia	Understanding and quantifying impacts of invasive <i>Pasiflora foetida</i> on freshwater crocodiles in the east Kimberley	\$40,000	S van Leeuwen
CSIRO	Coral recruitment patterns in the Dampier Archipelago, Western Australia	\$8,000	M Moustaka
CSIRO	Fire regimes and impacts in transitional woodlands and shrublands	Nil	C Yates, C Gosper
CSR Gyprock	Wetland flora and fauna of the Jurien coast	\$138,000	A Pinder, M Lyons, K Quinlan, R Coppen
Caring for our Country	Identifying threats to marine biodiversity of the Ningaloo World Heritage Area: deeper water fish community surveys within the Ningaloo Marine Park	\$65,000	T Holmes
Central Desert Native Title Services	Fire scar mapping - Kiwirrkurra Indigenous Protected Area	\$1,000	K Zdunic, G Loewenthal
Charles Sturt University	Introduced predator interactions with an endangered native predator, the Pilbara northern quoll	\$78,000	J Dunlop
Chevron - Gorgon Net Conservation Benefit, James Cook University, Australian Research Council Centre of Excellence for Coral Reef Studies	Decision support system for prioritising and implementing biosecurity on Western Australia's islands	\$5,000,000	C Lohr, K Morris, L Gibson
Chevron - Net Conservation Benefit	Cat eradication on Dirk Hartog Island	\$3,000,000	D Algar, M Johnston, J Fletcher, N Hamilton, C Tiller, M Onus
Chevron - Wheatstone	Conserving critical seagrass habitat for dugong: an integrated assessment across the Pilbara	\$1,236,754	K Waples, H Raudino
Chevron	Translocations of mammals from Barrow Island: offset program	\$9,500,000	K Morris, N Thomas, C Sims, J Angus, S Garretson, M Blythman
Cliffs Asia Pacific Iron Ore Pty Ltd, The University of Western Australia	Integrated conservation and translocation of the threatened banded ironstone species <i>Tetratheca erubescens</i> (Elaeocarpaceae)	\$997,000	J Stevens, B Miller, S Krauss, D Merritt, W Lewandrowski, C Elliott
Cooperative Research Centre for Honey Bee Products, University of Adelaide, Dijilarup Manuka Pty Ltd, Spring Gully Foods	Understanding the genetic diversity of native <i>Leptospermum</i> species for high value honey products	\$416,100	M Byrne, R Binks
Curtin University, Australian Institute of Marine Science, The University of Western Australia, Department of Primary Industry and Regional Development, Flinders University, Department of Environment and Water (SA), Deakin University, Department of Primary Industries (NSW), University of Tasmania, CSIRO, FinPrint	Australian wide synthesis of baited video data to answer broad-scale ecological questions	Nil	T Holmes, J Goetze, S Wilson

Partners	Project Title	External Funding	Departmental Involvement
Curtin University, Department of Primary Industries and Regional Development	Cross and long-shore variations in reef fish assemblage structure and implications for biodiversity management	Nil	T Holmes
Curtin University, The University of Western Australia, Society for Ecological Restoration Australasia, BHP, Sinosteel Midwest Corporation, Mineral Resources, Hanson Construction Materials, Karara Mining Limited	ARC Training Centre for Mining Restoration	\$4,961,622	D Merritt, S Krauss, J Stevens
Curtin University, The University of Western Australia	The energetic basis to seed longevity and storage	\$336,000	D Merritt
Dambimangari Wanjina-Wungurr Aboriginal Corporation, Bardi and Jawi Niimidiman Aboriginal Corporation	Benthic biodiversity surveys of intertidal <i>wooddooroo</i> (coral reefs) in the Lalang-garram, North Kimberley and proposed Buccaneer marine parks	\$214,500	T Holmes, E D'Cruz, W Robbins
Department of Industry, Innovation and Science, The University of Western Australia	Eco-engineering solutions to improve mine-site rehabilitation outcomes	\$1,314,652	D Merritt
Department of Organismal Biology & Ecology, Colorado College (USA), St John University (USA)	Phylogenetics and floral symmetry development of the core Goodeniaceae	Nil	K Shepherd
Department of Planning, Lands and Heritage, Perth NRM	Hydrology of the Ashfield Flats	Nil	G McGrath, J Rutherford, A Pinder, B Huntley
Department of Primary Industries and Regional Development, CSIRO, Australian Institute of Marine Science, Curtin University	Connectivity of coral trout populations between individual reefs on the Rowley Shoals	Nil	W Robbins, E D'Cruz
Department of Primary Industries and Regional Development	Developing novel remote camera approaches to assess and monitor the population status of Australian sea lions	Nil	K Waples
Department of Water and Environmental Regulation, Water Corporation	Millstream riparian vegetation monitoring	\$2,000	B Huntley
Department of Water and Environmental Regulation	Statewide vegetation statistics and south-west vegetation complex statistics (CAR analyses)	\$14,000	J Kinloch, G Pitt
Department of the Environment and Energy - Threatened Species Commissioner, Rangelands NRM Western Australia	Development of Hisstory bait for feral cat control	\$250,000	M Johnston, N Hamilton, M Onus, D Algar
Department of the Environment and Energy	Western Australian black spot biological survey campaign	\$170,000	S van Leeuwen, A Pinder, M Lyons, M Cowan
Digital Earth Australia, Geoscience Australia, Earth Observation Governmental Network	Remote sensing based marine monitoring framework development with Geoscience Australia	\$14,000	B Huntley, K Murray, K Zdunic, G Pitt, K Bancroft, W Robbins

Partners	Project Title	External Funding	Departmental Involvement
Digital Life Project, University of Massachusetts - Amherst (USA), Murdoch University	Exploring the benefits of state-of-the-art 3D imaging techniques to create 3D digital and physical specimens of live flat-back turtles for science, conservation and education	Nil	S Fossette-Halot, S Whiting, Tucker
Ecological Horizons, Fortescue Metals Group, Roy Hill	Testing the efficiency and efficacy of Felixer feral cat grooming traps	\$85,000	J Dunlop
Florida International University, Australian Institute of Marine Science, James Cook University	Global FinPrint	Nil	J Goetze
Fortescue Metals Group, Millennium Minerals, Roy Hill	Ecology and management of the bilby in the Pilbara	\$2,005,000	M Dzimirski, K Morris, F Carpenter, S van Leeuwen
Geocatch, Edith Cowan University, Department of Primary Industries and Regional Development	The long-term monitoring of seagrass communities in Geographe Bay	\$10,000	B French
Hanson Construction Materials	Restoring <i>Banksia</i> Woodland communities after mining	\$25,000 pa	J Stevens, W Lewandrowski
James Cook University, The University of Western Australia, Australian Institute of Marine Science, CSIRO Marine and Atmospheric Research, Department of Primary Industries and Regional Development, Western Australian Museum	Temporal and spatial variation in coral cover on Western Australian reefs	Nil	S Wilson
James Cook University	Human impacts on coral reef communities	Nil	S Wilson
James Cook University	Establishing baselines and assessing vulnerability of commercially harvested corals across northern Australia	\$150,000	S Wilson, M Moustaka
Kanyirninpa Jukurrpa	Western Desert Land Cover Classification Pilot Project	\$17,000	K Zdunic, J Chapman
Landgate	Western Australian State Government Data Catalogue	\$12,000	F Mayer
Macquarie University	Investigating the potential for interactive communication between geographically isolated groups of female Asian elephants (<i>Elephas maximus</i>) using electronic media	Nil	P Mawson
Main Roads Western Australia, Kimberley Land Council, Rangelands NRM Western Australia, Nyamba Buru Yawuru Ltd, Walalakoo Aboriginal Corporation, Bardi Jawi Aboriginal Corporation	Conservation and management of the bilby (<i>Macrotis lagotis</i>) on the Dampier Peninsula, Kimberley	\$600,000	M Dzimirski, F Carpenter, K Morris, S van Leeuwen
Metals X Limited	Great Sandy Desert restoration	\$127,128	J Stevens
Millennium Seed Bank, Australian Seed Bank Partnership, Department of the Environment and Energy	Seed collection, storage and biology	\$12,000	A Crawford

Partners	Project Title	External Funding	Departmental Involvement
Murdoch University, Curtin University	Evidence based management of foxes adjacent to turtle beaches in Western Australia	\$300,000	S Whiting
Murdoch University	Collation of historic data for Shark Bay, Marmion and Shoalwater Islands Marine Parks.	\$20,000	S Wilson, A Kendrick
Murdoch University	Baseline microbial surveys in Swan Canning	Nil	K Trayler
Murdoch University	Swimming and diving performances of inter-nesting flatback turtles	\$50,000	S Fossette-Halot, S Whiting, Tucker
Murdoch University	Using Unmanned Aerial Vehicles (UAVs) to investigate visual detection probability of coastal dolphins during aerial surveys	\$115,757	K Waples, H Raudino
Murdoch University	The health status of marine turtles in northern and western Australia	\$200,000	S Whiting
Murdoch University	Genetic studies of Pilbara EPBC Act listed threatened vertebrate fauna	\$235,000	K Morris, D Pearson, S van Leeuwen, M Cowan, J Dunlop
NSW Rural Fire Service	A new National Fire Danger Rating System for Australia	Nil	L Mccaw
National Environmental Science Program - Northern Australia Environmental Resources Hub, Environs Kimberley, Kimberley Land Council	Securing the future for bilby in the Fitzroy Catchment / West Kimberley	\$540,000	F Carpenter, M Dziminski, S van Leeuwen
National Environmental Science Program - Threatened Species Recovery Hub	Project 4.3: Improving threatened plant reintroduction success and species recovery	\$699,000	L Monks, R Dillon, M Byrne
National Science Foundation (USA)	Systematics and biogeography of the Inocybaceae	\$19,000	N Bougher
Net Conservation Benefits, CSIRO	Molecular characterisation of stinking passionflower (<i>Passiflora foetida</i>)	\$913,000	M Byrne, T Hopley, S van Leeuwen
Office of Environment and Heritage (NSW)	Evaluating BioSys within the Office of Environment and Heritage (NSW) data environment	\$150,000	P Gioia
Parks Australia and other Christmas Island land management organisations	Christmas Island cat eradication	\$250,000	D Algar, N Hamilton
Rio Tinto, BHP	Seed collection zones for the Pilbara	\$450,000	M Byrne, R Binks, S van Leeuwen
Rio Tinto	Satellite imagery assessment of the fire regime on Yarraloola and Red Hill Stations, Pilbara	\$4000	K Zdunic, J Chapman
Rio Tinto	Vegetation cover change assessment on Yarraloola and Red Hill stations	\$8,600	R Van Dongen
Rio Tinto	Introduced predator control and baiting program - Yarraloola	\$3,000,000	R Palmer, H Anderson, K Morris
Rio Tinto	Identification botanist position at the Western Australian Herbarium	\$120,000	J Huisman, S Dillon

Partners	Project Title	External Funding	Departmental Involvement
RioTinto	Genetic assessment of Western Range populations of <i>Aluta quadrata</i>	\$83,000	M Byrne, R Binks, S van Leeuwen
Roy Hill, Atlas Iron, CSIRO, Pilbara Corridors, Rangelands NRM Western Australia, Pilbara Mesquite Management Committee	Strategic weed assessment of the Pilbara Bioregion	\$350,000	S van Leeuwen
Royal Botanic Gardens - Kew, University of Portsmouth (UK)	The <i>Stylidium</i> phylogeny and pollination project	Nil	J Wege
South Coast NRM	Conservation of the threatened Australasian bittern in south-western Australia	Nil	J Lane, A Clarke
South Coast NRM	Inundation products derived from remote sensing data for Lake Warden, Lake Gore wetlands and neighbouring systems in the south-west and the rest of Western Australia	\$16,600	B Huntley
South Coast NRM	Implementing recovery actions for EPBC listed species of the South Coast	\$30,000	A Friend
The University of Western Australia, Department of Water and Environmental Regulations,	Ashfield Flats Hydrological Project	\$10,000	G McGrath
The University of Western Australia, National Marine Fisheries Service (USA), Northern Territory Museum, Western Australian Museum, Queensland Department of Environment and Science, Pendoley Environmental, AUSTurtle	Skeletochronology and stable isotope analyses of flatback turtles	\$400,000	Tucker, S Whiting
The University of Western Australia, University of Tasmania, Australian National University, Australian Institute of Marine Science, CSIRO	Investigating the effect of recreational fishing using 30 years of data from Ningaloo Marine Park, a meta-analysis	Nil	T Holmes, S Wilson
The University of Western Australia	Using tree rings to reconstruct long term rainfall patterns in south-west Western Australia	Nil	L Mccaw
The University of Western Australia	Susceptibility of frogs to declining rainfall in a biodiversity hotspot	Nil	M Cowan
The University of Western Australia	Assessing the vulnerability of honey possums to climate change and habitat disturbances in south-western Australia	Nil	M Cowan
The University of Western Australia	Coral physiology and calcification mechanisms under varying temperature and light regimes	Nil	C Ross
University of Adelaide, Uppsalla University, Australian Genomed Research Facility, National Research Council Italy	Understanding adaptation to improve conservation of Australian flora	\$605,188	M Byrne
University of Adelaide	Aquatic microinvertebrate identification and systematics	\$5,000	A Pinder, K Quinlan, D Cale, M Pennifold

Partners	Project Title	External Funding	Departmental Involvement
University of Michigan - Department of Ecology and Evolutionary Biology	Contemporary ecological factors and historical evolutionary factors influencing the distribution and abundance of arid-zone reptile species in space and time	Nil	M Cowan
University of Queensland, Karara Mining Limited, The University of Western Australia, Curtin University	Eco-engineering soil from mine tailings for native plant rehabilitation	\$590,000	J Stevens
University of Queensland	Development of a male dibbler and numbat fertility index through the evaluation of spermatorrhoea characteristics to determine if there is a male factor in breeding success	Nil	P Mawson
Western Australian Museum	<i>NatureMap</i> : data sharing and joint custodianship	Nil	P Gioia
Yawuru Park Council, Nyamba Buru Yawuru Aboriginal Corporation	A biological survey of Nimalaragan Wetland, Broome	\$20,000	A Pinder, M Lyons, M Cowan



Student Projects

DBCA Officer	Student	Academic	Project Title	Duration	Page
D Algar	S Comer (PhD)	Dr D Roberts (The University of Western Australia), Dr P Speldewinde (The University of Western Australia)	Ecology of the feral cat in coastal heaths of the south coast of Western Australia	2014 – 2021	159
R Bunn	L Whelehan (BSc Honours)	Professor RL Mancera (Curtin University)	Assessing the effect of cryopreservation on mitochondrial function in plant shoot tips	2017 – 2018	159
R Bunn	H Clark (BSc Honours)	Dr B Funnekotter (Curtin University), Professor RL Mancera (Curtin University)	How does seed maturity affect cell membrane composition and cryotolerance / cryosensitivity? A biochemical and biophysical study	2017 – 2018	160
R Bunn	K Ang (BSc Honours)	Dr B Funnekotter (Curtin University)	Orthodox but non-conformist: the perplexing problem of cryopreserving short-lived native orchid seeds	2017 – 2018	160
R Bunn	R Streczynski (BSc Honours)	Dr B Funnekotter (Curtin University), Professor RL Mancera (Curtin University)	Oxidative damage to cell membranes during cryopreservation	2017 – 2018	161
A Burbidge	M Lohr (PhD)	Dr R Davis (Edith Cowan University)	Responses of southern boobooks to threatening processes across urban, agricultural and woodland ecosystems	2017 – 2019	161
A Burbidge	N Leseberg (PhD)	A/Prof R Fuller (University of Queensland), Dr S Murphy (Australian National University), Dr J Watson (University of Queensland)	Ecology and conservation biology of the night parrot	2017 – 2019	161

DBCA Officer	Student	Academic	Project Title	Duration	Page
M Byrne, R Binks	T Robbins (BSc Honours)	Prof S Hopper (The University of Western Australia)	Molecular and morphometric analysis of two disputed subspecies, <i>Banksia seminuda</i> subsp. <i>remansens</i> and <i>Banksia occidentalis</i> subsp. <i>formosa</i>	2018 – 2018	162
M Byrne	S Walters (PhD)	Dr P Nevill (Curtin University), A/Prof G Wardell-Johnson (Curtin University), Dr T Robinson (Curtin University)	Adaptive and phylogeographic variation in sympatric parasitic and non-parasitic species in Western Australia	2017 – 2020	162
M Byrne	J Bruce (MSc)	Dr A Koenders (Edith Cowan University), Prof P Horwitz (Edith Cowan University), Dr K Lemson (Edith Cowan University), Dr Q Burnham (Edith Cowan University)	<i>Reedia spathacea</i> F. Muell.: a study of phylogeography, population structure and co-occurrence	2016 – 2020	163
M Byrne	N Delnevo (PhD)	Dr E van Etten (Edith Cowan University), Prof W Stock (Edith Cowan University)	<i>Conospermum undulatum</i> : insights into genetics and ecology of an endangered species	2017 – 2019	163
M Byrne	A Lullfitz (PhD)	Prof S Hopper (The University of Western Australia)	Vegetation responses to Noongar land management practices in old and young landscapes	2014 – 2018	164
M Byrne, C Yates	R Dillon (PhD)	Prof M Waycott, Dr R Standish (The University of Western Australia)	Mating systems, reproductive output and progeny fitness of translocated plant populations compared to wild populations	2017 – 2019	165
M Byrne, C Yates	L Monks (PhD)	Dr R Standish (The University of Western Australia)	Factors affecting the success of threatened flora translocations	2016 – 2019	165
J Cosgrove	B Owen (PhD)	Dr NR Moheimani (Murdoch University), Dr F Valesini (Murdoch University), Dr CS Hallett (Murdoch University)	Phytoplankton in a microtidal temperate estuary: drivers, historical trends and future predictions	2017 – 2020	166
R Davis	T Hammer (PhD)	Prof L Mucina	Phylogeny, systematics and evolution of the Australian arid-zone <i>Ptilotus</i>	2015 – 2018	166
J Dunlop	M Cowan (BSc Honours)	Dr D Nimmo (Charles Sturt University), Dr J Turner (Charles Sturt University)	Thermal, physical and prey requirements for northern quoll denning habitat	2018 – 2019	166
J Dunlop	H Moore (PhD)	Dr D Nimmo (Charles Sturt University), Prof D Watson (Charles Sturt University), Dr L Valentine (The University of Western Australia)	The influence of invasive predators and fire regimes on northern quolls in the Pilbara	2017 – 2019	167
S Fossette-Halot	M Gammon (PhD)	A/Prof N Mitchell	Predicting the vulnerability of flatback turtle rookeries to a changing climate	2018 – 2022	167
S Fossette-Halot	J Stubbs (PhD)	Dr M Vanderklift (The University of Western Australia), A/Prof N Mitchell	Foraging ecology and energetics of green turtles in the Ningaloo coast world heritage area	2017 – 2019	168

DBCA Officer	Student	Academic	Project Title	Duration	Page
J Goetze	LH Hellmrich (BSc Honours)	Prof E Harvey (Curtin University)	A cost benefit analysis for the collection of reef fish density data with a micro remote operated vehicle versus SCUBA divers.	2019 – 2020	168
J Goetze	ER Rastion (PhD)	Prof E Harvey (Curtin University)	Integrated study of shallow and deep-sea fish communities status and their main stressors in a highly dynamic Galapagos seascape	2018 – 2022	169
J Goetze	KS Schramm (MSc)	Prof E Harvey (Curtin University)	A comparison of stereo-BRUV, diver operated and remote stereo-video transects for assessing reef fish assemblage	2018 – 2020	169
J Goetze	B Price (MSc)	Prof E Harvey (Curtin University)	Cyclone impact or natural variation? Assessment of damage on coral and fish in Kubulau District, Fiji by cyclone Winston	2018 – 2020	170
J Goetze	MC Márquez (PhD)	Prof E Harvey (Curtin University)	Conservation of elasmobranchs - ecology, public perception, and legal protections	2019 – 2023	170
T Holmes	S Zarco (PhD)	Dr T Wernberg (The University of Western Australia), Dr T Langlois (The University of Western Australia)	Persistence of tropical herbivorous fish in temperate ecosystems and its impact on habitat-forming macrophytes	2017 – 2021	171
S Krauss	W Thomas (BSc Honours)	Dr P Grierson (The University of Western Australia)	Conservation genetics of the critically endangered <i>Styphelia longissima</i>	2018 – 2018	171
S Krauss, D Merritt	S Adhikari (PhD)	Dr E Veneklaas (The University of Western Australia)	Optimising seed sourcing for effective ecological restoration	2018 – 2022	171
S Krauss, J Stevens	B Mirfakhraei (The University of Western Australia) (PhD)	Dr E Veneklaas (The University of Western Australia)	A genecological assessment of seed sourcing strategies for plant community restoration under environmental change.	2017 – 2020	172
S Krauss	B Ayre (PhD)	Prof S Hopper (The University of Western Australia)	Novel consequences of bird pollination in the kangaroo paw <i>Anigozanthos manglesii</i>	2015 – 2019	172
S Krauss	N Bezemer (PhD)	Prof S Hopper (The University of Western Australia)	Evolution and conservation consequences of bird pollination: an ecological and genetic study of mating, pollen dispersal and recruitment in <i>Eucalyptus caesia</i>	2016 – 2019	173
C Lohr	S Treloar (MSc)	Dr R Davis (Edith Cowan University), Dr A Hopkins (Edith Cowan University)	Resource competition between co-existing threatened mammals in a predator-free enclosure in central Western Australia	2019 – 2020	173
C Lohr	B Palmer (PhD)	Dr L Valentine (The University of Western Australia), Prof R Hobbs (The University of Western Australia)	Reintroduced digging mammals and ecosystem restoration	2018 – 2021	174

DBCA Officer	Student	Academic	Project Title	Duration	Page
P Mawson	S Bickford (PhD)	Prof N Longnecker (The University of Western Australia)	Optimising collaboration between secondary schools and informal science advisers: a stakeholder alignment perspective.	2012 – 2019	174
P Mawson	G Wilkinson (MSc)	Prof P Horwitz (Edith Cowan University)	The effect of diet on the growth and reproduction of western swamp tortoise at Perth Zoo	2018 – 2019	174
P Mawson	D Catto (MSc)	Prof C Lund (Curtin University)	Optimising energy provision at Perth Zoo via a renewable energy micro-grid.	2018 – 2018	175
P Mawson	M Bourrouosman, S Jeffries (3rd year)	Dr G Newland (Curtin University)	Social dynamics in a tufted capuchin group following the introduction of a novel male	2018 – 2018	176
P Mawson	J Scherpenhuizen (PhD)	Dr R Friere (Charles Sturt University)	Evaluation of the welfare and reproductive biology of captive tigers using non-invasive conservation physiology techniques	2017 – 2018	176
P Mawson	A Smith (MSc)	Dr B Jackson (Murdoch University)	Monitoring the behaviour of ghost bats before, during and after the reproductive season	2017 – 2018	177
P Mawson	F Coiacetto (PhD)	A/Prof K Warren (Murdoch University)	Hindlimb paralysis syndrome in Carnaby's cockatoos	2015 – 2019	177
P Mawson	E Hoffmann (PhD)	A/Prof N Mitchell	The effect of incubation temperature on development rates of <i>Geocrinia alba</i> and <i>G. vitellina</i> frog embryos	2018 – 2020	178
P Mawson	J Rendle (PhD)	A/Prof K Warren (Murdoch University)	Epidemiology of the clinical syndrome 'lumpy jaw' in captive macropods: influence of housing and husbandry	2015 – 2019	178
P Mawson	P Moore (MSc)	Dr J McLelland (Murdoch University)	Disease risk analysis in support of the translocation of dibblers from the Jurien Bay Islands to Dirk Hartog Island National Park	2018 – 2019	179
P Mawson	K Wood (PhD)	Dr T Hyndman (Murdoch University), A/Prof K Warren (Murdoch University), Dr S Vitali (Murdoch University)	The prevalence of arenavirus, bornavirus, nidovirus/coronavirus, sunshinevirus and ferlavirus in captive and wild populations of Stimson pythons, pygmy pythons and carpet pythons	2017 – 2019	179
R Mazanec	K Bhandari (PhD)	Dr E Veneklaas (The University of Western Australia), Dr M Renton (The University of Western Australia)	Predicting effects of climate change and thinning on growth, health and water yield of jarrah and karri stands using individual-based modelling	2018 – 2020	180

DBCA Officer	Student	Academic	Project Title	Duration	Page
L Mccaw	H Etchells (PhD)	Dr P Grierson (The University of Western Australia), Dr A O'Donnell (The University of Western Australia)	The impacts of severe wild-fire on the interactions among regenerating vegetation, fungi and small foraging marsupials in south-west Australia	2017 – 2020	180
D Merritt, T Erickson	A Bateman (The University of Western Australia) (PhD)	Dr M Muñoz-Rojas (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)	The use of soil amendments and alternative soil substrates to increase soil function and seedling recruitment in post-mining arid landscapes	2017 – 2021	181
D Merritt, T Erickson	E Ling (MSc)	Dr A Guzzomi (The University of Western Australia)	Design and testing of novel seed processing equipment and methods to improve seed-based restoration	2018 – 2020	181
D Merritt, T Erickson	M Masarei (PhD)	Dr A Guzzomi (The University of Western Australia)	Native seeding mechanisation to facilitate efficient large-scale restoration of degraded lands	2017 – 2021	182
B Miller, D Merritt	R Miller (PhD)	Dr J Fontaine (Murdoch University), Prof J Enright (Murdoch University)	Ecologically tolerable fire regimes for key <i>Banksia</i> woodland plant species	2015 – 2019	182
B Miller, D Merritt	R Tangney (PhD)		Fire intensity, seasonal variation and seeds traits may influence seed fates in <i>Banksia</i> woodlands	2015 – 2018	183
B Miller	C Slee (PhD)	Dr E van Etten (Edith Cowan University), Prof W Stock (Edith Cowan University)	The assessment of ecosystem risk in <i>Banksia</i> woodlands of the Swan Coastal Plain, Western Australia	2017 – 2019	183
K Ottewell, M Byrne, C Lohr	K Rick (BSc Honours)	Dr J Kennington (The University of Western Australia)	Population genomics of the burrowing bettong at Matuwa: a case study on the implications of genetic mixing	2018 – 2018	184
R Palmer	B Ross (PhD)	Dr B Murphy (Charles Darwin University), Prof J Woinarski (Charles Darwin University), Dr T Cremona (Charles Darwin University)	Ecological responses of the northern quoll to a large-scale feral cat baiting program in the western Pilbara region, Western Australia	2017 – 2019	184
A Pinder	S Atkinson (BSc Honours)	Dr J Chambers (Murdoch University), Dr B Robson (Murdoch University)	The impact of a drying climate on the alpha, beta and gamma biodiversity of freshwater macroinvertebrates in wetlands in a salinised landscape	2018 – 2019	185
A Pinder	A Lawrie (PhD)	Dr J Chaplin (Murdoch University)	Taxonomy of the salt lake gastropod, <i>Coxiella</i> : how useful are empty shells as a source of taxonomic information?	2018 – 2019	185
A Pinder	K Schmolz (MSc)	Adjunct A/Prof G Gollmann (University of Vienna)	Aquatic invertebrate food resources in western swamp tortoise translocation sites	2016 – 2017	186

DBCA Officer	Student	Academic	Project Title	Duration	Page
I Radford	S Collett (PhD)	Dr H Campbell (Charles Darwin University)	Influence of fire history and seed distribution on the movements of granivorous finches in the East Kimberley	2018 – 2021	186
I Radford	C E Penton (PhD)	Dr LA Woolley (Charles Darwin University), Dr B Murphy (Charles Darwin University)	Is there a housing crisis in tropical savannas? Changing fire regimes, hollows and declining arboreal mammals	2017 – 2020	187
K Shepherd, T Macfarlane	N Dakin (PhD)	Dr M Ludwig (The University of Western Australia), Prof G Kadereit (Mainz University, Germany)	Evolution of C ₄ photosynthesis in the genus <i>Tecticornia</i> at the anatomical and molecular levels	2017 – 2019	187
J Stevens, A Ritchie, T Erickson	V Brown (PhD)	Prof R Hobbs (The University of Western Australia)	Restoring highly degraded <i>Banksia</i> woodlands through innovative seed enhancement technology	2018 – 2021	188
J Stevens	S Sullivan (PhD)	A/Prof P Poot (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)	The influence of drought on plant morphology, physiology and establishment in the post iron ore mining environments of semi-arid Western Australia	2016 – 2020	188
J Stevens	J Ruscalleda Alvarez (PhD)	Dr J Yong (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)	Near-surface remote sensing of plant condition in mine site restoration environments	2017 – 2021	189
J Stevens	W Wong (PhD)	A/Prof R Trengove (Murdoch University), Dr J Yong (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)	Soil-microbial-plant signals and effects on plant eco-physiological performance for mine site restoration	2017 – 2021	189
J Stevens	E Arora (PhD)	Dr A Guzzomi (The University of Western Australia), Dr S Tomlinson (Curtin University), Prof K Dixon (Curtin University)	Implications for wind management in restoration ecology, linking ecosystem aerodynamics to physiological drivers in arid and semi-arid systems	2015 – 2019	190
J Stevens, B Miller	L Svejcar (PhD)	Dr J Fontaine (Murdoch University), Dr R Standish (The University of Western Australia)	How do species interactions drive community assembly of <i>Banksia</i> woodlands?	2016 – 2019	190
K Trayler	A Saeed (PhD)	A/Prof M Hipsey (The University of Western Australia), Prof C Oldham (The University of Western Australia)	Identification of controls on the metabolism of the Swan-Canning Estuary using numerical modelling and high-frequency data	2018 – 2021	191
K Trayler	B Poh (PhD)	R Tweedley (Murdoch University), Dr J Chaplin (Murdoch University), Prof N Loneragan (Murdoch University)	Evaluating the population genetics, recruitment limitations and release strategies of western school prawns during a restocking program in the Swan-Canning Estuary	2018 – 2021	191
K Trayler	S Fulwood (PhD)	A/Prof G Hyndes (Edith Cowan University)	Investigating habitat values of seagrass, macroalgae and wrack in the Swan Canning Riverpark	2016 – 2018	191

DBCA Officer	Student	Academic	Project Title	Duration	Page
A Wayne	W Geary (PhD)	A/Prof E Ritchie (Deakin University), A/Prof D Nimmo (Charles Sturt University), Dr T Doherty (Deakin University), Dr A Tulloch (University of Sydney)	Modelling species interactions and other environmental factors in the Upper Warren	2019 – 2022	192
A Wayne	S Thorn (PhD)	A/Prof N Mitchell, Dr R Firman (The University of Western Australia)	The population and spatial ecology of the numbat in the Upper Warren	2018 – 2021	192
A Wayne	A Seidlitz (PhD)	Dr K Bryant (Murdoch University), Dr N Armstrong (Murdoch University)	Survey methods and ecology of the numbat population at the Upper Warren region	2017 – 2019	193
S Whiting	J Stuart (PhD)	Dr T Fleming (Murdoch University), Dr P Adams (Murdoch University), Dr B Bateman (Curtin University)	Evidence based management of foxes adjacent to turtle beaches in Western Australia	2016 – 2019	193
S Whiting	P Wilson (PhD)	Dr M Thums (Australian Institute of Marine Science), Dr C Pattiaratchi (The University of Western Australia), Dr M Meekan (Australian Institute of Marine Science)	Understanding the early offshore movement of flatback turtle hatchlings and the effects of anthropogenic light	2015 – 2019	193
S Whiting	E Young (PhD)	Dr R Vaughan-Higgins (Murdoch University), A/Prof K Warren (Murdoch University), Dr L Yeap (Murdoch University), Dr N Stephens (Murdoch University)	The health status of marine turtles in northern and western Australia	2016 – 2019	194
S Wilson	D Ellis (PhD)	Dr C Fulton (Australian National University)	Habitat quality as a driver of epinepheline serranid productivity and replenishment	2018 –	194
S Wilson	R Harris (MSc)	Dr C Fulton (Australian National University)	How does environmental disturbance effect macroalgal assemblages at Ningaloo	2019 –	195
S Wilson	J Van Lier (PhD)	Dr M Depczynski (Australian Institute of Marine Science), Dr C Fulton (Australian National University)	The effect of patch habitat networks in shaping the distribution, abundance and diversity of coastal fishes	2015 – 2018	195



Student Project Reports



Ecology of the feral cat in coastal heaths of the south coast of Western Australia

STP 2016-018

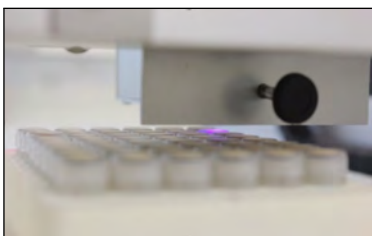
Scientist(s): D Algar

Student: S Comer (PhD)

Academic(s): Dr D Roberts (The University of Western Australia), Dr P Speldewinde (The University of Western Australia)

This part-time project is investigating habitat use, movement, dietary preferences and prey availability in important conservation reserves of the region. The relationship of landscape fragmentation to these factors is being examined, and builds on work completed through the South Coast Integrated Fauna Recovery Project and South West Fauna Recovery Project. The objective is to provide essential information for optimising the effectiveness of control programs for this introduced predator in south coast ecosystems.

In the past 12 months a further 23 feral cat stomach samples were collected from nature reserves and national parks in the south coast region and Bush Heritage properties in the Fitz-Stirling, and samples collected from 29 animals for stable isotope analysis. GPS radio collars were deployed on seven feral cats in the Gondwanalink Landscape in partnership with Bush Heritage Australia. GPS collar data from feral cats were reviewed, with preliminary analysis of spatial ecology including habitat preferences and home range use completed for all retrieved collars.



Assessing the effect of cryopreservation on mitochondrial function in plant shoot tips

STP 2019-025

Scientist(s): R Bunn

Student: L Whelehan (BSc Honours)

Academic(s): Professor RL Mancera (Curtin University)

This project aimed to utilise oxygen sensing (via Astec Global Q2 oxygen sensing apparatus) as a measure of metabolic activity of shoot material undergoing cryopreservation. Cryopreservation (the process of cryo-protection and storage in liquid nitrogen at -196C) incurs various stresses to plant tissues including intracellular

organelles such as mitochondria. Mitochondrial damage has been seen in post liquid nitrogen treated plant material and has been postulated to contribute to poor survival and regeneration of plant material after revival from cryopreservation.

This study showed that a moderately high pre-cryopreservation rate confers the best post-cryopreservation survival of shoot tips for *Anigozanthos viridis*. Results for *Androcalva perularia* were similar but more variable. Further studies will enable a deeper understanding of the impact of cryopreservation on plant mitochondrial function and assist the refinement of cryopreservation for threatened Australian plant species.



How does seed maturity affect cell membrane composition and cryotolerance / cryosensitivity? A biochemical and biophysical study

STP 2019-010

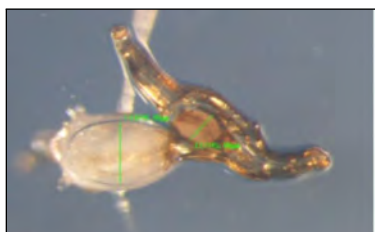
Scientist(s): R Bunn

Student: H Clark (BSc Honours)

Academic(s): Dr B Funnekotter (Curtin University), Professor RL Mancera (Curtin University)

Development of desiccation protocols is crucial for successful cryopreservation. Experimentation with seed axes of *Syzygium paniculatum* has indicated that achieving optimal drying time and water content is very difficult with these recalcitrant-seeded species. *Syzygium paniculatum* expresses much reduced survival as water content of the seed axes is reduced. Further development of this critical step will be needed to develop successful desiccation for recalcitrant-seeded species.

Preliminary analysis of the lipid content of cell membranes shows significant differences between species and tissue type abundance of sterol glucosides, sterol esters, phytosterols and glycerolipids. No large double-bond index differences between species or tissue types were observed. The preliminary data suggests that the best possibility of getting post-cryopreservation survival for embryonic axes of both species is with selection based on maturity and the use of longer cryo-protective agents incubation time.



Orthodox but non-conformist: the perplexing problem of cryopreserving short-lived native orchid seeds

STP 2019-009

Scientist(s): R Bunn

Student: K Ang (BSc Honours)

Academic(s): Dr B Funnekotter (Curtin University)

Orchid seeds are usually desiccation tolerant but recent research has indicated that their storage life is compromised by premature loss of viability under standard storage conditions and even following cryostorage. This study investigated why orchid seeds behave in this manner.

Seeds from most orchid species are classified as short-lived orthodox seeds, that is, the seeds age quicker than normal orthodox seeds in a seed bank, with the cause of this rapid aging remaining unknown. This study optimised asymbiotic germination of *Caladenia latifolia* and *Microtis media* on various culture media and incubation temperatures, and also determined the effects of artificial seed ageing on seed germinability. Over 90% of *C. latifolia* germinated on half-strength Murashige and Skoog basal salts agar with 5% (v/v) coconut water at 15°C whereas *M. media* favoured basic water agar medium and higher incubation temperature (94.2 ± 1.6%). Most of the asymbiotic germination conditions resulted in similar total germination, but germination rates were very different between two species. A preliminary screening on seed sugar contents showed that *C. latifolia* seeds stored more sugars compared to *M. media* that was found to be more resistant to artificial seed ageing temperatures than *C. latifolia*. At 45°C, $-p_{50}$ (time for viability to fall 50%) for *C. latifolia* seed was 5.8 days, while for *M. media* seeds $-p_{50}$ was 19.9 days, suggesting that seeds of these species stored under standard seed bank storage conditions should be regularly assessed for viability.



Oxidative damage to cell membranes during cryopreservation

STP 2019-007

Scientist(s): R Bunn
 Student: R Streczynski (BSc Honours)
 Academic(s): Dr B Funnekotter (Curtin University), Professor RL Mancera (Curtin University)

It is important to understand the significance of lipid peroxidation damage to cell membranes during cryopreservation, and how this affects post-cryogenic survival. Cryopreservation involves the long-term storage of plant germplasm, usually embryonic axes or shoot tips, in liquid nitrogen (-196°C), but requires the removal of intracellular water to avoid physical damage of ice crystallisation. This can be achieved through preculture on sucrose desiccation media or dehydration with cryoprotective agents; however, this leads to other forms of damage such as osmotic shock, toxicity, and the formation of reactive oxygen species.

In this project, antioxidants (GSH and AsA) were added to the preculture step in the cryopreservation of *S. australe* and *S. paniculatum*, to alleviate oxidative damage to cell membranes (lipid peroxidation), which was detected with the fluorescent probe C11-BODIPY581/591, and measurement of MDA and 4-HNE using LCMS. GSH was significantly beneficial in increasing regeneration following preculture. Results showed that lipid peroxidation does occur during preculture, and GSH can be used to alleviate oxidative stress experienced during this time, in order to increase the chances of post-cryogenic survival of recalcitrant species.



Responses of southern boobooks to threatening processes across urban, agricultural and woodland ecosystems

STP 2017-052

Scientist(s): A Burbidge
 Student: M Lohr (PhD)
 Academic(s): Dr R Davis (Edith Cowan University)

The Australian boobook (*Ninox boobook*) is a cryptic owl that appears to be declining in south-west Western Australia. This project aimed to identify possible causes, including secondary poisoning from anticoagulant rodenticides, across a series of landscapes impacted differently by human activity.

Results of the project show that artificial nest box supplementation does not appear to affect boobook occupancy in fragmented habitats in south-western Australia. Most risk factors previously implicated in increased risk of *Toxoplasma* infection did not show significant correlations with observed seropositivity in boobooks. However, the season in which the sample was collected did correlate significantly with seropositivity. Boobooks in Western Australia show weak spatial genetic structuring and no evidence of genetic erosion associated with inbreeding in heavily fragmented landscapes, probably a consequence of the dispersal capacity of boobook offspring and their ability as habitat and dietary generalists to make use of highly altered landscapes.



Ecology and conservation biology of the night parrot

STP 2017-051

Scientist(s): A Burbidge
 Student: N Leseberg (PhD)
 Academic(s): A/Prof R Fuller (University of Queensland), Dr S Murphy (Australian National University), Dr J Watson (University of Queensland)

The night parrot is an enigmatic species of ground dwelling parrot that is believed to occur across arid Australia but has rarely been seen as it is nocturnal and occupies remote habitat. Recent discovery of birds in Queensland and Western Australia has provided an opportunity to study the ecology and biology of this species at several

sites across the Australian arid zone. Little is known about habitat use and ecology of this bird so studies are being undertaken to improve recognition and management of potential habitat.

Much of the work in this project over the last year has been in Queensland. A recently published paper has documented all known calls of the species (including some known only from Western Australia) and this will be of considerable assistance in future survey and monitoring efforts. Current analyses of historical occurrences will assist in planning future survey work.



Molecular and morphometric analysis of two disputed subspecies, *Banksia seminuda* subsp. *remanens* and *Banksia occidentalis* subsp. *formosa*

STP 2018-111

Scientist(s): M Byrne, R Binks

Student: T Robbins (BSc Honours)

Academic(s): Prof S Hopper (The University of Western Australia)

Banksia seminuda subsp. *remanens* and *B. occidentalis* subsp. *formosa* from Western Australia's south coast were described as subspecies in the late 1980s based on differences in leaf morphology, canopy density and height between them and their common subspecies. However, this status has since been rejected and has led to dispute over their current classification. Historically, taxonomic decisions such as these have been based primarily on morphological traits, an approach that has provided many correct classifications. However, morphology alone is not always the most appropriate basis for assessment as it is not always under genetic control and therefore heritable, and where morphological differences are minor or variable (such as between infraspecies) differentiating taxa may not be possible by simple visual examination. These issues are further compounded by a lack of consensus on infraspecific definitions, characters to delimit them, and the degree of differentiation that constitutes recognition as distinct taxa. Nonetheless, contemporary analysis techniques in morphometrics and genomics are providing insight into taxonomic inconsistencies that may assist in resolving taxonomic boundaries. This research seeks to obtain information to resolve the subspecific classifications given for *B. seminuda* subsp. *remanens* and *B. occidentalis* subsp. *formosa*, hypothesising that both do constitute distinct subspecies. This project aims to conduct morphometric analyses to determine statistically how respective subspecies differ in their morphology; perform genomic sequencing of nuclear DNA to determine the presence and level of genotypic variation within and between respective subspecies; and use this information to determine subspecies delimitation in each species.

Samples of leaves were collected for morphometric and genomic analysis from populations of *B. seminuda* subsp. *remanens* and *B. occidentalis* subsp. *formosa* on coastal headlands, along with populations of their common subspecies. Samples were also collected from a location for each species where the two subspecies appeared to intergrade. Information on plant height and floral density of canopy was also collected at each location. Morphometric and genomic analysis has been completed. Both genomic and morphometric data indicated a single primary division within *B. seminuda*, providing strong support for the recognition of two subspecies, *B. seminuda* subsp. *seminuda* and subsp. *remanens*. Morphological differences within *B. occidentalis* were less distinct, but genetic data revealed evidence of three divergent evolutionary lineages indicating more complex, cryptic partitioning within the taxon than previously thought.



Adaptive and phylogeographic variation in sympatric parasitic and non-parasitic species in Western Australia

STP 2017-030

Scientist(s): M Byrne

Student: S Walters (PhD)

Academic(s): Dr P Nevill (Curtin University), A/Prof G Wardell-Johnson (Curtin University), Dr T Robinson (Curtin University)

This project aims to improve our understanding of local adaption and phylogeographic patterns in parasitic

and non-parasitic plant species' important for mine site restoration in Western Australia. Range-wide sampling and next generation sequencing technologies will be utilised to examine: signals of adaptive genetic variation; and phylogeographic patterns for four plant species endemic to Western Australia. The research will determine whether generalist and limited host-specific parasitic species have similar adaptive variation and phylogeographic patterns compared to sympatric non-parasitic plants. Species distributions will be extrapolated using spatial modelling to predict patterns of adaptive genetic variability across the landscape and develop a tool to guide seed sourcing for restoration.

Fieldwork was undertaken to collect range-wide samples of leaf material for the limited host-specific parasitic species, *Amyema gibberula* subsp. *tatei*, and its main host, *Hakea recurva* subsp. *recurva*. Nuclear DNA was sequenced for both species using next generation sequencing technologies. Analysis of nuclear data is underway for all four species, including the generalist parasite, *Nuytsia floribunda*, and sympatric non-parasitic species, *Melaleuca rhapsiophylla* previously collected and sequenced. Three regions of chloroplast DNA were also sequenced for each species using Sanger sequencing technology, and phylogeographic analysis is currently underway.



***Reedia spathacea* F. Muell.: a study of phylogeography, population structure and co-occurrence**

STP 2017-029

Scientist(s): M Byrne

Student: J Bruce (MSc)

Academic(s): Dr A Koenders (Edith Cowan University), Prof P Horwitz (Edith Cowan University), Dr K Lemson (Edith Cowan University), Dr Q Burnham (Edith Cowan University)

Reedia spathacea (Cyperaceae) is a species of sedge found in the peat swamps of the Jarrah Forest and Warren biogeographical regions. The growth habit is particular to the species and it has apical meristems and above ground rhizomes protected by retained leaf sheaths with lateral roots that act as a means of clonal dispersal. Knowledge of morphology and reproductive strategy remain poorly known. The species is currently listed as Critically Endangered and occurs in ecological communities that are threatened by feral pig damage, increased fire frequency, weed invasion, fluctuations in water quality and changes to land use, such as groundwater extraction and land clearing. This study aims to evaluate the morphology and ecology of the species and to determine its genetic structure and historical biogeography. Microsatellite DNA analyses will be used to determine population genetic structure of *R. spathacea* and chloroplast sequence data will be used to determine the evolutionary history.

Extensive fieldwork to investigate morphology and collect genetic specimens has been completed. Genotyping with microsatellites has been completed and data analysis has been undertaken. Significant departure from Hardy Weinberg Equilibrium was found across all populations indicating presence of inbreeding, with no recent bottlenecks detected by either a sign or Wilcoxon sign-rank test for any population under any mutation model. Genetic differentiation between populations was high, suggesting populations have been isolated over long time frames. Sequencing of chloroplast genes has been undertaken to provide inference on evolutionary history of the species and analysis is nearly complete.



***Conospermum undulatum*: insights into genetics and ecology of an endangered species**

STP 2017-028

Scientist(s): M Byrne

Student: N Delnevo (PhD)

Academic(s): Dr E van Etten (Edith Cowan University), Prof W Stock (Edith Cowan University)

Anthropogenic loss and fragmentation of natural habitats has been increasing during the last 60 years and is now at unprecedented levels, making land use change one of the most important drivers affecting biodiversity.

Conospermum undulatum is endemic to southwest Western Australia, a global biodiversity hotspot. Significant reductions in population size, connectivity, area and floral display of remnant patches are likely to constrain the reproduction of this species by altered plant-pollinator interactions and expression of inbreeding depression because of reduced gene flow between unrelated individuals. This project will investigate the reproductive biology and genetic diversity in the species to inform recovery actions to enhance the future persistence of *C. undulatum* by means of an improved understanding of factors that constrain both its reproduction and its adaptation ability over long-term.

Reproductive data on fruit and seed production, and seedling germination and mortality, was collected from 210 individuals in 12 populations. Fruit production was affected only by the population's floral display, i.e. its potential to attract pollinators, whereas seed production was significantly related to population size, connectivity and floral display. These results identified these three variables as those that best explain the reproductive trend of *C. undulatum*, and indicate that both pollen limitation and genetic factors prevent the development of the embryo. Quantification of the amount of pollen limitation showed that hand cross-pollination produced a ten-fold increase in seed production compared to natural pollination. Also, using pollen sourced from different populations showed that small populations are producing approximately 50% less seeds than they are able to produce via inter-population cross-breeding due to the combined effects of pollen limitation and reduction in compatible mate availability. These results suggest that habitat fragmentation may result in patches that are too small and isolated to be attractive for pollinators and to allow a long-term population viability based on reproduction by seed.



Vegetation responses to Noongar land management practices in old and young landscapes

STP 2016-001

Scientist(s): M Byrne

Student: A Lullfitz (PhD)

Academic(s): Prof S Hopper (The University of Western Australia)

This project aims to improve our understanding of the nexus between Noongar culture and contemporary floristic distributions, ultimately informing both biodiversity conservation in the South-West Australian Floristic Region (SWAFR) and connection of Noongar people with Country. Through collaborative research with southern coastal Noongar Elders and archaeologists, the project explores how specific cultural activities may have influenced biodiversity within the SWAFR through a series of investigations examining vegetation patterns and processes. Specific areas of focus include testing for evidence of Noongar plant resource concentration around cultural nodes and botanical differentiation between nodes of varying historic cultural use; phylogeographical investigation of culturally important taxa in the genus *Platysace*; investigations of resource concentration effects of edible *Platysace* tuber harvest; and an analysis of Noongar land use patterns in relation to landscape age and propensity to disturbance.

The phylogeographical work is testing the hypothesis that humans are a historical vector influencing the distribution of the staple Noongar food species, *P. deflexa* and *P. trachymenioides*. Leaf samples were collected and analysed from 49 populations of *P. deflexa*, *P. trachymenioides*, *P. effusa*, *P. compressa* and *P. juncea* located in inland areas southwest of a line from Northampton to the Cape Arid National Park. Noncoding chloroplast DNA regions, trnS-trnG52S, trnV-ndhc and psbD-trnT were examined in a total of 239 individuals, using a range of analytical tools. Genetic patterns in the species were different, supporting expectations based on aboriginal use. The pattern in *P. effusa* (which has no known cultural significance) showed a general pattern of high population divergence, low gene flow and multiple refugia, consistent with a long evolutionary history and past climatic oscillations and persistence in a highly fragmented landscape. In contrast, patterns in *P. deflexa* and the southeastern part of the range of *P. trachymenioides* showed higher gene flow estimates, less divergence between populations, and ancestral common haplotypes that are consistent with anthropogenic influences. A paper has been submitted for publication.



Mating systems, reproductive output and progeny fitness of translocated plant populations compared to wild populations

STP 2017-027

Scientist(s): M Byrne, C Yates

Student: R Dillon (PhD)

Academic(s): Prof M Waycott, Dr R Standish (The University of Western Australia)

Translocations are a key conservation recovery action for threatened plant species and determining their success is an important aspect of ongoing management. This project is investigating success of translocation in *Banksia brownii* and aims to: (1) compare the mating systems and genetic diversity of translocated populations with wild populations; (2) determine how reproductive output and progeny performance of translocated populations compares to wild populations; and (3) assess the efficacy of using measures of mating system parameters, genetic diversity and reproductive potential to better understand translocation success. The findings have a number of potential implications for not only assessing long term translocation success, but for also improving translocation design and establishment technologies.

Genotyping and initial mating system and genetic diversity analysis has been completed on one translocated *B. brownii* population and seven natural populations to benchmark mating system performance and genetic diversity in the translocated population. Pollination studies are near completion to assess pollination adequacy in the translocated population and suspected differences in pollinator type between montane and lowland populations. Fitness trait studies are ongoing in a common garden experiment involving 1,100 seedlings to assess the implications for population mixing, and the performance of the translocated population. Reproductive output measurements, seed and leaf material were collected from three natural and two translocated populations of *Acacia rhotinocarpa*, to benchmark genetic diversity and reproductive output in the translocated populations.



Factors affecting the success of threatened flora translocations

STP 2017-026

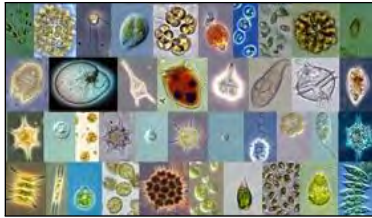
Scientist(s): M Byrne, C Yates

Student: L Monks (PhD)

Academic(s): Dr R Standish (The University of Western Australia)

Determining the factors influencing success of plant translocations is an important component of recovery programs. The aim of this study is to investigate factors affecting success of plant translocations, to inform future translocations and help prevent the extinction of plant species.

Data analysis has commenced for the meta-analysis of past plant translocations in Western Australia to provide an insight into factors that contributed to successful outcomes. Laboratory work is underway to assess genetic diversity and mating systems of translocated compared to the wild, source populations of *Lambertia orbifolia*. Preliminary analysis of monitoring data from translocated and wild populations of *Acacia cochlocarpa* subsp. *cochlocarpa* has commenced to inform the development of a Population Viability Analysis (PVA) model to determine the trajectory of translocated populations compared to wild populations. A glasshouse cross pollination study of *Schoenia filifolia* has been completed and follow up assessment of fitness traits is underway, to evaluate whether the genetic composition of the founder populations contributes to translocation success.



Phytoplankton in a microtidal temperate estuary: drivers, historical trends and future predictions

STP 2018-097

Scientist(s): J Cosgrove

Student: B Owen (PhD)

Academic(s): Dr NR Moheimani (Murdoch University), Dr F Valesini (Murdoch University), Dr CS Hallett (Murdoch University)

Understanding the historic conditions of the Swan-Canning Estuary is important to help predict future conditions and guide management activities. This project aims to identify spatial and temporal patterns in the phytoplankton community of the estuary and relate these to environmental drivers. Phytoplankton and a range of environmental variables have been monitored across the estuary since 1994; however, this long-term data set has not been extensively analysed. Multivariate analyses of the phytoplankton data and correlation with key hydrological and physico-chemical variables will facilitate the characterisation of current and past phytoplankton community patterns and their drivers across space and time.

Predictions for future phytoplankton dynamics will be made for the system, by applying historical relationships between phytoplankton and environmental drivers to modelled predicted hydrological and climatic trends. The data set for this project has been sourced and training in the use of e-Primer multivariate analysis software has been undertaken. Analysis of data has commenced.



Phylogeny, systematics and evolution of the Australian arid-zone *Ptilotus*

STP 2015-012

Scientist(s): R Davis

Student: T Hammer (PhD)

Academic(s): Prof L Mucina

Ptilotus is a genus of annual and perennial herbs and shrubs, common in arid and semi-arid areas of Australia. This project is addressing three key questions on the evolution of *Ptilotus*: (1) what key phylogenetic patterns in the genus can help explain its evolutionary success in arid Australia; (2) how do biogeography patterns in the genus relate to its evolution; and (3) how have *Ptilotus* species adapted to low soil phosphorus in Australia over evolutionary time.

A substantially resolved phylogeny for *Ptilotus* including a well-supported backbone has been derived from genomic data, along with an improved understanding of the phylogenetic position of the unusual Australian genera *Kellita* and *Omegandra*. The new genus *Wadithamnus*, an anomalous and phylogenetically disjunct species from the Arabian Peninsula previously included in *Aerva*, has been described. Species boundaries in the widespread Australian *P. exaltatus*-*P. nobilis* and *P. gaudichaudii* groups have been resolved and papers published. Several papers have been submitted for publication.



Thermal, physical and prey requirements for northern quoll denning habitat

STP 2019-062

Scientist(s): J Dunlop

Student: M Cowan (BSc Honours)

Academic(s): Dr D Nimmo (Charles Sturt University), Dr J Turner (Charles Sturt University)

The northern quoll (*Dasyurus hallucatus*) once extended across the northern third of the Australia, with a 75% reduction in distribution this century alone. The Pilbara bioregion of Western Australia has been identified as a last remaining stronghold for the northern quoll. However, the mesas and ranges that make up the preferred

habitat of Pilbara northern quolls are increasingly subject to destruction and large scale modification due to mining development. The creation of artificial habitat may be used to mitigate direct impacts on resident quoll populations. The primary aim of this study is to quantify characteristics of northern quoll natural denning habitat in order to understand necessary conditions to be replicated as part of future artificial habitat creation.

Results have indicated that female northern quolls prefer crevices that are cooler and deeper, most likely to avoid lethal temperatures and provide protection from predators. While artificial dens supply appropriate thermal properties, there are differences in physical structure, vegetation structure, and prey availability when compared to occupied dens. These differences must be addressed if artificial dens are to be a plausible mitigation strategy for northern quoll habitat loss. Draft manuscripts for publication are being prepared.



The influence of invasive predators and fire regimes on northern quolls in the Pilbara

STP 2017-045

Scientist(s): J Dunlop
 Student: H Moore (PhD)
 Academic(s): Dr D Nimmo (Charles Sturt University), Prof D Watson (Charles Sturt University), Dr L Valentine (The University of Western Australia)

The study aims to explore the hypothesis that northern quolls previously utilised a range of different habitat types in their movement and foraging activities in the Pilbara, but pressure from predators (feral cats, foxes and dingoes), in conjunction with other threats such as grazing and fire, have restricted their occurrence to the more protected rocky habitat.

The primary data collection phase is now complete, culminating in a total of 49,433 trap nights, 1,923 independent northern quoll detections and hundreds of feral predator detections. Northern quolls were detected at 69% of study landscapes. Detections were collected using camera traps orientated in either a horizontal or vertical direction, and a comparison of the efficacy of either orientation at detecting quolls along with other target species is currently in preparation for publication. Using vertically orientated cameras, over 100 northern quolls were identified based on unique spot patterning. By combining this data with detailed habitat assessments, the process of constructing comprehensive occupancy models that will provide crucial insight into the way in which quolls interact with both predators and their environment has commenced. Finally, 11 GPS collars have been deployed to elucidate the fine-scale spatial and temporal movements of northern quolls.



Predicting the vulnerability of flatback turtle rookeries to a changing climate

STP 2019-047

Scientist(s): S Fossette-Halot
 Student: M Gammon (PhD)
 Academic(s): A/Prof N Mitchell

The North West Shelf Flatback Turtle Conservation Program (NWSFTCP) is one of two additional conservation programs delivered from the Gorgon Gas Project via the Variation Agreement (2009) of the Barrow Island Act (2003). The program aims to increase the conservation and protection of the North West Shelf flatback turtle population. The NWSFTCP Strategic Conservation Plan has identified climate change as an important pressure on the North West Shelf flatback turtle population. Increasing temperatures are likely to lead to reduced hatching success, altered sex ratios and changes in spatial and temporal distribution of nesting and changes to foraging habitat.

The main aim of this project is to predict the vulnerability of flatback turtle rookeries on the North West Shelf to increasing sand temperatures, sea level rise and increased storm frequency. The project will provide critical information for the management of marine turtles and their rookeries and help fill a gap in the scientific literature regarding the impact of increasing temperatures on turtle eggs and hatchling survival. This could help assess

vulnerability and long-term conservation value of different nesting sites and determine if there is need for human intervention.



Foraging ecology and energetics of green turtles in the Ningaloo coast world heritage area

STP 2017-050

Scientist(s): S Fossette-Halot

Student: J Stubbs (PhD)

Academic(s): Dr M Vanderklift (The University of Western Australia),
A/Prof N Mitchell

This project is part of the Ningaloo Outlook CSIRO-BHP research partnership and is investigating green turtle foraging ecology and energetics. This outcome will be achieved by: (1) investigating the diet and variation in diet between size/age classes using stable isotope analysis; (2) describe the movement of foraging and nesting green turtles using satellite tags; and (3) use dynamic energy budget (DEB) modelling to investigate allocation to growth and reproduction throughout the lifecycle.

A field trip was undertaken to recapture turtles and increase sample size for amino acid stable isotope analysis. Processing samples for amino acid stable isotope analysis is now finished, isotope data are being analysed and DEB model simulations are being run.



A cost benefit analysis for the collection of reef fish density data with a micro remote operated vehicle versus SCUBA divers.

STP 2019-043

Scientist(s): J Goetze

Student: LH Hellmrich (BSc Honours)

Academic(s): Prof E Harvey (Curtin University)

The most common method for sampling shallow water reef fish populations is Underwater Visual Census (UVC), where a SCUBA diver or snorkeler collects information on the abundance, composition and length of fishes within a known sample unit. One of the major limitations with UVC techniques is inter-observer variability and a lack of accuracy and precision with length and distance estimates. Underwater stereo-video operated by a SCUBA diver (stereo-DOVs) were developed to overcome these challenges. While stereo-DOVs overcome some of the biases associated with UVC, they still rely on a SCUBA diver to operate them. In Australia, occupational health and safety guidelines mean that SCUBA divers rarely operate deeper than 20 metres, leaving a vast proportion of the ocean off limit. Due to the safety concerns of these approaches, there has been a focus on the development of fishery independent sampling techniques that do not rely on SCUBA divers. One alternative is Remote Operated Vehicles (ROVs), which can operate for extended periods of time and at depths of up to 2,500 m or greater. In recent years micro ROVs have become increasingly available and have decreased dramatically in price making them an affordable sampling tool. By equipping a micro ROV with a lightweight stereo-video system, it is now possible to survey fish assemblages using UVC sampling theories. This project aims to compare the data collected from micro ROVs equipped with a stereo video system to those collected by a SCUBA diver as well as compare and contrast cost efficiencies of each method for monitoring finfish.

ROV and stereo-DOV surveys have been completed inside and outside of the Maud Sanctuary Zone in the Ningaloo Marine Park. These videos are currently being annotated to provide information on the abundance, length and behaviour of finfish.



Integrated study of shallow and deep-sea fish communities status and their main stressors in a highly dynamic Galapagos seascape

STP 2019-042

Scientist(s): J Goetze
 Student: ER Rastion (PhD)
 Academic(s): Prof E Harvey (Curtin University)

In 2016, the Galapagos National Park authorities increased the surface area of full no-take areas in the Galapagos Marine Reserves from 0.8% to 33%. However, no specific measures (e.g. seasonal closure, maximum or minimum size limit, quotas) have been implemented to mitigate the downward trends observed in fisheries targeted species outside of the reserve. As a consequence, new fish resources are being sort in deeper waters. The project aims to assess the effect of the Galapagos Marine Reserve, changes in fisher effort and environment on fish assemblages in the Galapagos. The results of conservation approaches in the Galapagos can be compared and contrasted to Western Australia to inform and potentially improve on the monitoring and conservation of marine fishes in both locations.

All data has been collected and is currently being analysed. A manuscript examining the ability of diver operated stereo-video (stereo-DOVs) to characterise reef fish spawning aggregations, has been submitted for publication in *Estuarine, Coastal and Shelf Science*. Stereo-DOVs are the primary method used to monitor finfish in Western Australia's' Marine Parks and this study shows that diver operated stereo-video system produce accurate measures of fish length, density and reproductive behaviours, providing an easily repeatable and non-destructive tool for the monitoring of spawning events.



A comparison of stereo-BRUV, diver operated and remote stereo-video transects for assessing reef fish assemblage

STP 2019-041

Scientist(s): J Goetze
 Student: KS Schramm (MSc)
 Academic(s): Prof E Harvey (Curtin University)

Monitoring programs that aim to measure the diversity, abundance and biomass of fishes depend on accurate and reliable biological data to guide the development and implementation of robust management plans. It is important to implement an appropriate sampling technique that provides a comprehensive assessment, while reducing associated biases in the data collection process. Ongoing advancements in technology can provide new opportunities for collecting fish assemblage data, overcoming limitations and biases of more traditional approaches. This project aims to compare the sampling abilities of four different, underwater stereo-video methods, two of which are relatively new methodologies (slow-towed stereo-video (STV) and remotely operated vehicle (ROV) fitted with a stereo-video), in a temperate reef system within Geographe Bay. This information can be used to inform monitoring and research programs on which methods are most effective for sampling fishes of varying life histories.

Surveying fish within temperate systems suggests that assemblages from ROV, DOV and tow techniques are comparable, but BRUVs better represent predatory species often targeted by fishers. Analysis of a similar methodological comparison in tropical Western Australia waters is underway.



Cyclone impact or natural variation? Assessment of damage on coral and fish in Kubulau District, Fiji by cyclone Winston

STP 2019-040

Scientist(s): J Goetze

Student: B Price (MSc)

Academic(s): Prof E Harvey (Curtin University)

Cyclones are a prominent feature force along the coast of northern Australia that can have a strong influence on coral reef communities. With a changing climate it is predicted that cyclones will increase in severity, increasing degradation to coral reefs, and compromising the services they provide to coastal communities. In 2016, Fiji was impacted by category 5 tropical cyclone Winston, which at the time was the most severe cyclone recorded in the southern hemisphere. Ongoing monitoring using diver operated stereo-video, enabled the assessment of cyclone impacts on both coral reef habitat and fish assemblages, which will provide insights into the relationships between habitat and fish on reefs. This type of information that can be used to inform recovery and sustainable management of habitat and fish stocks after a severe cyclone. Socioeconomic data was also collected, facilitating an assessment of how cyclones impact on coastal communities and how this relates to changes in ecosystem services post-cyclone.

Survey work has been completed to describe the impacts of cyclone Winston on habitat and fish populations in Fiji. Data on the socio-economic impacts of cyclone Winston and how this relates to the ecological changes is being collected.



Conservation of elasmobranchs - ecology, public perception, and legal protections

STP 2019-039

Scientist(s): J Goetze

Student: MC Márquez (PhD)

Academic(s): Prof E Harvey (Curtin University)

The life history traits of many shark species, including large body size, slow growth, late maturity, and low fecundity, makes them particularly vulnerable to over-fishing and other anthropogenic threats. Thirty-one percent of the world's sharks and rays are threatened with extinction and declines have led to an increased need for conservation and sustainable management. Little is known of essential habitats of sharks and why sharks choose one habitat over another as a nursery ground. Sharks are often depicted poorly and the public opinion and attitude towards them can significantly affect the implementation and success of conservation initiatives. However, sharks play important ecological and socioeconomic roles and the consequences of population declines are not well studied. This research will identify nursery habitats and compare cultural beliefs and public attitudes towards sharks in areas where sharks are depleted (e.g. Bangladesh) to areas where they are relatively healthy (e.g. Australia). To understand the drivers of peoples perceptions of sharks, socioeconomic surveys will be implemented across a broad range of stakeholders in these regions. This information will be used to develop educational strategies aimed at improving the conservation of sharks.

Work has commenced on identifying the approach to determine ecological factors in shark populations in a number of Marine Parks, particularly their habitat use, socioeconomic standings in regards to human behaviour, and how these aspects influences conservation efforts.



Persistence of tropical herbivorous fish in temperate ecosystems and its impact on habitat-forming macrophytes

STP 2018-020

Scientist(s): T Holmes

Student: S Zarco (PhD)

Academic(s): Dr T Wernberg (The University of Western Australia), Dr T Langlois (The University of Western Australia)

This project aims to examine the impact that range expanding tropical herbivorous fish can have on temperate ecosystems by analysing the variability of their abundances, recruitment and consumption rates at different spatial and temporal scales in south-western Australia. The research will answer fundamental questions about the longer term persistence, and the present and future potential impacts, of the most common tropical herbivorous fish group extending into high-latitude ecosystems around the world (family Siganidae), on temperate marine ecosystems in Western Australia.

Field work in the Perth metropolitan region has been completed and data is being analysed. Data has shown that overwintering tropical herbivores accelerate the detritus production of temperate reefs. While not currently considered to be a sustaining population, tropical siganids continue to be present in the region following the 2011 heatwave event. A manuscript is in preparation.



Conservation genetics of the critically endangered *Styphelia longissima*

STP 2019-005

Scientist(s): S Krauss

Student: W Thomas (BSc Honours)

Academic(s): Dr P Grierson (The University of Western Australia)

Styphelia longissima (Ericaceae) is a critically endangered shrub located north of Perth near Eneabba and is represented by a single small and isolated population. Levels of genetic variation and its spatial structure, mating system parameters and patterns of pollen dispersal in *S. longissima* were examined. A survey of the population was undertaken with 221 of 947 adults, and 106 seeds collected from 14 maternal plants, genotyped using 14 microsatellite markers. The resulting genetic data were used to obtain measures of genetic diversity, generate mating system parameters and assign paternity.

Results of the project have shown that allelic richness and levels of expected heterozygosity were higher than predicted and reflect high levels of genetic diversity in *S. longissima*. Outcrossing rate was moderate at 66%, and extensive inbreeding was found, in both selfing and bi-parental inbreeding. Restricted pollen dispersal was evident, with 95% of matings occurring over a distance of 7 m or less and a mean pollen dispersal distance of 3.65 m.



Optimising seed sourcing for effective ecological restoration

STP 2019-004

Scientist(s): S Krauss, D Merritt

Student: S Adhikari (PhD)

Academic(s): Dr E Veneklaas (The University of Western Australia)

Successful ecological restoration hinges greatly on sourcing germplasm from appropriate provenances. Local seeds are conventionally used, but rapidly shifting selection pressures under climate change has prompted the demand to enhance climate resilience in seed sources – so called ‘climate-adjusted provenancing’. To assess

the merit of this strategy, the variation in climate responses of *Stylidium hispidum* sourced from climatic extremes at the north and south of its distribution was tested via germination and early growth experiments under varied temperature and moisture regimes.

The results of the project have shown that northern provenance seeds displayed some traits that are potentially climate adaptive and suggest higher resilience to hotter and drier conditions, although not all measured traits exhibited a northern provenance advantage.



A genealogical assessment of seed sourcing strategies for plant community restoration under environmental change.

STP 2019-003

Scientist(s): S Krauss, J Stevens

Student: B Mirfakhraei (The University of Western Australia)

Academic(s): (PhD)

Dr E Veneklaas (The University of Western Australia)

This research aims to provide a comprehensive test of the influence of climatic and edaphic variation on the performance of genotypes from multiple provenances, to identify best-practice seed sourcing for restoration. Although many strategies for seed sourcing have been proposed, there are few empirical tests of different strategies. In this project, multiple genetic provenances of *Banksia menziesii*, a restoration priority plant species on the Swan Coastal Plain, will be tested in post-mining rehabilitation field sites, as well as glasshouse growth trials where environmental parameters will be modified. In addition, physical, chemical and biological properties of soils from these multiple source sites will be assessed and compared to the performance of seeds sourced from these sites.

Field trials have been completed and preliminary results show no significant provenance effect on seedling survival based on pairwise comparisons. However, in three out of four field trials, seedling survival of local provenances was above the overall average after six months. Further analysis of the glasshouse experiment is in progress. The soil microbiome and chemical data are being analysed and preliminary results illustrate a significant correlation between soil chemical structure and soil microbiome community in some of the soil samples.



Novel consequences of bird pollination in the kangaroo paw *Anigozanthos manglesii*

STP 2019-002

Scientist(s): S Krauss

Student: B Ayre (PhD)

Academic(s): Prof S Hopper (The University of Western Australia)

Pollinator services underpin the function and sustainability of most terrestrial ecosystems. Optimal foraging theory predicts that the majority of pollen dispersed by animals will be among the nearest neighbours. However, pollen carryover, and differences in the movement behaviour between vertebrates and invertebrate pollinators, will affect paternity in natural plant populations. The South West Australian Floristic Region has the highest incidence of vertebrate pollination worldwide. Recent studies suggest that almost near random mating may occur in populations of plants pollinated by highly mobile nectar feeding bird species. This research project aims to address the consequences of bird pollination on mating, spatial genetic structure, and fitness in kangaroo paws (*Anigozanthos manglesii*).

A combination of pollinator observations, exclusion experiments and molecular analysis for paternity assignment have been used to track pollinator behaviour and pollen dispersal within populations of *Anigozanthos manglesii*. Controlled hand pollinations showed that selfing and nearest neighbour mating, results in severe inbreeding depression and there is a decline in reproductive success with increasing mate distance. These results suggest an optimal outcrossing distance among near (but not nearest) neighbours in natural populations.

Paternal diversity and pollen dispersal following bird-pollination is 10x greater than that following pollination by insects. Introduced honeybees are frequent visitors to flowers but ineffective pollinators, and therefore native nectar-feeding birds (honeyeaters) are critical for effective pollination of *A. manglesii*.



Evolution and conservation consequences of bird pollination: an ecological and genetic study of mating, pollen dispersal and recruitment in *Eucalyptus caesia*

STP 2019-001

Scientist(s): S Krauss

Student: N Bezemer (PhD)

Academic(s): Prof S Hopper (The University of Western Australia)

Compared to other regions around the globe, the South West Australian Floristic Region has an exceptionally high incidence of plant species that are predominantly pollinated by vertebrates, with approximately 2,000 species pollinated by birds. The behaviour of these birds suggests unique genetic consequences for the plants they pollinate. A combination of genetic techniques and field experiments with *Eucalyptus caesia* were used to examine three critical issues in pollination ecology and reproductive biology: (1) the relative contribution of native and introduced animals to pollen dispersal in plants adapted for bird pollination; (2) whether genetic factors such as heterozygosity and sibling relatedness influence seedling fitness; and (3) the consequences of bird pollination in range-wide genetic diversity.

A comprehensive population genetic analysis of all known plants in all known populations with 14 microsatellite markers demonstrated low genetic diversity, extensive clonality and strong population genetic differentiation. Assessment of a rare natural recruitment event showed no evidence for inbreeding depression. A weak association between geographic distance and genetic distance indicated a randomness to historical dispersal at a landscape scale. A common garden trial showed no association between seedling mortality and vigour with individual heterozygosity across multiple substrates. These results suggest that purging of genetic load as well as individual longevity explains the persistence of woody perennial plants endemic to granite outcrops, despite historically small population sizes. Pollinator exclusion experiments showed that bird-pollination increases paternal diversity above that of insect pollination in some populations, suggesting that insects may be effective pollinators in some populations but ineffective in others. Collectively, these results show that conservation of old individual trees and small populations is integral to conserve the genetic diversity of historically fragmented woody perennials.



Resource competition between co-existing threatened mammals in a predator-free enclosure in central Western Australia

STP 2019-035

Scientist(s): C Lohr

Student: S Treloar (MSc)

Academic(s): Dr R Davis (Edith Cowan University), Dr A Hopkins (Edith Cowan University)

An understanding of resource requirements and inter-specific competition is essential when undertaking reintroductions, especially in fenced environments where dispersal and access to resources are limited. The burrowing bettong (*Bettongia lesueur*), or boodie, and the rufous hare-wallaby (*Lagorchestes hirsutus*), or mala, are both extinct in the wild on the Australian mainland and only occur on a few offshore predator-free islands and in several predator-free enclosures across Australia. Both species were reintroduced to an enclosure on the Matuwa Indigenous Protected Area in Western Australia. Little is known about the ability of these species to co-exist in a fenced environment and how they partition resources.

Camera traps have been established near browsed vegetation to monitor competitive behaviour between the two species. Scat samples (50 boodie, 50 mala) from inside the enclosure were collected and the foraging distribution has been plotted for each species. Further scat collection during the dry season will be undertaken

for comparison. Extraction of DNA from the collected scat samples for the dietary analysis, and comparison of the two species is currently underway.



Reintroduced digging mammals and ecosystem restoration

STP 2018-082

Scientist(s): C Lohr
 Student: B Palmer (PhD)
 Academic(s): Dr L Valentine (The University of Western Australia), Prof R Hobbs (The University of Western Australia)

This project aims to explore the roles of digging mammals in ecosystem restoration by investigating: (1) how boodie warrens alter soils and vegetation communities; (2) whether the presence of digging mammals alters soils and vegetation communities at landscape scales; and (3) whether digging mammals disperse seeds in their scats. Field work for this project is being conducted in and around the predator-free enclosure on the Matuwa Indigenous Protected Area, and several other locations managed by other organisations.

The soil and vegetation surveys of relic and newly-constructed boodie warrens and foraging grounds inside and outside the fenced area have been completed. Scats have been collected from boodie (*Bettongia lesueur*) and golden bandicoot (*Isodon auratus*) and are being processed.



Optimising collaboration between secondary schools and informal science advisers: a stakeholder alignment perspective.

STP 2018-126

Scientist(s): P Mawson
 Student: S Bickford (PhD)
 Academic(s): Prof N Longnecker (The University of Western Australia)

Perth Zoo provides educational experiences that link to the school curriculum and can facilitate a connection between students and nature. This project will compare the goals, expectations and practices of teachers, informal educators and students participating in excursions in order to identify common areas of alignment and areas for improvement. Case studies will include excursions to Perth Zoo and Perth Hills Discovery Centre. This knowledge will be used to strengthen collaboration for the benefit of informal science institutions, schools and students.

A conceptual framework of alignment to examine how the goals and practices of teachers and informal educators relate to each other and to student learning from excursions and incursions has been developed. A mixed-methods approach was utilised including a quantitative survey of science teachers throughout WA and three qualitative case studies of excursion and incursion activities. A manuscript is currently in preparation.



The effect of diet on the growth and reproduction of western swamp tortoise at Perth Zoo

STP 2018-124

Scientist(s): P Mawson
 Student: G Wilkinson (MSc)
 Academic(s): Prof P Horwitz (Edith Cowan University)

The western swamp tortoise (*Pseudemydura umbrina*) is a threatened species listed as Critically Endangered. The species occurs in only two natural populations at very low numbers. Establishing new populations entirely with wild caught tortoises is not feasible and captive breeding provides a source of animals for supplementation

of wild populations and establishment of new populations. Following a review of the diet of the captive-breeding colony of western swamp tortoises, a second manufactured diet based on white-fleshed fish was developed to address concerns about low levels of omega-3 fatty acids in the 'traditional' red meat diet. For four years approximately half the tortoises in the colony have been maintained on the original red-meat based diet and half on the white-fleshed fish diet. The project will determine whether there are any significant differences between the diets in hatchling and juvenile growth rates, weight loss associated with aestivation and female reproductive output (as determined by clutch size, egg mass and hatchling mass).

Data collation and vetting has been completed and data analysis has commenced. Chemical analysis of the two diet formats has been undertaken through the ChemCentre and another external provider for the analyses of vitamin content of the two diets. Preliminary results indicate that there is no significant difference in the growth rate of adult tortoises on the two diets. Similarly, there is no significant difference in each of the year cohorts, hatchling (age 0) to age 4, between the two diets. Analyses of the effect of diet on reproductive performance of the breeding females is yet to occur.



Optimising energy provision at Perth Zoo via a renewable energy micro-grid.

STP 2018-123

Scientist(s): P Mawson

Student: D Catto (MSc)

Academic(s): Prof C Lund (Curtin University)

As the effects of climate change continue to compile, and electricity prices increase, the technical and economic feasibility of integrating renewable energy technology is becoming a key focus in the energy industry. This project examines the current provision and current and predicted future consumption of electricity by Perth Zoo, and explores the current and future opportunities for increasing the renewable energy penetration within the site via the implementation of a microgrid. This is of particular interest to management and planning staff at Perth Zoo as it provides an insight into the technology that may be able to exploit the current renewable energy resources on site and examine the price points at which these technologies may become feasible. As more companies begin to adopt microgrid technologies the review of their performance and potential lessons learned will help future decisions regarding scale, configuration and installation.

The project began with the examination of previous energy audits, reviewing their accuracy to current electricity consumption. The site was then examined for potential renewable energy technologies such as wind, solar photovoltaics and energy storage systems based on the technical requirements of each system. Once this assessment was completed, each feasible system was then modelled using HOMER Pro to investigate its feasibility. It was found that in order for Perth Zoo to implement a renewable energy microgrid capable of eliminating its reliance on the electrical grid completely, the capital investment prices for solar photovoltaics and energy storage would need to decline by 90-95%; however, smaller systems become economically viable at much more modest reductions. Considering a decrease in capital investment costs of 30% for photovoltaic modules and 60% for energy storage systems, several system configurations were found to have payback periods of less than seven years. These results lead to the conclusion that whilst further expanding the current photovoltaic array at Perth Zoo may not be economically feasible, with current predictions in technology prices there will be several systems that can assist in reducing Perth Zoo's reliance on fossil fuels for energy provision.



Social dynamics in a tufted capuchin group following the introduction of a novel male

STP 2018-122

Scientist(s): P Mawson

Student: M Bourrouosman, S Jeffries (3rd year)

Academic(s): Dr G Newland (Curtin University)

The tufted capuchin (*Sapagus apella*) is a new world monkey native to the Amazon rainforest ranging inland from the north-eastern coast of South America, across to eastern Columbia. Perth Zoo houses five tufted capuchins, one of whom, a mature male, was introduced approximately twelve months ago, to provide a mate for a female who had started undergoing oestrus. This resulted in a successful pregnancy. The aim of the project was firstly to record the behaviour profiles and interactions of each animal, to determine whether the male had been integrated into the resident troop or not. The secondary aim was to evaluate the adequacy of the captive environment.

The project involved filming the monkeys individually by two observers over six weeks, which was then edited into an hour of footage per individual, containing the most representative of their activities. Overall, the results revealed a pattern of behaviour very similar to that obtained from studies in the wild and captivity, with most time devoted to movement, foraging, feeding and resting, though reduced a little, as is typical of captive studies. There were very low levels of inter-animal aggression. There was very little or no interaction and social exchange between the introduced male and the resident colony, apart from an exchange of aggression displayed on one occasion from the female. There was also very little social contact between the mated animals, in contrast to that shown by the resident dominant pair. We conclude that the introduced male is still a separate entity within the enclosure, and his general behaviours are different in many respects from those shown by the others capuchins.



Evaluation of the welfare and reproductive biology of captive tigers using non-invasive conservation physiology techniques

STP 2018-117

Scientist(s): P Mawson

Student: J Scherpenhuizen (PhD)

Academic(s): Dr R Friere (Charles Sturt University)

Sumatran tigers (*Panthera tigris sumatraeare*) are a threatened species listed by the IUCN as Critically Endangered. Perth Zoo, along with all major zoos in Australia, are involved in a regional breeding program for Sumatran tigers. This project will develop and refine non-invasive assessment methods of tiger welfare and determine their effectiveness. Behavioural observations and analysis of faecal samples will be used to determine cortisol and sex hormone (testosterone, oestradiol and progesterone) levels. Behavioural observations are underway and tiger faecal samples have been collected.

Faecal samples collected from the two Perth Zoo tigers have been transferred to Charles Sturt University for analyses. Most of the samples sourced from other zoological institutions have already been processed and assays to measure hormones in the processed samples are currently being conducted. Behavioural data collection and entry for the main behavioural study has been completed and is being analysed.



Monitoring the behaviour of ghost bats before, during and after the reproductive season

STP 2018-116

Scientist(s): P Mawson
 Student: A Smith (MSc)
 Academic(s): Dr B Jackson (Murdoch University)

This observational study aims to assess the behaviour and welfare of six groups of ghost bats (*Macroderma gigas*) across the breeding and post-breeding seasons within a zoo environment. Although no national recovery plan has been established, data collected on breeding behaviour for this Vulnerable species will aid in future conservation efforts aimed towards recovery plans and captive breeding programs.

Scan sampling was used to record behavioural states and interactions along with spatial preferences within enclosures over approximately 198 hours of observations. Analysis of social behavioural interactions across the breeding and post-breeding seasons showed 40.2% were negative, while 59.8% were positive/neutral. Negative interactions were shown to decrease for both the bachelor group and non-breeding female group during the post-breeding season, whilst a slight increase was documented in the breeding female group. Enclosure size was found to have a significant ($p < 0.001$) positive correlation with observed exploratory behaviours. Temperature further affected ghost bat behaviour. When the daily recorded maximum temperature was greater than or equal to 19°C the frequency of flight events significantly increased, whilst hanging and huddling behaviours significantly decreased ($p < 0.001$). On days where the temperature dropped to below 19°C, flying significantly decreased and huddling was shown to significantly increase ($p < 0.001$). Mating was not observed on days when the recorded daily maximum temperature was below 22°C. The findings of the study help identify areas for improvement in captive management practice, along with providing insight into the behaviours and interactions of ghost bats across the breeding and post-breeding seasons.



Hindlimb paralysis syndrome in Carnaby's cockatoos

STP 2018-113

Scientist(s): P Mawson
 Student: F Coiacetto (PhD)
 Academic(s): A/Prof K Warren (Murdoch University)

This study aims to characterise and investigate the cause of Cockatoo Hindlimb Paralysis Syndrome (CHiPS) in Western Australian black cockatoos. To date, only Carnaby's cockatoos (*Calyptorhynchus latirostris*) have been consistently affected since 2012, with one possible case in a Forest red-tailed black cockatoo (*Calyptorhynchus banksii naso*). Gross and histopathologic necropsy examinations have been performed on 17 CHiPS cases and 14 control cases. No significant changes pertinent to the cause of the neurologic disease have been found.

Alterations in brain Neuropathy Target Esterase (NTE) have been investigated in the 17 CHiPS and 14 control cases. A significant difference between CHiPS and control cases has been demonstrated and thus this will be expanded. Thus far, three of the 17 CHiPS cases have had undetectable brain NTE levels and, whilst a reference interval is currently being produced, this will fall within the category of significant inhibition. By contrast, no histopathological findings are consistently reported in cases of regular organophosphate toxicity, when >20% inhibition of Acetyl cholinesterase (AChE) alone causes clinical signs. AChE assays have been performed on the brain of 17 CHiPS and 14 control birds. There was no significant difference between CHiPS and control birds and levels were within the limits of a published reference interval for AChE in Carnaby's cockatoos. Additional testing will involve the inclusion of more CHiPS cases as they are submitted through Perth Zoo to increase the statistical power of the study. The ability to detect paraoxonase in the serum of Carnaby's cockatoos has been investigated in 31 birds and has proven successful. This will now be expanded to include at least 40 control animals.



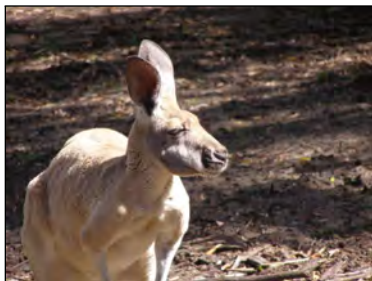
The effect of incubation temperature on development rates of *Geocrinia alba* and *G. vitellina* frog embryos

STP 2018-110

Scientist(s): P Mawson
 Student: E Hoffmann (PhD)
 Academic(s): A/Prof N Mitchell

Geocrinia alba and *G. vitellina* have a restricted distribution and are listed as Critically Endangered and Vulnerable. These frogs lay large clutches of eggs; however, the survival rate to adult frogs is low. Captive rearing of eggs to metamorphs is an effective means of providing supplementation of animals into the populations. Eggs clutches of both species are collected from the wild and metamorphs are raised and subsequently released. This project is part of the ongoing research and husbandry management to achieve regular and reliable captive breeding in both species.

To quantify the effect of temperature on development rates of *G. vitellina* embryos, incubation of seven *G. vitellina* clutches were split across three temperature treatments (constant 20 °C, constant 24.5 °C, and a fluctuating 24.5 ± 5 °C) chosen based on available field temperature data and expert consultation. However, the two warmer treatments resulted in unexpected abnormality and mortality of 36 embryos after 5 days so the treatment temperatures were reduced to constant 19.5 °C, constant 20.5 °C, and fluctuating 20.5 ± 2 °C, and the remaining healthy embryos successfully developed to metamorphosis. Results show that some juveniles exposed to the initial warmer temperatures are gaining weight more slowly than those that were exposed to the lower temperature. From the data obtained during the experiment, a non-linear development rate function for *G. vitellina* has been developed, but empirical development rate data collected across a wider span of incubation temperatures are needed to confirm the shape of the function and to better estimate peak development rates. Juvenile frogs from the seven clutches of *G. vitellina* that were the subject to the initial incubator temperature trial have had their second round of weighing and tank changes at approximately 18 weeks post-metamorphosis. The *G. vitellina* juveniles incubated at the two higher temperature treatments continue to develop at a slower rate (190% and 200% increase post-metamorphosis) than those incubated at the lower temperatures (307% increase).



Epidemiology of the clinical syndrome 'lumpy jaw' in captive macropods: influence of housing and husbandry

STP 2018-107

Scientist(s): P Mawson
 Student: J Rendle (PhD)
 Academic(s): A/Prof K Warren (Murdoch University)

Lumpy jaw is a well-recognised cause of morbidity and mortality in captive macropods (Macropodidae) worldwide. The extent and causes of the disease are largely unknown, although multiple risk factors associated with a captive environment are thought to contribute to the development of clinical disease. Identification of risk factors associated with lumpy jaw would assist with the development of preventive management strategies, potentially reducing mortalities.

A cross-sectional study was undertaken from 2011 to 2015, to determine prevalence and risk factors for this disease through the distribution of a survey to 527 institutions across Australia and Europe; two regions where macropods are popular exhibits. The data were analysed in a retrospective cohort study to examine risk factors for developing the disease and treatments used, and computed tomography was used to examine disease occurrence in wild macropods using skulls from population management culls. The prevalence of lumpy jaw was found to differ between the two regions. A review of 6,178 records for 2,759 macropods housed within eight zoos across, Australia and Europe, found incidence rates and risk of infection differed between geographic regions and individual institutions. Risk of developing lumpy jaw increased with age, particularly for macropods >10 years. Treatment approach varied and prognosis was typically poor with 62.5% mortality for Australian and European regions combined. Lumpy jaw was detected in all captive genera examined, but was absent from the

wild populations studied. Geographic region influenced the incidence of lumpy jaw, the risks associated with developing clinical disease, and preferred treatment approach and may assist institutions in providing optimal long-term health management for captive macropods.



Disease risk analysis in support of the translocation of dibblers from the Jurien Bay Islands to Dirk Hartog Island National Park

STP 2018-106

Scientist(s): P Mawson

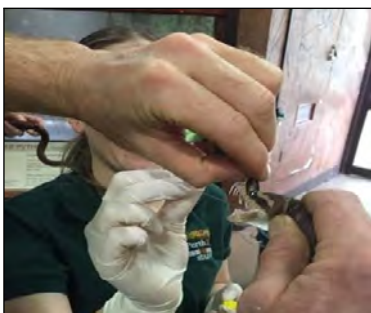
Student: P Moore (MSc)

Academic(s): Dr J McLelland (Murdoch University)

Dibblers (*Parantechinus apicalis*) are ranked as Endangered and have a limited area of occupancy in the south-west and on islands off the midwest coast of Western Australia. Establishing new populations entirely with wild caught dibblers is not feasible and captive breeding provides a source of animals for supplementation of wild populations and establishment of new populations. Dibblers are one of the species intended for reintroduction to Dirk Hartog Island following cat and goat eradication, and this will be achieved through captive breeding of animals sourced from the midwest islands.

The project aims to: (1) produce a literature review of the Dasyuridae family with a specific focus on dibblers; (2) identify known hazards associated with the dabbler translocation and undertake a risk assessment; (3) investigate how commensal or potentially pathogenic parasites can be conserved through modification of therapeutic regimes to ensure native parasites are maintained in the reintroduced population; (4) consider disease risk management options and advise on future screening protocols for dabbler translocations; (5) supplement existing knowledge by collecting samples from wild caught animals for the captive breeding program for disease screening; and (6) present a summary of findings and the implications for managing future dabbler translocations.

A Disease Risk Analysis (DRA) has been produced to facilitate the success of the translocation and inform on any potential hazards and make recommendations to accommodate these hazards. A list of infectious and non-infectious hazards were identified of which two hazards were investigated further, these being gastrointestinal parasites and trypanosomes. The majority of the animals for captive breeding were assessed to be in good health and body condition. Previously recorded gastrointestinal parasites (strongyles and *Coccidia*) were recorded in the island populations along with a potential new finding of *Klossiella*; however, further investigation is required to confirm this. *Demodex* mites are present in populations on the Jurien Bay islands and are causing pathological disease in the form of demodectomas. There was no evidence of infection with *Trypanosoma* spp.; however, it is possible this pathogen is present at levels below detection limits. Further sampling over a longer temporal span of the populations is required to confirm presence/absence. The DRA has identified a number of knowledge gaps in baseline health and disease in wild dabbler populations. Whilst there is an extensive list of parasites and diseases for Dasyuridae in general, the known parasite list of dibblers is extremely low, and this study has identified priorities for further studies.



The prevalence of arenavirus, bornavirus, nidovirus/coronavirus, sunshinevirus and ferlavivirus in captive and wild populations of Stimson pythons, pygmy pythons and carpet pythons

STP 2018-105

Scientist(s): P Mawson

Student: K Wood (PhD)

Academic(s): Dr T Hyndman (Murdoch University), A/Prof K Warren (Murdoch University), Dr S Vitali (Murdoch University)

The field of reptile virology is continually evolving with the discovery of novel reptile viruses; however, the importance and implications of these viruses are yet to be determined and the prevalence in both captive and wild populations is unknown. This project will investigate the prevalence of arenavirus, bornavirus, nidovirus/coro-

navirus, sunshinevirus and ferlavirus in both captive and wild populations of snakes. Three populations will be examined including Perth Zoo captive pythons, confiscated pythons (obtained by the department) and wild free ranging python species. The project aims to incorporate and build on data obtained from individuals housed at Perth Zoo, and samples from the wild to investigate whether these viruses are present in the wild population.

All samples collected have been tested for mycoplasma and most have been tested for nidovirus. The bornavirus PCR has required some troubleshooting so this testing has not yet been completed in its entirety, and the sunshinevirus PCR is also still pending. A retrospective analysis of the snakes that have been tested historically in the Perth Zoo collection has been completed.



Predicting effects of climate change and thinning on growth, health and water yield of jarrah and karri stands using individual-based modelling

STP 2018-081

Scientist(s): R Mazanec

Student: K Bhandari (PhD)

Academic(s): Dr E Veneklaas (The University of Western Australia), Dr M Renton (The University of Western Australia)

The jarrah (*Eucalyptus marginata*) and karri (*Eucalyptus diversicolor*) forests of south-west Western Australia are important sources of timber, wildlife habitat and water. However, as climate changes, issues of forest productivity, tree health and mortality, and water yield need to be addressed. Individual-based modelling (IBM) is an ecological modelling approach that represents individuals within populations or communities, and the interactions between them, with a relatively high level of detail and complexity. This study aims to develop an IBM of tree growth in water limited environments, to parameterise the model for jarrah and karri and to predict the impact of tree thinning on timber production, tree health and mortality and water yield using time series data collected from 1965 and 1992, respectively.

Supplementary data for jarrah and karri stand dynamics were collected and the effect of thinning and fertilizer on allometry and growth of jarrah and karri were analysed. Thinning had a positive impact on growth of both species. Fertilizer also had positive impact on growth of jarrah. The most intense thinning resulted in 538% and 149% more growth on individual trees compared with unthinned treatments in jarrah and karri respectively. Stand volume growth of jarrah increased with increasing stand volume at low stand density, reached a peak and declined at higher levels of residual stand volume. Karri followed a similar pattern of stand basal area growth. Thinning had a significant effect on allometry of stem diameter with height, ratio of height and diameter, crown width and bark thickness. A linear IBM for diameter growth prediction has been developed for jarrah that predicts stem diameter growth based on initial diameter, initial height, size and distance of the nearest neighbours using competition indices. Similar IBM for growth prediction of karri will be developed. Effects of thinning on timber and water yield will then be simulated for the full rotation age of jarrah and karri using these models.



The impacts of severe wildfire on the interactions among regenerating vegetation, fungi and small foraging marsupials in south-west Australia

STP 2016-016

Scientist(s): L Mccaw

Student: H Etchells (PhD)

Academic(s): Dr P Grierson (The University of Western Australia), Dr A O'Donnell (The University of Western Australia)

This project seeks to enhance understanding of the ecological response of a variety of vegetation types to bushfire, focusing on the large O'Sullivan fire of February 2015. The study is examining the response of vegetation and fungal community composition to different levels of fire severity across four vegetation types (tall open eucalypt forest, open eucalypt forest, *Melaleuca/Allocasuarina* forest, *Banksia/sedge* heathland).

Fire severity has been determined from remotely sensed imagery. Field data have been collected at 48

sites and include details of overstorey composition and crown condition, seedling germination and survival, and understorey plant composition. Fungal community composition was determined using DNA extracted from soil samples, amplifying the fungal ITS2 region, to estimate relative abundance of fungal taxonomic entities. Results to date are being prepared for publication.



The use of soil amendments and alternative soil substrates to increase soil function and seedling recruitment in post-mining arid landscapes

STP 2019-024

Scientist(s): D Merritt, T Erickson

Student: A Bateman (The University of Western Australia) (PhD)

Academic(s): Dr M Muñoz-Rojas (The University of Western Australia),
Dr E Veneklaas (The University of Western Australia)

Restoration of degraded land following mining is challenged by factors including the limited availability of natural topsoil and low soil fertility. This project aims to assess the effectiveness of current practices in rehabilitation in the Pilbara including the use of soil amendments to improve soil function and seedling recruitment.

A glasshouse study examining how the inorganic amendments gypsum and urea affects plant growth and substrate quality has been completed. The addition of urea to mine waste substrates produced a 3-fold increase in plant growth of *Acacia inaequilatera*, and up to a 25-fold increase in growth of *Triodia wiseana* when grown under high watering regimes, but this effect was not evident in a low watering regime. The amendments decreased substrate pH and increased electrical conductivity, total nitrogen and N-mineralisation, but did not have an effect on soil microbial activity. Overall, water was the dominant driver for determining the effectiveness of the amendments to improve the quality of mine waste substrates and increase plant growth. In an arid region characterised by erratic, unreliable and often intense rainfall events, these results indicate that limited water will minimise plant access to inorganic amendments and restrict their effectiveness.



Design and testing of novel seed processing equipment and methods to improve seed-based restoration

STP 2019-014

Scientist(s): D Merritt, T Erickson

Student: E Ling (MSc)

Academic(s): Dr A Guzzomi (The University of Western Australia)

Irregular surface features on native seeds hinder the application of seed coatings and the flow of seeds through seeding machinery. Flash flaming technology removes these surface features from seeds imparting a significant reduction in volume and enhancing their flowability, without impacting on viability. This project will expand the application of flaming to diverse species and design and construct new large-scale flash flaming machinery.

Modifications continue to be made to the seed flammers, with continual testing on a diversity of seeds. Construction of a second flamer has been completed, and construction of a third continues. The most recent focus has been on automating and streamlining design features including reconfiguring the electric motor and gear set-up, re-positioning the gas line to improve safety, and more efficient feeding hoppers and pneumatic exit hatches for batch processing. A multi-hectare direct seeding trial was installed at two rehabilitation sites in the Pilbara, with seeding of a blend of *Triodia* species using a D10 bulldozer and current seeding machinery used by the mining sector. Seed batches pre-treated using different methods, including flaming and dormancy-break treatments, were trialled to examine the mechanics of seed delivery and germination potential. Monitoring will continue over the next few growing seasons to assess the performance of the varying treatments.



Native seeding mechanisation to facilitate efficient large-scale restoration of degraded lands

STP 2019-013

Scientist(s): D Merritt, T Erickson

Student: M Masarei (PhD)

Academic(s): Dr A Guzzomi (The University of Western Australia)

Using direct seeding machinery to sow native seeds for restoration can be challenging as many seeds possess complex morphological features that impede controlled and reliable flow through the machinery. The increasing requirement to deliver biodiverse seed mixes to a variety of landscapes motivates continued improvement in direct seeder design. This project aims to analyse current seed distribution methods and to design, construct, and test new or modified seeders for use in mine site rehabilitation. The primary objectives include the capability for controlling seed depth and spacing, sowing at rates applicable to large-scale rehabilitation, and seeding over diverse landforms including rocky and sloping land.

A field trial was completed to test the influence of rock content on seedling emergence. Seeds of *Triodia pungens* were sown at different depths within three soil profiles sieved to rock diameters of <2mm, <25mm, and un-sieved soil. Rock content did not hinder the ability of seeds to emerge when sown to shallow depths; however, when sown deeper than 15 mm, increasing rock content decreased emergence. Although rock content contributed to a reduction in emergence at depths below 15 mm, sowing depth remained the primary factor controlling emergence across the soil profiles. A range of direct seeding machinery components are now being evaluated in the field for their capacity to place seeds in the upper 10 mm of these rock soil profiles. These components include double disc opener type assemblies used as pasture drills in the agriculture industry, as well as knife point tynes, and more novel designs which aim to splay the soil fraction over the seeds, thereby creating a suitable seed bed.



Ecologically tolerable fire regimes for key *Banksia* woodland plant species

STP 2018-089

Scientist(s): B Miller, D Merritt

Student: R Miller (PhD)

Academic(s): Dr J Fontaine (Murdoch University), Prof J Enright (Murdoch University)

Fire is a dominant disturbance that shapes the structure, composition and function of ecosystems around the world. This process has been occurring in the Australian landscape for millennia and such a long engagement with fire means that plants have developed strategies and adaptations to cope with this disturbance in the landscape. It is important to note that species are built on a tolerance to certain patterns of fire (the fire regime) rather than simply to fire itself. If fire occurs too frequently, too intensely, or otherwise outside of the limits of a species tolerance, then populations are likely to decline or disappear. This project aims to determine the impact of varying fire regimes on the demographics of key *Banksia* woodland plant species. This knowledge will be used to identify potential limits to a species tolerance of fire using a Bayesian network modelling approach.

Using a space-for-time approach, surveys of population size structure, flowering, and canopy seed bank were conducted for six common shrub and tree species along a fire age chronosequence. Population size structures suggest that interfire recruitment may play a large role in the population dynamics of some species, possibly allowing them to persist for longer than expected in the long absence of fire. Juvenile periods ranged from 1.4-4.8 years and varied for resprouters vs obligate seeders, canopy- vs soil-stored species, and depending on the previous season of fire. Canopy seed banks did not accumulate over time, consistent with observations that canopy-stored species in *Banksia* woodland are weakly serotinous. A separate controlled field experiment has shown that the timing of seed planting throughout the year (emulating the timing of fire) influences seedling recruitment, where recruitment is best when seeds are cued for germination immediately prior to winter rainfall. All data collection has been completed, and data analyses and writing are close to completion.



Fire intensity, seasonal variation and seeds traits may influence seed fates in *Banksia* woodlands

STP 2018-087

Scientist(s): B Miller, D Merritt

Student: R Tangney (PhD)

Academic(s):

This project examined the interactions between fire, fuels and seed biology to assess how seeds survive through fire in *Banksia* woodlands. In fire-prone ecosystems, recruitment from seeds following fire is prolific and provides a pathway for populations to expand into new niches to persist through fire. For many species, recruitment from seed is their only means of population recovery following fire events, so seed survival through fire is vital in order to maximise post-fire recruitment. This project aimed to measure spatially diverse temperatures within soil during fire, examine lethal tolerances of seeds to elevated temperatures associated with fire, establish interactions between lethal tolerances and emergence behaviour and predict weather conditions that may decrease seeds ability to survive fire events.

A new method for measuring soil temperatures during fire that uses distributed temperature sensing within optic fibre was developed. The relationship between seed moisture and lethal thresholds of seeds (seeds high in moisture content have a reduced tolerance to high temperatures) have been established. The relationships between temperature penetration into soils and fuel loads, and the depth from which seeds are able to emerge from soils and their lethal temperatures have been determined.



The assessment of ecosystem risk in *Banksia* woodlands of the Swan Coastal Plain, Western Australia

STP 2017-035

Scientist(s): B Miller

Student: C Slee (PhD)

Academic(s): Dr E van Etten (Edith Cowan University), Prof W Stock (Edith Cowan University)

Banksia woodlands of the Swan Coastal Plain are part of the south-west Western Australian biodiversity hotspot and have been subjected to extensive clearing. These *Banksia* woodlands are now listed as a threatened ecological community (TEC) by the Commonwealth through the *EPBC Act*. There are numerous floristic community types (FCTs) within *Banksia* woodlands, of which several are threatened. An example is the Swan Coastal Plain floristic community type 20a (SCP20a) (*Banksia attenuata* woodlands with species rich dense shrublands). The threatening processes impacting on *Banksia* woodland include further land clearing, fragmentation, weed invasion, inappropriate fire regimes, altered hydrological processes, disease due to *Phytophthora cinnamomi* and a drying climate. This project aims to address knowledge gaps for improving the understanding of *Banksia* woodland floristic communities with a focus on SCP20a through a meta-analysis of Swan Coastal Plain data, combined with targeted assessment of new sites and re-assessment of existing sites with the aim of detecting change. The study also aims to integrate spatial analysis of environmental factors with biological data to identify predictive capability and assess risk to *Banksia* woodlands using the IUCN Red List of Ecosystems criteria, with reference to alternative risk assessment techniques.

Targeted field surveys have been completed over the past two years for a selection of SCP20a sites. In addition, a meta-dataset of Swan Coastal Plain floristic plots has been developed, collating data from government, consulting and other sources. The data set has been subjected to revision to allow for reliable comparison over time using current nomenclature. Initial meta-analysis of the consolidated data set has occurred and is being used to target specific *Banksia* woodland sites for follow-up assessment. A final season of targeted surveys is occurring along with closure of the meta-dataset to allow for completion of the project.



Population genomics of the burrowing bettong at Matuwa: a case study on the implications of genetic mixing

STP 2018-003

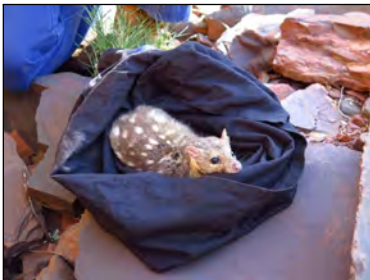
Scientist(s): K Ottewell, M Byrne, C Lohr

Student: K Rick (BSc Honours)

Academic(s): Dr J Kennington (The University of Western Australia)

The burrowing bettong (*Bettongia lesueur*) is a threatened macropod isolated to three offshore islands off the coast of Western Australia. As a result of geographical isolation, *B. lesueur* has been found to consist of two genetically distinct populations, which are currently listed as different subspecies. Multiple translocation attempts have been made to reintroduce *B. lesueur* back to mainland Australia, with Matuwa, located in the Goldfields region of Western Australia, being the first to establish a reintroduced population admixed from the two genetically distinct source locations. However, the genetic and demographic consequences of mixing genetically distinct populations is yet to be fully understood. Through the use of next generation sequencing using reduced representation methods, this study aims to investigate the introgression between these two geographically isolated source populations and assess how this impacts genetic diversity and fitness across different generations.

Genomic analyses were completed on 192 boodie samples from Matuwa encompassing samples from 2010-2017 and statistical analyses conducted to determine their hybrid status. Long-term trapping data was used to estimate survivorship and fecundity of the sampled individuals to assess whether there was a difference in fitness outcomes dependent on patterns of introgression. Results showed that there was no significant difference in fitness outcomes amongst hybrid classes with all groups having high survivorship and that the population retains high genetic diversity. A manuscript is currently in preparation.



Ecological responses of the northern quoll to a large-scale feral cat baiting program in the western Pilbara region, Western Australia

STP 2017-047

Scientist(s): R Palmer

Student: B Ross (PhD)

Academic(s): Dr B Murphy (Charles Darwin University), Prof J Woinarski (Charles Darwin University), Dr T Cremona (Charles Darwin University)

This project builds on an existing large-scale feral cat baiting and northern quoll (*Dasyurus hallucatus*) monitoring program in the Pilbara being undertaken by the department in partnership with Rio Tinto. The aims of the project are to: (1) evaluate the use of camera trap grids for assessing change in cat densities following aerial baiting; (2) use giving-up densities (GUDs) to test whether northern quolls exhibit risk-sensitive foraging responses in areas subject to feral cat baiting; and (3) use landscape genetic techniques to understand how northern quoll gene-flow is influenced by cat baiting.

Field work was undertaken following the final quoll trapping session to collect tissue samples from adults and pouch young. Camera traps deployed to monitor cats after the winter baiting program were also retrieved. Field and camera trap data was entered/processed and analysis commenced. Quoll tissue samples were curated ready for genetics analysis.



The impact of a drying climate on the alpha, beta and gamma biodiversity of freshwater macroinvertebrates in wetlands in a salinised landscape

STP 2018-141

Scientist(s): A Pinder

Student: S Atkinson (BSc Honours)

Academic(s): Dr J Chambers (Murdoch University), Dr B Robson (Murdoch University)

A program of monitoring vegetation, groundwater and wetland fauna at 25 wetlands in the Wheatbelt Region was undertaken as part of the department's contribution to the State Salinity Strategy, with a wetland fauna component running from 1996 to 2012. The original focus of the program was to determine the ongoing effects of salinity on biodiversity in representative wetlands. However, declining rainfall became another important process affecting wetlands during the project. Some of this data has been analysed and written up for individual wetlands, but trends in diversity across the wetlands had not been examined. This project aimed to examine the influence of rainfall and wetland inundation on the alpha, beta and gamma diversity of invertebrates, and investigate patterning in aquatic plant seed bank diversity.

Analyses demonstrated a strong relationship between wetland hydrology (depth and proportion of wetlands that were dry) and both alpha and gamma diversity of invertebrates. This manifested as a decline in alpha and gamma diversity over time as wetlands became increasingly shallower and drier during the study period. By contrast, beta diversity remained high as each wetland retained a distinct fauna when water was present. These results suggest that if the Wheatbelt continues to experience declining rainfall then the range of species inhabiting the region's wetlands is likely to decline significantly.



Taxonomy of the salt lake gastropod, *Coxiella*: how useful are empty shells as a source of taxonomic information?

STP 2018-140

Scientist(s): A Pinder

Student: A Lawrie (PhD)

Academic(s): Dr J Chaplin (Murdoch University)

Salt lakes in Western Australia are threatened by climate change, secondary salinity and mining, with consequences for the unique but poorly understood fauna that they support, including the endemic gastropod genus *Coxiella* which appears to have greatest diversity in south-west of Western Australia. The consequences of these threats to *Coxiella* is currently unclear as specimens cannot be confidently identified due to the existing insufficient taxonomy.

The principal aim of this project is to resolve the taxonomy of *Coxiella* to provide a sound platform for future work on this taxon. The project will also determine the salinity tolerances and desiccation resistance of different species and assess how past climate change has influenced the evolutionary histories of selected species. This means it will be possible to assess the vulnerability of *Coxiella* species to environmental change and to predict the impact of future changes. This project follows a DBCA summer scholarship project in 2018-19 that aimed to determine if DNA extracted from dead shells could be used for species identification. Since live *Coxiella* are only collectable for short periods, using their dead shells to determine what species were present would increase the scope of future studies investigating this taxon. This study extracted high molecular weight DNA from shells but the identity of the DNA was not verified due to issues encountered with amplification. The lack of successful amplification was attributed to inappropriate primer design and the presence of PCR inhibitors that could not be resolved using the methodologies attempted.



Aquatic invertebrate food resources in western swamp tortoise translocation sites

STP 2016-086

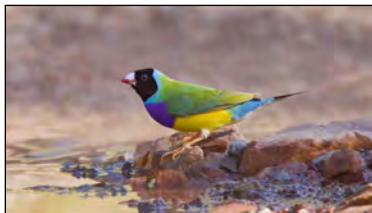
Scientist(s): A Pinder

Student: K Schmolz (MSc)

Academic(s): Adjunct A/Prof G Gollmann (University of Vienna)

Seasonal claypans on the Swan Coastal Plain are predicted to become less suitable for the endangered western swamp tortoise (*Pseudemys umbrina*) in coming decades as rainfall declines further. One response to this threat is to seek alternative habitats in higher rainfall areas of the south coast. A trial translocation into two wetlands (near Northcliffe and east of Augusta) was undertaken in 2016. This project aimed to compare invertebrate food resources between these sites and a wetland on the Swan Coastal Plain (Moore River Nature Reserve) that currently supports a translocated population. Western swamp tortoise gut contents were also obtained and the identity and biomass of food items calculated.

Invertebrate biomass did not differ between the three wetlands, but the southern sites had lower diversity. Greater numbers of prey, from a wider range of groups, were consumed at Moore River than at the other sites, possibly reflecting the warmer conditions there (which promotes feeding). The south coast sites support sufficient food resources and may be suitable as translocation sites as more northern wetlands become drier and the southern sites warmer. Two endangered fish species were present in the southern sites and, while neither were consumed by the tortoises, food web effects on fish prey would need to be considered.



Influence of fire history and seed distribution on the movements of granivorous finches in the East Kimberley

STP 2019-057

Scientist(s): I Radford

Student: S Collett (PhD)

Academic(s): Dr H Campbell (Charles Darwin University)

Populations of the granivorous Gouldian finch have not recovered from historical population declines prior to the 1980's. It is hypothesised that this lack of recovery is due to a decline in grass seed diversity in response to higher frequency and intensity fires across the landscape, which is forcing Gouldian finches to move longer distances to meet their dietary requirements in a more homogeneous landscape. The project aims to estimate the activity range, habitat use and dispersal for threatened Gouldian finches, and compare this with the more common masked and long tailed finches, to look at reasons for rarity in Gouldians and also to design management options to improve Gouldian finch status. This presents technical challenges due to the small size and high mobility of study animals using automated radio telemetry.

Automated radio-telemetry was used to track the local and broader-scale movements of Gouldian finches in the East Kimberley. This technology provides location data with high temporal (up to every 11s) and spatial precision when animals are within range of a receiving tower. This technology is being used to develop methods to estimate home range size of individual finches, and test whether and how home range size varies with fire history and grass seed availability.



Is there a housing crisis in tropical savannas? Changing fire regimes, hollows and declining arboreal mammals

STP 2017-017

Scientist(s): I Radford

Student: C E Penton (PhD)

Academic(s): Dr LA Woolley (Charles Darwin University), Dr B Murphy (Charles Darwin University)

There has been a significant amount of research conducted in northern Australia regarding fire regimes and their effect on savanna systems. However, the fire ecology of tree hollows has not been studied in northern Australia. It has been suggested that the drivers of tree hollow development and retention will be different to that known from studies in southern Australia, as savanna systems experience different fire regimes and are subjected to additional processes such as cyclone events and termite activity. Tree hollows are an important ecological resource for around 40% of vertebrates in the Top End including mammals, reptiles and birds. Developing optimal strategies for managing fire for arboreal mammals and thresholds of hollow abundance mediated by fire frequency and intensity will be a major advance in our understanding of Australian forest ecology and conservation in northern Australia.

Analysis has shown that termite activity in tropical savanna trees not only forms hollows, but also blocks them. This is an important potential source of error in ground-based estimates or counts of tree hollows to gauge habitat value for threatened arboreal mammals which often rely on hollows for nests and shelter. Camera traps set on nest boxes and tree hollows have revealed complex patterns of hollow use over time by different individuals, different species and also arboreal predators including tree goannas, tree snakes and pythons. Analysis of tree hollow distribution data from the Northern Territory has revealed that aside from rainfall, soil depth and tree size, tree hollow abundance is mainly driven by disturbance regimes including fire, cyclones and termite activity. Frequent late dry season fires can result in reduced hollow abundance, particularly of trees with large hollows, which are the most used hollows by arboreal mammals.



Evolution of C₄ photosynthesis in the genus *Tecticornia* at the anatomical and molecular levels

STP 2017-044

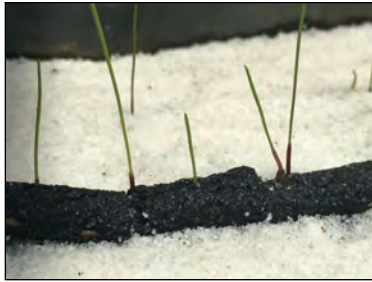
Scientist(s): K Shepherd, T Macfarlane

Student: N Dakin (PhD)

Academic(s): Dr M Ludwig (The University of Western Australia), Prof G Kadereit (Mainz University, Germany)

This project aims to study the evolution of C₄ photosynthesis in the genus *Tecticornia* (Chenopodiaceae) at the molecular and anatomical levels. The genus includes two species identified as using the C₄ photosynthetic pathway, and 39 species currently categorised as C₃ plants.

The project has four objectives, and all are complete. The first objective involved phylogenetic analyses of molecular sequence data to clarify relationships between *Tecticornia* species, and identify C₃ species most closely related to C₄ species. Phylogenetic analyses of nrDNA internal and external transcribed spacer (ITS and ETS) sequences of *Tecticornia* species and closely allied *Salicornia* species were completed. The second objective involved a broad anatomical survey of key species identified from the phylogenetic analyses, and identification of C₃ species with C₄-like characteristics. In the third objective, these species were analysed using immunoblotting techniques. Abundance of photosynthetic proteins were determined, including glycine decarboxylase P-subunit (GDC-P), ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), and phosphoenolpyruvate carboxylase (PEPC). The fourth objective quantified the location and abundance of photosynthetic proteins (including GDC-P, RuBisCO, and PEPC) in selected *Tecticornia* species. Immunocytochemistry techniques at the electron microscope level were used to determine the relative abundance and location of these proteins. Ultrastructural characteristics, including mitochondria planar area, chloroplast planar area, and organelle position were also quantified. C₄, C₃, and potential C₃-C₄ intermediates were compared. Statistical analyses are complete and a manuscript is being prepared for publication.



Restoring highly degraded *Banksia* woodlands through innovative seed enhancement technology

STP 2018-150

Scientist(s): J Stevens, A Ritchie, T Erickson

Student: V Brown (PhD)

Academic(s): Prof R Hobbs (The University of Western Australia)

Restoration of native plant communities through direct seeding often have low seedling establishment success rates. A significant factor in restoring post pine and degraded agricultural lands back to native vegetation is competition with invasive weed species, and as native seedlings are susceptible to herbicide application, weed control strategies are limited. This project will examine how seed pelleting technologies can be applied to biodiverse *Banksia* woodland species to protect seeds from herbicide application and offer innovative weed control strategies for restoration in high weed load environments.

A large field trial was established at Hanson Construction and Building Materials Quarry, near Ellenbrook, within a post-pine and post-mine site. Approximately 39,000 *Jacksonia furcellata* seeds were planted out across five different management treatments (i.e. herbicide, rip, rip then herbicide, herbicide then rip or control) to test the efficacy of different seed enhancement technologies to protect against a post-emergent herbicide (fusilade). These seed enhancement technologies include extruded pellets or seed coatings with either activated carbon or biochar (both ingredients known to adsorb herbicides) and a control where seeds were left untreated (no seed enhancement technology). This field trial will also be used to see how these technologies impact the emergence, growth and survival post summer of *J. furcellata* across the different management treatment types. Currently emergence data is being collected twice a week until peak emergence is reached, and then monitoring will continue approximately once a fortnight.



The influence of drought on plant morphology, physiology and establishment in the post iron ore mining environments of semi-arid Western Australia

STP 2018-147

Scientist(s): J Stevens

Student: S Sullivan (PhD)

Academic(s): A/Prof P Poot (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)

Mining companies have a legal responsibility to return native biota to post-mining environments; however, ecological restoration is challenging, especially in water limited environments. The chemical and physical properties of substrates do not always explain high seedling mortality therefore other factors such as drought should be explored. This research project aims to improve restoration outcomes by obtaining a greater understanding of the influence of soil water availability and phenotypic plasticity on juvenile plant morphology, physiology and survival in the post iron ore mining environments of semi-arid Western Australia.

Field trials have been completed in the mid west in which tubestock and seeds of six species were introduced into a waste rock dump environment and exposed to experimental watering regimes. Seedling emergence, survival, growth and physiology was monitored over a period of 18 months to examine the effect of rainfall frequency and intensity on seedling performance. Hydrothermal germination thresholds for seeds of the six study species were explored further in a series of lab trials. A glasshouse trial investigating how preconditioning seedlings to water stress may influence drought tolerance in restoration programs is ongoing.



Near-surface remote sensing of plant condition in mine site restoration environments

STP 2018-146

Scientist(s): J Stevens

Student: J Ruscallada Alvarez (PhD)

Academic(s): Dr J Yong (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)

Plant physiological condition is a key indicator in the early stages of restoration progress assessment. Current methods to determine condition are difficult to undertake over large areas and are time consuming. This research project aims to determine if near-surface remote sensing measurements (particularly hyperspectral sensing and thermography) can reliably quantify plant drought stress condition in a biodiverse plant community. Quantitative criteria will be proposed to evaluate restoration success by defining a fast, accurate and easy to perform methodology, and potentially establishing the foundation for scaling up to more remote imaging platforms that allow monitoring of larger areas in shorter periods of time.

Data analysis from a controlled drought glasshouse experiment is showing that certain spectral reflectance regions located in the near infra-red and short-wave infrared part of the spectrum (specifically water absorption features as well as optimised vegetation indices) have the capacity to accurately predict relevant physiological variables such as leaf water potential in several common species of a *Banksia* woodland, both at the leaf and plant scales. Thermography data analysis, although at an early stage, is showing a general solid relationship between leaf temperature and stomatal conductance, although it is variable across species. An ongoing field experiment in a recently restored *Banksia* woodland plant community is looking at seasonal plant physiological variability, assessed through traditional ecophysiological methods as well as with hyperspectral reflectance and thermography, with the goal of determining the potential of these remotely sensed indicators as practical tools for plant restoration monitoring.



Soil-microbial-plant signals and effects on plant eco-physiological performance for mine site restoration

STP 2018-145

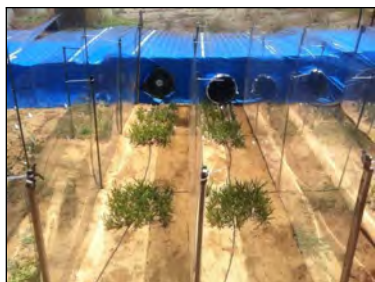
Scientist(s): J Stevens

Student: W Wong (PhD)

Academic(s): A/Prof R Trengove (Murdoch University), Dr J Yong (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)

The importance of soil biological properties such as microbial composition and the benefits conferred to soils and plants are often undervalued in mine site restoration. Microorganisms have been widely reported to be beneficial for agricultural crops (e.g. growth stimulation, increased nutrient uptake, plant tolerance against abiotic stress such as drought) through inducement by microbial signals, such as phytohormones and enzymes. Some of these beneficial microorganisms are also present in natural soil systems; however, their role in facilitating seedling establishment is yet to be identified. This project aims to investigate if microorganisms known to benefit agricultural species can be identified and isolated from the Western Australian natural systems. The project will also elucidate the mechanisms involved in the positive effects of microorganisms on the plants and explore how these findings can be integrated to improve mine site restoration strategies, including topsoil handling techniques.

Methodology enabling simultaneous multi-phytohormone detection on the ultra-performance liquid chromatography triple quadrupole mass spectrometry (UPLC-MS/MS) platform has been successfully established. Xylem sap collected from Western Australian natives subjected to various growth conditions and commercial microbial solutions inoculation under glasshouse conditions have been subjected to analysis. The link between improved plant physiological performance in microbial inoculated plants and xylem sap phytohormone profiles is currently being assessed.



Implications for wind management in restoration ecology, linking ecosystem aerodynamics to physiological drivers in arid and semi-arid systems

STP 2018-143

Scientist(s): J Stevens

Student: E Arora (PhD)

Academic(s): Dr A Guzzomi (The University of Western Australia), Dr S Tomlinson (Curtin University), Prof K Dixon (Curtin University)

Plant mortality in restoration programs leads to reduced outcomes for biodiversity and is costly for practitioners. Understanding the drivers of mortality, in particular factors influencing soil water availability are critical. Wind dynamics play a significant role in drying soils and creating atmospheric deficits whereby plants lose water. In altered systems such as restoration environments, the wind dynamics may be different compared to reference communities and may impact seedling establishment. This project aims to capture reference wind dynamics of many Western Australian ecosystems including the *Banksia* woodland ecosystem, and compare restoration sites to the reference state. Understanding the critical thresholds for wind dynamics and the impacts on plant physiological performance will be assessed for *Banksia* species.

Analysis of wind data from major vegetation units across Western Australia is continuing, and will serve as a reference state with which to compare rehabilitation sites to. Furthermore analysis of wind impacts on seedling ecophysiology has commenced to understand impacts on *Banksia* seedling mortality patterns in rehabilitation areas.



How do species interactions drive community assembly of *Banksia* woodlands?

STP 2018-142

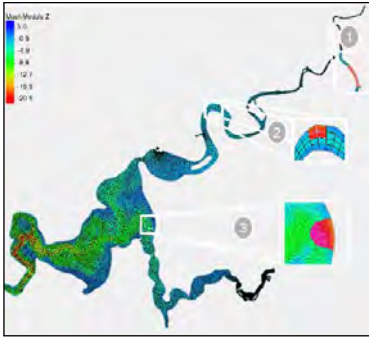
Scientist(s): J Stevens, B Miller

Student: L Svejcar (PhD)

Academic(s): Dr J Fontaine (Murdoch University), Dr R Standish (The University of Western Australia)

Over time, the diversity of plant species present in restoration sites decreases. In particular, many seedlings die after their second summer of growth, which is posited to be the result of plants competing for limited soil water and nutrient resources. However, plant-plant interactions have not been extensively studied in this ecosystem. This research project is investigating: (1) what do spatial patterns among species reveal about the importance of competition and facilitation in early and mid-successional stages of community development following restoration?; (2) do varying densities of a native annual grass (*Austrostipa compressa*) facilitate growth of seedlings from topsoil transfer?; and (3) do clustered or dispersed seeding strategies increase or decrease seedling survival?

Spatial mapping of individual perennial plants has been conducted in five restoration areas at 1, 2, 3, 7 and 11 years old. Three field trials have been established: (1) a two year study to determine whether the spatial interactions of seedlings differs based on their ability to fix nitrogen; (2) a two year study testing the impact of six densities of *A. compressa* (0, 20, 165, 310, 455 and 600 *A. compressa* m⁻²) on seedling diversity and establishment; and (3) a one year study testing varying spatial arrangements of planted seed.



Identification of controls on the metabolism of the Swan-Canning Estuary using numerical modelling and high-frequency data

STP 2018-093

Scientist(s): K Trayler
 Student: A Saeed (PhD)
 Academic(s): A/Prof M Hipsey (The University of Western Australia),
 Prof C Oldham (The University of Western Australia)

The Swan Canning Estuarine Response Model (SCERM) is an important tool for management of the waterway. The model has been shown to capture seasonal and spatial variability in some physico-chemical parameters, but could be improved through targeted research. This project is working to improve understanding of the estuarine metabolism of the waterway through high frequency monitoring. New understandings will be applied to improving model dynamics.

High frequency data has been collected at 3 locations (Guildford, Maylands and Como) for diurnal oxygenation analysis and time series plotting. These are being compared to the Swan Canning Estuarine Response Model (SCERM) outputs to validate oxygen dynamics. Effort is progressing towards the deployment of a water quality monitoring buoy in Melville waters. The monitoring buoy will comprise a floating surface buoy, with power supply, solar panels, connected subsurface water quality sensors, plus a frame with water quality sensors that sits on the riverbed.



Evaluating the population genetics, recruitment limitations and release strategies of western school prawns during a restocking program in the Swan-Canning Estuary

STP 2018-091

Scientist(s): K Trayler
 Student: B Poh (PhD)
 Academic(s): R Tweedley (Murdoch University), Dr J Chaplin (Murdoch University), Prof N Loneragan (Murdoch University)

This project is linked to a restocking program for western school prawns (*Metapenaeus dalli*) in the Swan-Canning Estuary. It aims to understand the population genetics and ecology of this species and increase the success of the restocking.

Sampling at 36 sites in the estuary has been undertaken over five years (2013-2018). The temporal patterns of distribution and abundance of *M. dalli* in nearshore waters were positively related to water temperature. The spatial distribution of *M. dalli* differed significantly from another penaeid (*Penaeus latissulcatus*), but was indistinct from the apogonid *Ostorhinchus rueppellii*, which was identified as a major predator of postlarval prawns. A suite of microsatellite markers is being developed to evaluate the genetic diversity of the wild *M. dalli* population and genetic implications of the restocking. Five hundred and sixty two primer pairs were sequenced and screened, yielding 71 sequences, four of which currently show both reliable amplification and useful polymorphism.



Investigating habitat values of seagrass, macroalgae and wrack in the Swan Canning Riverpark

STP 2018-090

Scientist(s): K Trayler
 Student: S Fulwood (PhD)
 Academic(s): A/Prof G Hyndes (Edith Cowan University)

This project is investigating the biodiversity and ecological values of seagrass, *Halophila ovalis*, meadows and macroalgae, *Chaetomorpha* accumulations, and accumulated shoreline wrack.

Two seasons of sampling invertebrates and fish communities were completed prior to a major flood event in February 2017 impacting a third sampling event by causing major seagrass die-off. A total of 20 fish species were found across three habitats (seagrass, macroalgae and sand) but did not differ significantly in richness or density between habitats. Results suggest that *H. ovalis* provides little habitat or direct food resource for fishes, but does contribute to the production of invertebrates. Drift algae did not appear to enhance or impact fish communities or provide a major food resource to fish, but did contribute to invertebrate production. Seagrass and algal wrack did not appear to be beneficial to invertebrate or fish assemblages. However the decomposition pathway of this material and its contribution to the detrital food web is not known at this time.



Modelling species interactions and other environmental factors in the Upper Warren

STP 2019-051

Scientist(s): A Wayne

Student: W Geary (PhD)

Academic(s): A/Prof E Ritchie (Deakin University), A/Prof D Nimmo (Charles Sturt University), Dr T Doherty (Deakin University), Dr A Tulloch (University of Sydney)

This project aims to identify the major correlates of population changes in four critical weight range (CWR) mammals (woylie, chuditch, koomal, quenda) in the Upper Warren Region, including fire history, logging history, climate and weather variation and predator management. This will be done by modelling trapping data from the region from 2000-2019 across 12 transects against a range of spatially explicit variables. Some analysis will also be conducted on predator sand plot monitoring data collected between 2006 and 2012 in the Upper Warren Region, relating this to predator management intensity and other correlates.

Progress made to date includes initial exploratory modelling of correlations between predator management and CWR mammal capture rate, which suggests woylies and chuditch may have displayed initial positive responses to more intense predator management. Next steps include modelling these relationships in more detail, as well as exploring spatial and temporal variation in capture rate against other variables relating to management and disturbance histories (e.g. fire).



The population and spatial ecology of the numbat in the Upper Warren

STP 2019-050

Scientist(s): A Wayne

Student: S Thorn (PhD)

Academic(s): A/Prof N Mitchell, Dr R Firman (The University of Western Australia)

The aim of this project is to increase knowledge about the baseline population and spatial ecology of the numbat population in the Upper Warren region. This information will assist in informing future management practices for this population.

Initial methods for location of numbats have been trialled including: 1) the use of a detection dog to assist with locating numbats for capture and collaring; and 2) a pilot study to assess the viability of obtaining trace DNA from numbat scats for individual identification. Pilot studies for the above methods were unsuccessful. Results showed that a detection dog was unable to adequately track numbats to bolt holes or burrows. Trace DNA of sufficient quantity and quality was found only on scat samples from Perth Zoo that had not been exposed (freshly deposited) and all scat samples from wild animals (including fresh scats) failed to amplify.

Preliminary analysis of camera trap images using spatially explicit capture recapture modelling has demonstrated that this may be a viable method for studying numbat populations and estimated a density of 0.014

numbats ha^{-1} (± 0.004). In upcoming work, camera and hair traps will be used to assist with individual identification and population parameter estimates. Collars fitted with GPS receivers and VHF transmitters will be used to study numbat spatial ecology.



Survey methods and ecology of the numbat population at the Upper Warren region

STP 2017-041

Scientist(s): A Wayne
 Student: A Seidlitz (PhD)
 Academic(s): Dr K Bryant (Murdoch University), Dr N Armstrong (Murdoch University)

This study aims to improve the understanding of the numbat population in the Upper Warren region (UWR), to inform management for the conservation of this endangered species. The objectives are to develop robust survey methods for numbat population monitoring, and to determine anthropogenic and environmental factors influencing the population.

Earlier fieldwork established that sign surveys were most suitable for numbat detection in the UWR. Further fieldwork was undertaken and 78 sites were established within a forested area of approximately 140,000 hectares. Stratified random sampling was used to explore numbat occupancy rates in different key habitats. Habitat categories consisted of areas with different timber harvest- and fire histories, fox baiting intensities and forest types (Wandoo and Jarrah). During four repeat surveys, more than 800 numbat scats were found at 65/78 sites, resulting in a naïve occupancy rate of 83%. Preliminary results show that numbats appear to be generalists with no clear preference for any key habitat. Fieldwork for this project has been completed, and several papers are being prepared for publication.



Evidence based management of foxes adjacent to turtle beaches in Western Australia

STP 2016-025

Scientist(s): S Whiting
 Student: J Stuart (PhD)
 Academic(s): Dr T Fleming (Murdoch University), Dr P Adams (Murdoch University), Dr B Bateman (Curtin University)

This project is investigating fox biology, distribution and seasonality and behaviour in relation to turtle nest predation. Predation by foxes is a key pressure acting on some turtle rookeries and this study will provide knowledge to inform the long-term management of foxes and turtles.

The movement and home ranges of 14 foxes were studied to design management actions including fox control and removal. A total of 15 foxes were culled from the coastal area with only one being previously satellite tagged, indicating a larger population. Further fox removal will occur prior to the turtle nesting season in November. Further work will include diet and trap camera analysis.



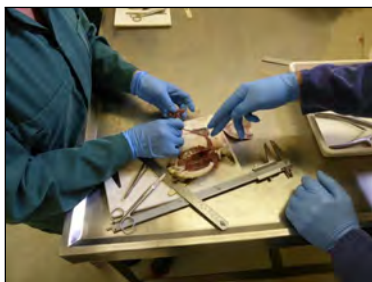
Understanding the early offshore movement of flatback turtle hatchlings and the effects of anthropogenic light

STP 2016-024

Scientist(s): S Whiting
 Student: P Wilson (PhD)
 Academic(s): Dr M Thums (Australian Institute of Marine Science), Dr C Pattiaratchi (The University of Western Australia), Dr M Meekan (Australian Institute of Marine Science)

Artificial light influences the orientation of hatchling flatback turtles and is a major pressure affecting this species in Western Australia. This project will investigate the extent of this influence under different light regimes and environmental cues and will quantify the impacts of light on hatchling turtles in nearshore waters. The aims of this project are to: (1) determine if flatback turtle hatchlings are attracted to different types of light when in the water and for how long using acoustic telemetry, whilst concurrently looking at what natural cues (e.g. currents and waves) they may be using to initially move offshore; (2) determine if flatback turtle hatchlings use wave cues to move offshore, and explore the relationship between light cues and wave cues in a wave tank for both flatback and green turtle hatchlings; and (3) examine the relationship between distance from light source and hatchling attraction, as well as what effect lingering around light sources on permanent light-emitting structures has on the predation rates of flatback hatchlings.

Field experiments used acoustic tracking to follow hatchlings through the nearshore zone at Thevenard Island with and without the influence of artificial light and with and without the influence of a jetty structure. Results showed that the nearshore transit of turtles was highly influenced by artificial light that increased the transit time of hatchlings, changed their direction and retained hatchlings in the light spill. A manuscript has been completed and is in final review, and another is in preparation. Information from this project contributed to the draft *National Light Pollution Guidelines for Wildlife Including marine turtles, seabirds and migratory shorebirds*.



The health status of marine turtles in northern and western Australia

STP 2016-022

Scientist(s): S Whiting
 Student: E Young (PhD)
 Academic(s): Dr R Vaughan-Higgins (Murdoch University), A/Prof K Warren (Murdoch University), Dr L Yeap (Murdoch University), Dr N Stephens (Murdoch University)

This project is assessing the health and disease status of sea turtles in Western Australia, with a focus on flatback turtles, and is investigating dead and injured turtles stranded along the coast and using pathology to diagnose the causes of death. Blood samples are being obtained from healthy turtles to determine reference ranges for species where gaps exist. Parasite infections and fibropapilloma virus are being specifically investigated. Although focused on flatback turtles, other species will be included as opportunities arise.

Blood samples have been collected from flatback turtles in both the nesting and foraging grounds. Samples have been analysed and synthesis of results is in progress. Over 200 necropsies have been performed and results show that plastic ingestion was the cause of death for some cases. Specific parasitology investigations were conducted with a world recognised parasitologist and resulted in the discovery a new parasite for flatback turtles.



Habitat quality as a driver of epinepheline serranid productivity and replenishment

STP 2019-038

Scientist(s): S Wilson
 Student: D Ellis (PhD)
 Academic(s): Dr C Fulton (Australian National University)

Understanding the habitat requirements of animals and how this influences their distribution is essential for effective management. Ongoing shifts in habitat due to changing climate and acute environmental disturbance emphasise the need to understand how changes in habitat effect associated fauna. Epinephelid serranids are ecologically important predators on tropical reefs that are an attraction for both tourists and fishermen. This project will focus on the habitat requirements of epinepheline serranids at Ningaloo, exploring mechanisms that influence their distribution, abundance and productivity. The project will examine fish within two habitat types, macroalgae and corals, representing extremes of the current regime shift paradigm on tropical reefs.

Information on the abundance of Epinephelid species has been collected from surveys within macroalgal and coral reef habitats that have been sampled annually by DBCA, ANU and AIMS researchers since 2013. Early results indicate there are distinct Epinephelid assemblages in the two habitats and that microhabitats within macroalgal and coral reefs are important determinants of fish abundance.



How does environmental disturbance effect macroalgal assemblages at Ningaloo

STP 2019-037

Scientist(s): S Wilson
 Student: R Harris (MSc)
 Academic(s): Dr C Fulton (Australian National University)

Tropical macroalgal meadows can cover extensive areas of the shallow seascape, providing habitat for an abundance of organisms. There is however a paucity of information on processes that drive distribution and structure of tropical macroalgal meadows, particularly how they respond to large-scale natural disturbances. To assess the effects of environmental disturbance on tropical macroalgae, this study will explore temporal and spatial patterns in community composition and physical structure of macroalgal assemblages at Ningaloo. The project will analyse macroalgal data collected annually from the Ningaloo lagoon between February 2013 and February 2018, incorporating periods before and after tropical cyclone Olwyn (March 2015) and a major flood event (April 2014).

Early assessments indicate that sediments have a strong influence on the distribution of canopy forming macroalgae. Detailed field studies to investigate the association between sediments and prominent macroalgae at Ningaloo are being undertaken.



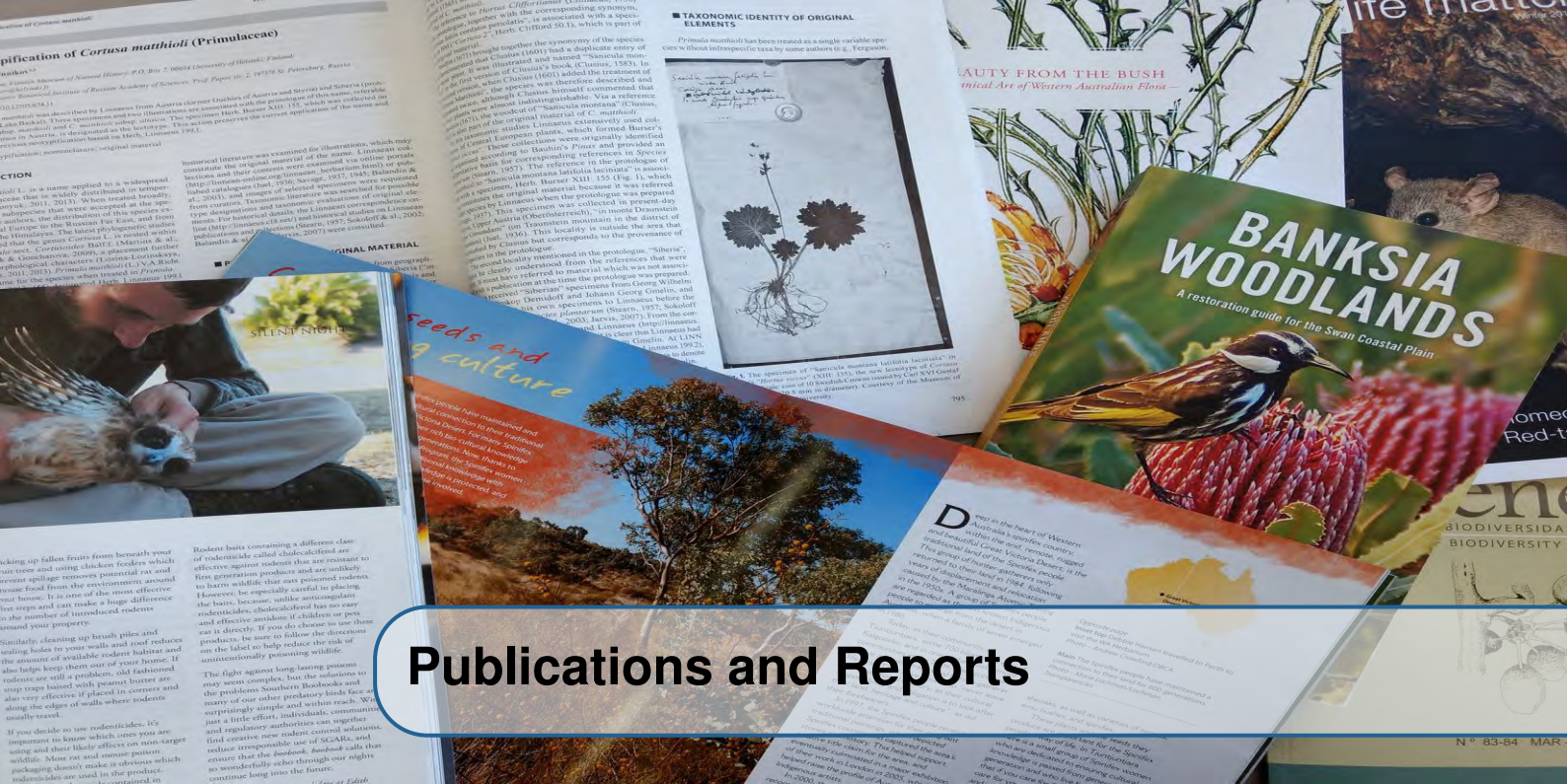
The effect of patch habitat networks in shaping the distribution, abundance and diversity of coastal fishes

STP 2015-006

Scientist(s): S Wilson
 Student: J Van Lier (PhD)
 Academic(s): Dr M Depczynski (Australian Institute of Marine Science),
 Dr C Fulton (Australian National University)

Seaweed-dominated habitats occur in tropical reef systems, where they play vital roles in supporting key species and processes. Habitat quality in seaweed patches, measured as canopy height, holdfast density or percentage cover, varies seasonally and can be a major driver of the presence and abundance of key functional and taxonomic fish groups. However, the relative influence of other seascape variables, such as patch shape, size and proximity, remains poorly understood. This project will study seaweed habitats at Ningaloo Marine Park, building on research in the region that has highlighted the importance of seaweed micro-habitat and intra-patch structure by including patch and inter-patch measures. The study will focus on fishes of the family Labridae (wrasses and parrotfishes), which are a diverse group of conspicuous reef fishes that span a wide range of trophic groups, body sizes, social structures, movement patterns and diel ranges. Specifically the project will: (1) establish how within and between patch habitat structure influences reef fish diversity within the Ningaloo lagoon; (2) explore how patch habitat configuration influences fish predator-prey dynamics; and (3) quantify how seaweed-associated fish assemblages respond to acute and unseasonal disturbances in patch-habitat condition.

Analysis of fish dynamics demonstrates that both seascape measures of connectivity among habitats and within patch measures of canopy structure are important predictors of fish diversity and should be considered in conservation planning. Study of the effects of experimentally reduced macroalgal canopy height on fish assemblages at Ningaloo found that canopy height and associated fish assemblages typically returned to post disturbance levels within two years, though canopies dominated by the genus *Sargassopsis* had not fully recovered and abundance of herbivorous fish on experimental meadows was lower than it was before the experiment.



Publications and Reports

- Abbott I (2019). *Contributions to the History of Australasian Ornithology*. Volumes 3 and 4 by William E. Davis Jr, Walter E. Boles and Harry F. Recher (eds). Published by Nuttall Ornithological Club, Cambridge, Massachusetts, USA, 2017 & 2018. (BOOK REVIEW) *Pacific Conservation Biology* **25**, 215-217
- Ahrens CW, Byrne M, Rymer PD (2019). Standing genomic variation within coding and regulatory regions contributes to the adaptive capacity to climate in a foundation tree species. *Molecular Ecology* **28**, 2502-2516
- Ahrens CW, Mazanec RA, Paap T, Ruthrof KX, Challis A, Hardy G et al. [Byrne M] (2019). Adaptive variation for growth and resistance to a novel pathogen along climatic gradients in a foundation tree. *Evolutionary Applications* **12**, 1179-1190
- Algar D (2018). Domestic cat survey program, October 2018. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 5 p.
- Algar D, Johnston M, Pink C (2019). Big island feral cat eradication campaigns: an overview and status update of two significant examples. In *Island Invasives: Scaling up to Meet the Challenge: Proceedings of the International Conference on Island Invasives 2017* (eds CR Veitch, MN Clout, AR Martin et al.). pp. 238-243. IUCN, Gland
- Algar D, Johnston M, Tiller C, Fletcher J, Onus M, Desmond G et al. [Hamilton, NJ] (2019). Feral cat eradication on Dirk Hartog Island, Western Australia. (ABSTRACT) In *Island Arks, Rottnest Island, Western Australia, 11-15th February 2019* p. 16
- Anderson BM, Thiele KR, Grierson PF, Krauss SL, Nevill P, Small I, et al. [Barrett MD] (2019). Recent range expansion in Australian hummock grasses (*Triodia*) inferred using genotyping-by-sequencing. *AoB Plants* **11**:plz017
- Anderson H, Palmer R (2018). No laughing matter: camera trap snaps a laughing dove on Yarraloola Station, SW Pilbara. *Western Australian Bird Notes* **168**, 35-36
- Armbruster WS, Wege JA (2019). Detecting canalization and intra-floral modularity in triggerplant (*Stylidium*) flowers: correlations are only part of the story. *Annals of Botany* **123**, 355-372
- Arnall SG, Mitchell NJ, Kuchling G, Durell B, Kooijman SALM, Kearney MR (2019). Life in the slow lane? A dynamic energy budget model for the western swamp turtle, *Pseudemys umbrina*. *Journal of Sea Research* **143**, 89-99
- Artega Claramunt AM, White NE, Bunce M, O'Connell M, Bullen RD, Mawson PR (2018). Determination of the diet of the ghost bat (*Macroderma gigas*) in the Pilbara region of Western Australia from dried prey remains and DNA metabarcoding. *Australian Journal of Zoology* **66**, 195-200
- Asher RJ, von Senger DM (2019). Return to 1616: the ecological restoration of Dirk Hartog Island. (ABSTRACT) In *Island Arks, Rottnest Island, Western Australia, 11-15th February 2019* p. 15
- Ayre B, Krauss S, Roberts D, Anthony J, Phillips R, Hopper, S (2018). Impact of nectar-feeding birds and European honeybees on *Anigozanthos manglesii*'s reproductive success. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* 6-7
- Bach LL, Saunders BJ, Newman SJ, Holmes TH, Harvey ES (2019). Cross and long-shore variations in reef fish assemblage structure and implications for biodiversity management. *Estuarine, Coastal and Shelf Science* **218**, 246-257
- Ball D, Bryant S, Moro D (2019). Island Arks Australia: can it guide a renaissance in Australian island conservation? (ABSTRACT) In *Island Arks, Rottnest Island, Western Australia, 11-15th February 2019* p. 21
- Barlow J, França F, Gardner TA, Hicks CC, Lennox GD, Berenguer E et al. [Wilson SK] (2018). The future of hyperdiverse tropical ecosystems. *Nature* **559**, 517-526
- Barrett M (2018). Fungi of the Kimberley. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham et al.). pp. 38-41. Kimberley Society, Perth
- Barrett M (2018). Hiding in the ranges: sandstone flora of the Kimberley. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham et al.). pp. 42-57. Kimberley Society, Perth
- Barrett MD, Trudgen ME (2018). *Triodia pisoliticola* (Poaceae), a new species from the Pilbara region, Western Australia, and a description for *T. sp. Mt Ella* (M.E. Trudgen MET 12739). *Nuytsia* **29**, 271-281
- Bates BC, McCaw L, Dowdy AJ (2018). Exploratory analysis of lightning-ignited wildfires in the Warren Region, Western Australia. *Journal of Environmental Management* **225**, 336-346
- Beatty S, Morgan D, Pinder A (2018). The enigmatic salamanderfish: living on burrowed time case-study. Available at: <https://southwest->

- snapshot.com.au/aquatic-biodiversity/. South West Catchments Council, Bunbury. 4 p.
- Bell U (2018). Native Grasses of Perth Hills: a Field Guide to Identification. U Bell, Perth. 71 p.
- Belton GS, Draisma SGA, Prud'homme van Reine WF, Huisman JM, Gurgel CFD (2019). A taxonomic reassessment of *Caulerpa* (Chlorophyta: Caulerpaceae) in southern Australia, based on *tufA* and *rbcL* sequence data. *Phycologia* **58**, 234-253
- Bentley BP, Whiting SD, Mitchell NJ (2019). End of the line? Nesting phenology shifts unable to mitigate adverse impacts of climate change on winter nesting sea turtles (ABSTRACT). In *SICB 2019 Annual Meeting Abstracts, January 3-7 2019, Tampa, FL* p. 28
- Bentley B, Whiting S, Stubbs J, Mitchell N (2018). Climate change. In *Marine turtles in the Kimberley: key biological indices required to understand and manage nesting turtles along the Kimberley coast: WAMSI Kimberley Marine Research Program, final report, Project 1.2.2* pp. 55-85. Western Australian Marine Science Institution, Perth
- Bessey C, Rule MJ, Dasey M, Brearley A, Huisman JM, Wilson SK *et al.* [Kendrick AJ] (2019). Geology is a significant indicator of algal cover and invertebrate species composition on intertidal reefs of Ngari Capes Marine Park, south-western Australia. *Marine and Freshwater Research* **70**, 270-279
- Bezemer N, Hopper SD, Krauss SL, Roberts DG (2018). Sex on the rocks: recruitment genetics of a tree endemic on granite outcrops. (POSTER ABSTRACT) In *The Royal Society of Western Australia Symposium, 2018: Program & Abstracts* p. 37
- Binks R, Byrne M, van Leeuwen S (2019). Genetic assessment of *Aluta quadrata* across the Western Range. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 20 p.
- Binks R, Gibson N, Ottewell K, Macdonald B, Byrne M (2019). Predicting contemporary range-wide genomic variation using climatic, phylogeographic and morphological knowledge in an ancient, unglaciated landscape. *Journal of Biogeography* **46**, 503-514
- Binks RM, Byrne M, McMahon K, Pitt G, Murray K, Evans RD (2019). Habitat discontinuities form strong barriers to gene flow among mangrove populations, despite the capacity for long-distance dispersal. *Diversity and Distributions* **25**, 298-309
- Birch J, Murphy D, Walsh N, Conran J, Macfarlane T, Pires JC (2018). The evolution and biogeography of Australian Asparagales. (ABSTRACT) In *Mind the Gap: Australasian Systematic Botany Society 2018 Conference, Brisbane Botanic Gardens* p. 64
- Blythman M, Sansom J (2019). Devitalising bird-seed to prevent dispersal of weeds by birds. *Australian Field Ornithology* **36**, 31-33
- Bougher NL (2018). Fungi. In *Augusta's Kings Park: Donovan Street Bushland* 68-78, 175-182. Environmental Research Group Augusta, Augusta, WA
- Bourke L, Rutherford J (2018). Hydrological response of Toolibin Lake to inundation in February 2017. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 100 p.
- Braby MF, Franklin DC, Bisa DE, Williams MR, Williams AAE, Bishop CL *et al.* [Coppin RAM] (2018). Atlas of Butterflies and Diurnal Moths in the Monsoon Tropics of Northern Australia. ANU Press, Canberra. 462 p.
- Braby MF, Franklin DC, Bisa DE, Williams MR, Williams AAE, Bishop CL, Coppin RAM (2018). Conserving a biodiversity hotspot: patterns of biodiversity of butterflies and diurnal moths in the monsoon tropics of northern Australia. (ABSTRACT) In *Australian Entomological Society 49th AGM and Scientific Conference: Alice Springs, 23rd to 26th September* p. 39
- Brace AJ, Ruthrof KX, Fontaine JB, Freund R, Hopkins A (2019). Understanding soil microbial community shifts in response to fire and weed invasions in urban *Banksia* woodlands. (ABSTRACT) In *AusME 2019, Australian Microbial Ecology Conference, 11-13 February 2019, University of Western Australia* 63-64
- Bradbury D, Binks RM, Coates DJ, Byrne M (2019). Conservation genomics of range disjunction in a global biodiversity hotspot: a case study of *Banksia biterax* (Proteaceae) in southwestern Australia. *Biological Journal of the Linnean Society* **127**, 390-406
- Breed MF, Harrison PA, Bischoff A, Durruty P, Gellie NJC, Gonzales EK *et al.* [Krauss SL] (2018). Priority actions to improve provenance decision-making. *Bioscience* **68**, 510-516
- Broadhurst L, Byrne M, Cantrill D, Crayn D, Fitzgerald A, King G *et al.* (2018). Genomics for Australian plants: developing genomic resources for the Australian plant community. (ABSTRACT) In *Mind the Gap: Australasian Systematic Botany Society 2018 Conference, Brisbane Botanic Gardens* p. 67
- Brown AP, Davis RW (2019). *Eremophila oldfieldii* subsp. *papula*, *E. sericea* and *E. xantholaema* (Scrophulariaceae), three new taxa from Western Australia. *Nuytsia* **30**, 25-31
- Brown VS, Ritchie AL, Stevens JC, Harris RJ, Madsen MD, Erickson TE (2019). Protecting direct seeded grasses from herbicide application: can new extruded pellet formulations be used in restoring natural plant communities? *Restoration Ecology* **27**, 488-494
- Bruce J, Byrne M, Burnham Q, Lemson K, Horwitz P, Koenders A (2018). *Reedia spathacea* F.Muell.: phylogeography and population structure. (POSTER ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* 116-117
- Bruce J, Koenders A, Burnham Q, Byrne M, Lemson K, Horwitz P (2018). Assessing relictual status via alpha and beta diversity. (POSTER ABSTRACT) In *The Royal Society of Western Australia Symposium, 2018: Program & Abstracts* p. 38
- Bruce J, Koenders A, Lemson K, Burnham Q, Byrne M, Horwitz P (2018). *Reedia spathacea* F.Muell.: phylogeography and population structure. (ABSTRACT) In *Mind the Gap: Australasian Systematic Botany Society 2018 Conference, Brisbane Botanic Gardens* p. 60
- Brundrett M, Wisolith A, Collins M, Longman V, Clarke K (2019). Several complimentary plant establishment methods are required to restore banksia woodland. (ABSTRACT) In *Nature City Seminar: Book of Abstracts* (ed L Commander). p. 6
- Bull JP, Dillon SJ, Brealey DR (2019). *Acacia corusca* (Fabaceae: Mimosoideae), a new species from the Pilbara bioregion in north-western Australia. *Nuytsia* **30**, 19-22
- Bunn E, Turner S (2019). Threatened plant translocation case study: *Symonanthus bancroftii* (Bancroft's symonanthus), Solanaceae. *Australasian Plant Conservation* **27(3)**, 16-18
- Burbidge A (2018). Night Parrot by Penny Olsen 2018. Published by CSIRO Publishing. (BOOK REVIEW) *Western Australian Bird Notes* **168**, p. 7
- Burbidge A (comp) (2019). Bibliography for Carnaby's black-cockatoo (*Calyptorhynchus latirostris*). Available at https://birdlife.org.au/documents/Bibliography_for_Carnabys_Black-Cockatoo.pdf. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 26 p.
- Burbidge A, Blythman M, Danks A, Hamilton N (2019). Bringing back the birds of the Montebellos. *Landscape* **34(3)**, 28-33
- Burbidge A, Comer S, Utber D, Pinder J, Thomas A, Berryman A (2019). Parks and Wildlife update: South West Fauna Recovery Project (SWFRP). *Friends of the Western Ground Parrot Newsletter* **81**, 1-4
- Burbidge AH, Cowen S, Comer S, Ford S (2019). Judging success in translocations of birds to islands. (ABSTRACT) In *Island Arks, Rottnest Island, Western Australia, 11-15th February 2019* p. 22

- Burrows N (2018). Conflicting evidence: prescribed burning: when evidence is not the reality. PowerPoint presentation at AFAC annual conference, Perth, 6-7 September 2018. 28 p.
- Burrows N, Liddelow G, Thoomes E, Ambrose C, Ambrose D (2018). Aerial and ground baiting, Matuwa 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 15 p.
- Burrows N, Ward B, Wills A, Williams M, Cranfield R (2019). Fine-scale temporal turnover of jarrah forest understory vegetation assemblages is independent of fire regime. *Fire Ecology* **15**:10
- Burrows ND (2018). Feral animals in the semi-arid and arid regions of Australia: origins, impacts and control. In *On the Ecology of Australia's Arid Zone* (ed H Lambers). pp. 331-373. Springer, Cham
- Butcher R (2018). Making it official: formal description of two orange-flowered *Tephrosia* (Fabaceae: Millettiae) from north-west Western Australia. *Nuytsia* **29**, 251-267
- Butcher R (2018). Treating *Tephrosia* (Fabaceae) for the eFlora of Australia: project progress and plans. (ABSTRACT) In *Mind the Gap: Australasian Systematic Botany Society 2018 Conference, Brisbane Botanic Gardens* p. 52
- Butcher R, Hislop M (2019). *Gastrolobium* sp. Harvey (G.J.Keighery 16821) (Fabaceae) is not distinct from *G. capitatum*. *Nuytsia* **30**, 23-24
- Byrne M (2018). A molecular journey in conservation genetics. *Pacific Conservation Biology* **24**, 235-243
- Byrne M (2018). Moving plants: revealing the past and informing the future. (ABSTRACT) In *APCC12 abstracts: 12th Australasian Plant Conservation Conference 2018, 11-15 November 2018, CSIRO, Canberra* p. 6
- Byrne M (2019). Genetics and ecology of plant species occurring on the banded iron formations in the Yilgarn, Western Australia. *Australian Journal of Botany* **67**, 165-171
- Byrne M (2019). Moving plants: revealing the past and informing the future. *Australasian Plant Conservation* **27**, 3-5
- Byrne M, Binks R, Wilkins C, Bradbury D, Markey A (2018). Conservation genomics for taxon delimitation and management of rare and threatened plants. (ABSTRACT) In *Mind the Gap: Australasian Systematic Botany Society 2018 Conference, Brisbane Botanic Gardens* p. 73
- Byrne M, Broadhurst L, Leishman M, Belov K (2018). Women in conservation science making a difference. *Pacific Conservation Biology* **24**, 209-214
- Byrne M, Joseph L, Yeates DK, Roberts JD, Edwards D (2018). Evolutionary history. In *On the Ecology of Australia's Arid Zone* (ed H Lambers). pp. 45-75. Springer, Cham
- Byrne M, Krauss SL, Millar MA, Elliott CP, Coates DJ, Yates C *et al.* [Binks RM, Nistelberger H, Butcher R, Barrett M, Gibson NJ] (2019). Persistence and stochasticity are key determinants of genetic diversity in plants associated with banded iron formation inselbergs. *Biological Reviews* **94**, 753-772
- Byrne M, Van Leeuwen S, Onton K (2018). Strategic science: planning for the future. *Landscape* **34**(1), 10-17
- Cale D, Pinder A (2019). Waterbird and invertebrate communities at Toolibin and Walbyring lakes during the 2017 fill event. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 40 p.
- Cale D, Pinder A (2019). Wheatbelt wetland biodiversity monitoring: fauna monitoring at Lake Pleasant View 1999-2012. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 28 p.
- Carr J, Rutherford J (2018). A review of hydrochemistry monitoring data: Lake Warden wetland system. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 66 p.
- Chabanne D, Marley S, Menzies J, Nicholson K, Raudino H, Salgado Kent C (2019). Dolphin Watch. *Landscape* **34**(3), 12-19
- Chapman J, Burrows N (2018). Remote sensing and spatial analysis. *Landscape* **34**(1), p. 17
- Chapman J, Zdunic K (2019). Red Hill annual desktop fire regime monitoring, 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 29 p.
- Chapman J, Zdunic K (2019). Yarraloola annual desktop fire regime monitoring, 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 27 p.
- Chilton AM, Munoz-Rojas M, Neilan BA (2019). Australian biocrusts in arid land rehabilitation. (ABSTRACT) In *AusME 2019, Australian Microbial Ecology Conference, 11-13 February 2019, University of Western Australia* 20-21
- Cinner JE, Maire E, Huchery C, MacNeil MA, Graham NAJ, Mora C *et al.* [Wilson SK] (2018). Gravity of human impacts mediates coral reef conservation gains. *Proceedings of the National Academy of Sciences of the USA* **115**, e6116-e6125
- Clarke A, Comer S (2018). Australasian bittern: research and monitoring techniques in selected wetlands along the south coast of Western Australia. (ABSTRACT) In *The Australasian Bittern & Its Wetlands: a Symposium, November 21st, 2018* 6-7
- Coates D, Dillon R, Barrett S (2018). Threatened plant translocation case study: *Banksia brownii* (feather leaved Banksia), Proteaceae. *Australasian Plant Conservation* **27**(1), 3-6
- Coates D, Monks L, Dillon R (2018). Plant mating systems and assessing translocation success. (ABSTRACT) In *APCC12 abstracts: 12th Australasian Plant Conservation Conference 2018, 11-15 November 2018, CSIRO, Canberra* p. 10
- Coates DJ, Byrne M, Moritz C (2018). Genetic diversity and conservation units: dealing with the species-population continuum in the age of genomics. *Frontiers in Ecology and Evolution* **6**:165
- Cochrane A (2019). Multi-year sampling provides insight into the bet-hedging capacity of the soil-stored seed reserve of a threatened *Acacia* species from Western Australia. *Plant Ecology* **220**, 241-253
- Cochrane A, Crawford A (2018). Western Australia's safe deposit box. (ABSTRACT) In *APCC12 abstracts: 12th Australasian Plant Conservation Conference 2018, 11-15 November 2018, CSIRO, Canberra* p. 21
- Cochrane A, Crawford A, Monks, L (2018). Making a difference: the impact of seed conservation and translocation on threatened plant recovery. (ABSTRACT) In *APCC12 abstracts: 12th Australasian Plant Conservation Conference 2018, 11-15 November 2018, CSIRO, Canberra* p. 24
- Comer S, Burbidge A, Mair G, Butler S (2019). Bushfire impacts western ground parrots: again. *Western Australian Bird Notes* **169**, 19-20
- Comer S, Burbidge A, Mair G, Utber D, Syme N (2018). Western ground parrot. Fire Management Information Note **S13**. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 16 p.
- Comer S, Butler S, Massenbauer E, Cowen S, Utber D, Atkins D *et al.* (2019). Blazing arks, potential refugia and management of threatened species on Mondrain Island. (ABSTRACT) In *Island Arks, Rottnest Island, Western Australia, 11-15th February 2019* p. 23
- Commander L (ed) (2019). Nature City Seminar: Book of Abstracts. 23 p.
- Commander L, Auld T, Rossetto M, Ooi M, Reiter N, Swarts N *et al.* [Monks L] (2018). Pre-translocation assessment of biology and ecology. In *Guidelines for the Translocation of Threatened Plants in Australia* (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 31-45. Australian Network for Plant Conservation, Canberra

- Commander L, Merino Martin L, Golos P, Elliott C, Stevens J, Miller B (2018). Restoring a threatened ecological community following mining. (ABSTRACT) In *APCC12 abstracts: 12th Australasian Plant Conservation Conference 2018, 11-15 November 2018, CSIRO, Canberra* p. 16
- Commander LE, Coates DJ, Broadhurst L, Offord CA, Makinson RO, Matthes M (2018). *Guidelines for the Translocation of Threatened Plants in Australia*. Third Edition. Australian Network for Plant Conservation, Canberra. 168 p.
- Corey B, Radford IJ (2018). Iconic and threatened: managing fire and feral animals to conserve small mammals. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham et al.). pp. 252-269. Kimberley Society, Perth
- Cowan M (2018). Reptiles of Dirk Hartog Island. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 15 p.
- Cowan M, Burbidge A (2018). Peterswald map sheet terrestrial vertebrate fauna survey: Great Victoria Desert, Western Australia. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 32 p.
- Cowan M, Teale R, Schmitt L, How R (2019). Variation in the herpetofauna on islands of the Houtman Abrolhos archipelago, Western Australia. (ABSTRACT) In *Island Arks, Rottneest Island, Western Australia, 11-15th February 2019* p. 57
- Cowen S, Rayner K, Scheelen L, Sims C, Gibson L (2019). Dirk Hartog Island National Park Ecological Restoration Project: stage two, year one, translocation and monitoring report. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 62 p.
- Cowen S, Sims C, Angus J, Garretson S, Rayner K, Morris K (2019). Wirruwana's wallabies: translocations of banded and rufous hare-wallabies to Dirk Hartog Island, Western Australia. (ABSTRACT) In *Island Arks, Rottneest Island, Western Australia, 11-15th February 2019* p. 19
- Cramer V, Dunlop J (2018). The ecology of the northern quoll (*Dasyurus hallucatus*) in the Pilbara bioregion, Western Australia: project plans for 2016-2020. Department of Environment and Conservation, Kensington, WA. 26 p.
- Crawford A (2018). Back from the dead: the rediscovery of a presumed extinct *Acacia*. Available at <http://seedpartnership.org.au/node/327>. Australian SeedBank Partnership, Canberra. 1 p.
- Crawford A (2018). Back from the dead: the rediscovery of a presumed extinct *Acacia*. Available at: <https://www.facebook.com/australianseedbankpartnership/posts/1167532256745778>. ABC South West, Bunbury
- Crawford A (2018). On the road to recovery from extinction: collecting seed from the pyramid mulla-mulla. *Bushland News* **107**, 9-10
- Cross A, Barrett M, Barrett R, Hopkins A, Birnbaum C, Burgess T et al. [Merritt D, Turner S] (2018). Small size, huge value: freshwater rockpools of the Kimberley. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham et al.). pp. 32-33. p. 25. Kimberley Society, Perth
- Cross A, Myers C, Mitchell C, Cross S, Waina R, Mucina L et al. (2018). Kimberley ants: a treasure trove of biodiversity. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham et al.). pp. 158-159. Kimberley Society, Perth
- Cross S, Bateman P, Tomlinson S, Craig M, Dixon K (2018). How do animals respond to mine site restoration? (POSTER ABSTRACT) In *The Royal Society of Western Australia Symposium, 2018: Program & Abstracts* p. 43
- Dalziell E, Merritt D, Tomlinson S, Withers P (2018). Seed banking Western Australian native species: short-lived seeds and novel methods of assessing longevity. (ABSTRACT) In *ISSS 2018, Fort Collins, Colorado, USA, the Second Seed Longevity Workshop, July 30th-August 1st* p. 23
- Dalziell EL (2018). Preserving Australian waterlilies through seed storage. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham et al.). pp. 96-97. Kimberley Society, Perth
- Dalziell EL (2018). Tropical waterlilies: ancient flowers of Western Australia. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham et al.). pp. 80-95. Kimberley Society, Perth
- Dalziell EL, Baskin CC, Baskin JM, Young RE, Dixon KW, Merritt DJ (2019). Morphophysiological dormancy in the basal angiosperm order Nymphaeales. *Annals of Botany* **123**, 95-106
- Dalziell EL, Erickson TE, Hidayati SN, Walck JL Merritt DJ (2018). Alleviation of morphophysiological dormancy in seeds of the Australian arid-zone endemic shrub, *Hibbertia glaberrima* F.Muell. (Dilleniaceae). *Seed Science Research* **28**, 286-293
- Dalziell EL, Funnekotter B, Mancera RL, Merritt DJ (2019). Seed storage behaviour of tropical members of the aquatic basal angiosperm genus *Nymphaea* L. (Nymphaeaceae). *Conservation Physiology* **7**: coz021
- Danks M, Ruthrof K, O'Hara G, Power M, Bunce M, Misra S et al. (2018). Harnessing the microbes associated with soil water repellency to enhance plant survival and growth. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 178
- Danks MA, Hopkins AJM, Power MWP, Bunce M, Birnbaum C, de Meyer SE et al [Ruthrof KX] (2019). Microbial assemblages of post-mining soils on Christmas Island: beneficial microbes for agricultural production. (ABSTRACT) In *AusME 2019, Australian Microbial Ecology Conference, 11-13 February 2019, University of Western Australia* 21-22
- Davis B (2018). Bussell's last stand: saving *Caladenia busselliana* from the brink of extinction. *For People & Plants* **104**, 30-32
- Davis B (2018). The queens of Kings Park. *For People & Plants* **104**, p. 33
- Davis RA, Lohr CA, Roberts JD (2019). Frog survival and population viability in an agricultural landscape with a drying climate. *Population Ecology* **61**, 102-112
- Davis RW, Hammer TA (2018). *Ptilotus yapukaratja* (Amaranthaceae), a new species from the Gascoyne bioregion of Western Australia. *Nuytsia* **29**, 157-160
- Davison E (2019). Identifying some local mushrooms. *Bushland News* **109**, p. 13
- Davoodian N, Bergemann SE, Hosaka K, Raspé O, Bougher NL, Fechner NA et al. (2018). A global view of *Gyroporus*: molecular phylogenetics, diversity patterns and new species. *Mycologia* **110**, 985-995
- Davoodian N, Bougher NL, Fechner NA, Bergemann SE, Halling RE (2019). Three new species of *Gyroporus* (Boletales: Basidiomycota) from Australia. *Muelleria* **37**, 101-107
- DBCA (2019). Dirk Hartog Island National Park ecological restoration project. Stage one, final report, February 2012-February 2019. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 35 p.
- De Brauwier M, Gordon LM, Shalders TC, Saunders BJ, Archer M, Harvey ES et al. (2019). Behavioural and pathomorphological impacts of flash photography on benthic fishes. *Scientific Reports* **9**:748
- De Brauwier M, Saunders BJ, Shalders TC (2019). Flash photography doesn't harm seahorses: but don't touch. *The Conversation* **Jan**, 1-5

- De Meyer SE, Ruthrof KX, Edward T, Hopkins AJM, Hardy G, O'Hara G *et al.* (2018). Diversity of endemic rhizobia on Christmas Island: implications for agriculture following phosphate mining. *Systematic and Applied Microbiology* **41**, 641-649
- Densmore VS (2019). Key factors contributing to two pyrocumulonimbus clouds erupting during a prescribed burn in Western Australia. Paper presented at Sixth International Fire Behavior and Fuels Conference, Sydney, April 29-May 3, 2019. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 6 p.
- Deshpande AS, Krishnan S, Janarthanam MK, Maslin BR (2019). Annotated checklist of *Senegalia* and *Vachellia* (Leguminosae: Mimosoideae) for the Indian subcontinent. *Nordic Journal of Botany* **34**:e02047
- Dethmers K, Trembl E, Leiper I, Adnyana IBW, McMahon C, Jensen MP *et al.* [Whiting SJ] (2019). Ghost nets jeopardise the remaining olive ridley populations of the SE Asia-W Pacific region. (ABSTRACT) In *Proceedings of the Thirty-Sixth Annual Symposium on Sea Turtle Biology and Conservation, 29 February to 4 March 2016, Lima, Peru* (comps JC Mangel, A Rees, M Pajuelo *et al.*). p. 191
- DiBattista JD, Berry O, Bunce M, Evans RD, Feng M, Gajdzik L *et al.* (2018). Genomics reveals patterns of dispersal, cryptic lineages and vagrant reef fish along the coast of Western Australia. (ABSTRACT) In *Australian Marine Sciences Association, 55th Annual Conference, Adelaide, 1-5 July 2018: Program Book & Abstracts* p. 106
- Dillon R, Benwell A, Emery N, Monks L, Offord C (2018). Pre-translocation preparation. In *Guidelines for the Translocation of Threatened Plants in Australia* (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 66-87. Australian Network for Plant Conservation, Canberra
- Dillon R, Monks L, Coates D (2018). Establishment success and persistence of threatened plant translocations in south west Western Australia: an experimental approach. *Australian Journal of Botany* **66**, 338-346
- Dixon B, Krauss S (2019). Threatened plant translocation case study: *Grevillea scapigera* (Corrigin grevillea), Proteaceae. *Australasian Plant Conservation* **27(3)**, 22-25
- Doherty TS, Davis NE, Dickman CR, Forsyth DM, Letnic M, Nimmo DG *et al.* [Palmer R] (2019). Continental patterns in the diet of a top predator: Australia's dingo. *Mammal Review* **49**, 31-44
- Dormontt EE, van Dijk K-J, Bell KL, Biffin E, Breed MF, Byrne M *et al.* (2018). Advancing DNA barcoding and metabarcoding applications for plants requires systematic analysis of herbarium collections: an Australian perspective. *Frontiers in Ecology and Evolution* **6**:134
- Duncan R, Dexter N, Hone J, Wayne A (2018). The dynamics of population release. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 51
- Dundas SJ, Hopkins AJM, Ruthrof KX, Tay NE, Burgess TI, Hardy G St J *et al.* (2018). Digging mammals contribute to rhizosphere fungal community composition and seedling growth. *Biodiversity and Conservation* **27**, 3071-3086
- Dundas SJ, Ruthrof KX, Hardy GESJ, Fleming PA (2019). Pits or pictures: a comparative study of camera traps and pitfall trapping to survey small mammals and reptiles. *Wildlife Research* **46**, 104-113
- Dunlop J (2019). Quolls spotted in the desert. *Landscape* **34(3)**, 20-23
- Dunlop J, Birch N, Moore H (2018). Pilbara northern quoll research program: 2017 annual report. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 44 p.
- Dunlop J, Birch N, Moore H, Cowan M (2019). Pilbara northern quoll research program, 2018 annual report. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 49 p.
- Duvall MR, Saarela JM, Burke SV, Wysocki WP, Barrett MD, Clark LG *et al.* (2018). A 250 plastome phylogeny of the grass family (Poaceae). In *Abstracts: 6th International Conference on Comparative Biology of Monocotyledons et al.: Natal, Brazil, 07-12 October 2018* 35-36
- Dziminski M, Carpenter F (2019). Genotyping of bilby scats collected from Roy Hill Mine Site, Pilbara, Western Australia. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 6 p.
- Dziminski M, Carpenter F (2019). Genotyping of bilby scats collected from the Tanami Desert, Northern Territory. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 3 p.
- Dziminski M, Carpenter F, Morris F (2019). Abundance monitoring of bilbies at Warralong, Western Australia, using DNA extracted from scats. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 10 p.
- Dziminski M, van Leeuwen S (2019). Dampier Peninsula Bilby Offset Project threat management plan. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 39 p.
- Dziminski MA, Bettink KA, Carpenter FM, Dickinson R, MacKenzie DI, Shovellor W *et al.* (2018). Greater bilby survey: La Grange project area: draft final report. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 112 p.
- Elliott C, Lewandowski W, Stevens J (2018). Three tonne rock breaker and teaspoon expose charismatic blushing tetraheca. *For People & Plants* **104**, 26-29
- Elliott C, Turner S, Bunn E (2019). Conserving Western Australia's threatened flora. *ESA Bulletin* **49**, 4-5
- Elliott C, Wilkinson K, Lewandowski W, Stevens J, Turner S (2019). Threatened plant translocation case study: *Tetradlea erubescens*, Elaeocarpaceae. *Australasian Plant Conservation* **27(3)**, 19-21
- Elliott CP, Lewandowski W, Miller BP, Barrett M, Turner SR (2019). Identifying germination opportunities for threatened plant species in episodic ecosystems by linking germination profiles with historic rainfall events. *Australian Journal of Botany* **67**, 256-267
- Emery N, Taylor D, Makinson B, Reiter N, North T, Commander L *et al.* [van Leeuwen S] (2018). Community participation and support. In *Guidelines for the Translocation of Threatened Plants in Australia* (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 140-145. Australian Network for Plant Conservation, Canberra
- Evans R, Field S, Wilson S, Moore J, Shedrawi G, Crane K (2018). Gorgon Dredge Offset Monitoring Evaluation and Reporting Project: final report. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 107 p.
- Evans RD, Berry O, Binks R, Byrne M, DiBattista JD, van Dijk K-J *et al.* [Murray K, Pitt G, Ryan N] (2018). Dispersal patterns for taxa with differing reproductive characteristics along the Western Australia coastline. (ABSTRACT) In *Australian Marine Sciences Association, 55th Annual Conference, Adelaide, 1-5 July 2018: Program Book & Abstracts* p. 115
- Evans RD, Ryan NM, Travers MJ, Feng M, Hitchen Y, Kennington WJ (2019). A seascape genetic analysis of a stress-tolerant coral species along the Western Australian coast. *Coral Reefs* **38**, 63-78
- Fernandes PM Sil A, Ascoli D, Cruz MG, Alexander ME, Rossa CG *et al.* [Burrows N, McCaw L] (2018). Drivers of wildland fire behaviour variation across the Earth. In *Advances in Forest Fire Research 2018* (ed DX Viegas). Imprensa da Universidade de Coimbra, Coimbra. 1267-1270 p.
- Fernandez-Carrillo A, McCaw L, Tanase MA (2019). Estimating prescribed fire impacts and post-fire tree survival in eucalyptus forests of Western Australia with L-band SAR data. *Remote Sensing of Environment* **224**, 133-144
- Field S, Waples K (2018). A regional view: using science to support conservation management. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham *et al.*). pp. 284-287. Kimberley Society, Perth

- Fomichev CI, Briggs BG, Macfarlane TD, Sokoloff DD (2019). Structure and development of female flowers in basal restiids, *Anarthria*, *Lyginia* and *Hopkinsia* (Restionaceae s.l.): further evidence of multiple pathways of gynoeceum reduction in wind-pollinated lineages of Poales. *Botanical Journal of the Linnean Society* **190**, 117-150
- Fossette-Halot S (2018). *Turtle Monitoring Field Guide: North West Shelf Flatback Turtle Conservation Program*. Edition 3. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 66 p.
- Foster CN, O'Loughlin LS, Sato CF, Westgate MJ, Barton PS, Pierson JC *et al.* [Chapman J] (2019). How practitioners integrate decision triggers with existing metrics in conservation monitoring. *Journal of Environmental Management* **230**, 94-101
- Friend JA, Bougher NL, Button TA (2019). Trial translocations to Middle Island, Recherche Archipelago, provide positive assessment of habitat suitability for the world's rarest marsupial, Gilbert's potoroo. (ABSTRACT) In *Island Arks, Rottnest Island, Western Australia, 11-15th February 2019* p. 24
- Fulton CJ, Abesamis RA, Berkström C, Depczynski M, Graham NAJ, Holmes TH *et al.* [Wilson SK] (2019). Form and function of tropical macroalgal reefs in the Anthropocene. *Functional Ecology* **32**, 989-999
- Funnekotter AV, Millar M, Krauss SL, Nevill PG (2019). Phylogeographic analyses of *Acacia karina* (Fabaceae) support long term persistence of populations both on and off banded ironstone formations. *Australian Journal of Botany* **67**, 194-204
- Getzin S, Yizhaq H, Munoz-Rojas M, Wiegand K, Erickson T (2019). A multi-scale study of Australian fairy circles using soil excavations and drone-based image analysis. *Ecosphere* **10**:e02620
- Gibson L (2018). Shedding new light on the cryptic world of subterranean fauna: an end user driven research program. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* 332-333
- Gibson L, Humphreys WF, Harvey M, Hyder B, Winzer A (2019). Shedding light on the hidden world of subterranean fauna: a transdisciplinary research approach. *Science of the Total Environment* **684**, 381-389
- Gibson L, Köhler F (2018). Species diversity and composition: land snails on Kimberley islands. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham *et al.*). pp. 160-161. Kimberley Society, Perth
- Gibson LA (2018). Treasures revealed: a biodiversity survey of the Kimberley islands. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham *et al.*). pp. 138-157. Kimberley Society, Perth
- Gibson N (2018). Availability of vegetation plot data in Western Australia: a reply to Gellie *et al.* *Phytocoenologia* **48**, 321-324
- Gibson N, Brown K, Paczkowska G (2019). Temporal changes in threatened ephemeral claypans over annual and decadal timescales in south-west Australia. *Australian Journal of Botany* **66**, 609-617
- Godfrey S, Northover A, Wayne A, Lymbery A, Thompson RCA (2018). Conserving hosts at the peril of their parasites? Conservation and parasite extinction in the woylie. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* 288-289
- Golos P (2019). Fires, floods, flies and research in the Great Sandy Desert. *For People & Plants* **105**, 22-26
- Gosper C (2019). Research update: effects of time since fire on woodland birds. *Woodlands on the Wing* **18**, p. 10
- Gosper C, Williams M (2018). Using ants to find a butterfly. *Land-scope* **34(1)**, p. 27
- Gosper CR, Fox E, Burbidge AH, Craig MD, Douglas TK, Fitzsimons JA *et al.* [Yates CJ] (2019). Multi-century periods since fire in an intact woodland landscape favour bird species declining in an adjacent agricultural region. *Biological Conservation* **230**, 82-90
- Gosper CR, Hopley T, Byrne M, Hopper SD, Prober SM, Yates CJ (2019). Phylogenomics shows lignotuber state is taxonomically informative in closely related eucalypts. *Molecular Phylogenetics and Evolution* **135**, 236-248
- Gosper CR, Yates CJ, Cook GD, Harvey JM, Liedloff AC, McCaw WL *et al.* (2018). A conceptual model of vegetation dynamics for the unique obligate-seeder eucalypt woodlands of south-western Australia. *Austral Ecology* **43**, 681-695
- Government of Western Australia (2019). 2018 south west vegetation complex statistics, current as of March 2019. Available at: <https://catalogue.data.wa.gov.au/dataset/dbca>
- Government of Western Australia (2019). 2018 statewide vegetation statistics incorporating the CAR reserve analysis (full report), current as of March 2019. Available at: <https://catalogue.data.wa.gov.au/dataset/dbca-statewide-vegetation-statistics>
- Government of Western Australia (2019). 2018 statewide vegetation statistics incorporating the CAR reserve analysis (simplified report), current as of March 2019. Available at: <https://catalogue.data.wa.gov.au/dataset/dbca-statewide-vegetation-statistics>
- Graham NAJ, Wilson SK, Carr P, Hoey AS, Jennings S, MacNeil MA (2018). Seabirds enhance coral reef productivity and functioning in the absence of invasive rats. *Nature* **559**, 250-253
- Gray F, Cochrane A, Poot P (2019). Provenance modulates sensitivity of stored seeds of the Australian native grass *Neurachne alopecuroidea* to temperature and moisture availability. *Australian Journal of Botany* **67**, 106-115
- Groom C, Mawson P (2019). Urban living for black cockatoos: hazards and solutions. (ABSTRACT) In *Nature City Seminar: Book of Abstracts* (ed L Commander). p. 11
- Grundler MR, Singhal S, Cowan MA, Rabosky DL (2019). Is genomic diversity a useful proxy for census population size? Evidence from a species-rich community of desert lizards. *Molecular Ecology* **28**, 1664-1674
- Guerin GR, Andersen AN, Rossetto M, van Leeuwen S, Byrne M, Sparrow B *et al.* (2018). When macroecological transitions are a fiction of sampling: comparing herbarium records to plot-based species inventory data. *Ecography* **41**, 1864-1875
- Guerin GR, Andersen AN, Rossetto M, van Leeuwen S, Byrne M, Sparrow B *et al.* (2019). Consistent sorting but contrasting transition zones in plant communities along bioclimatic gradients. *Acta Oecologica* **95**, 74-85
- Gunn BF, Murphy DJ, Walsh NG, Conran JG, Pires JC, Macfarlane TD *et al.* (2018). Phylogenomics of Australian (non-Orchidaceae) Asparagales. In: *Abstracts: 6th International Conference on Comparative Biology of Monocotyledons et al.: Natal, Brazil, 07-12 October 2018* 58-59
- Haberstroh J, McLean D, Holmes T, Langlois T (2018). Baited video, but not diver video, detects a greater abundance of legal size target species within no-take areas at Ningaloo. (ABSTRACT) In *Australian Marine Sciences Association, 55th Annual Conference, Adelaide, 1-5 July 2018: Program Book & Abstracts* p. 143
- Hammer T, Macintyre P, Brundrett M, Keighery G (2018). Combining approaches to identify biodiversity hotspots in Western Australia. (POSTER ABSTRACT) In *The Royal Society of Western Australia Symposium, 2018: Program & Abstracts* p. 49
- Hammer TA, Davis RW, Thiele KR (2018). A key to *Ptilotus* (Amaranthaceae) in Western Australia. *Nuytsia* **29**, 217-227
- Hammer TA, Davis RW, Thiele KR (2019). Of a different feather: two new species of featherheads from the *Ptilotus macrocephalus* (Amaranthaceae) complex. *Australian Systematic Botany* **32**, 61-70

- Hammer TA, Macintyre PD, Nge FJ, Davis RW, Mucina L, Thiele KR (2018). The noble and the exalted: a multidisciplinary approach to resolving a taxonomic controversy within *Ptilotus* (Amaranthaceae). *Australian Systematic Botany* **31**, 262-280
- Hampson H, Whiting, S (comps) (2018). North West Shelf Flat-back Turtle Conservation Program. Available at: <https://flat-backs.dbca.wa.gov.au/>
- Harvey J (2018). Rare flora search and rescue. *Western Wildlife: Land for Wildlife Newsletter* **22**, 8-9
- Harvey M, Abrams K, Car C, Didham R, Huey J, Humphreys W *et al.* [Pinder A] (2018). Invertebrates in modern WA terrestrial and inland-water environments. (ABSTRACT) In *The Royal Society of Western Australia Symposium, 2018: Program & Abstracts* p. 23
- Hays GC, Bailey H, Bograd SJ, Bowen WD, Campagna C, Carmichael RH *et al.* [Whiting SD] (2019). Translating marine animal tracking data into conservation policy and management. *Trends in Ecology and Evolution* **34**, 459-473
- Heriot S, Asher J, Williams MR, Moro D (2019). The eradication of ungulates (sheep and goats) from Dirk Hartog Island, Shark Bay World Heritage area, Australia. *Biological Invasions* **21**, 1789-1805
- Heriot SM, Asher RJ (2019). The eradication of sheep and goats on Dirk Hartog Island. (ABSTRACT) In *Island Arks, Rottneest Island, Western Australia, 11-15th February 2019* p. 17
- Hidayati SN, Merritt DJ, Turner SR, Dixon KW, Walck JL (2019). Temporal dynamics of seedling emergence among four fire ephemerals: the interplay of after-ripening and embryo growth with smoke. *Seed Science Research* **29**, 104-114
- Hoffmann AA, Rymer PD, Byrne M, Ruthrof KX, Whinam J, McGeoch M *et al.* (2019). Impacts of recent climate change on terrestrial flora and fauna: some emerging Australian examples. *Austral Ecology* **44**, 3-27
- Holmes T, Rule M, Bancroft K, Shedrawi G, Murray K, Wilson S, Kendrick A (2019). Ecological monitoring in the Shark Bay marine reserves 2019. Marine Monitoring Program Report **2**. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 92 p.
- Hopkins AJM, Ruthrof KX, Fontaine JB, Matusick G, Hardy G (2018). Forest die-off following global-change-type drought alters rhizosphere fungal communities. *Environmental Research Letters* **13**:095006
- Hopley T, Byrne M (2018). Connectivity in riparian plants: influence of vegetation type and habitat fragmentation overrides water flow. *Oecologia* **188**, 465-478
- Hueso-González P, Muñoz-Rojas M, Martínez-Murillo JF (2018). The role of organic amendments in drylands restoration. *Current Opinion in Environmental Science and Health* **5**, 1-6
- Huisman J (2018). I see red. *Landscape* **34(2)**, 12-17
- Huisman J (2018). Western Australian Herbarium. *Landscape* **34(1)**, p. 17
- Huisman J, Chapman AR, Richardson B (2018). Twenty years of FloraBase. *Landscape* **34(2)**, 18-21
- Huisman J, Kirkendale L, Wilson N (2019). *Caliphylla*, the green thief. *Landscape* **34(4)**, p. 11
- Huisman JM, Baldock RN (2018). The marine benthic algae of South Australia. *Swainsona* **30**, 33-40
- Hummerston S, Harvey J (2018). Rare flora search and rescue report, 2016-2018. WWF-Australia, Churchlands, WA. 40 p.
- Huss J, Eder M, Miller B, Merritt D (2018). Ingenious banksias: how they master seed protection and release. *For People & Plants* **103**, 22-23
- Huss JC, Fratzi P, Dunlop JWC, Merritt DJ, Miller BP, Eder M (2019). Protecting offspring against fire: lessons from *Banksia* seed pods. *Frontiers in Plant Science* **10**:283
- Jabaily RS, Shepherd KA, Michener PS, Bush CJ, Rivero R, Gardner AG *et al.* (2018). Employing hypothesis testing and data from multiple genomic compartments to resolve recalcitrant backbone nodes in *Goodenia s.l.* (Goodeniaceae). *Molecular Phylogenetics and Evolution* **127**, 502-512
- James S, Brown G, Knight K, Kusabs A, Milne J, Ranatunga D *et al.* (2018). Nagoya Protocol on Access and Benefit-Sharing: implications for herbaria and systematics research. *Australasian Systematic Botany Society Newsletter* **177**, 21-22
- James S, Brown G, Kusabs A, Knight K, Milne P, Ranatunga D (2018). Nagoya Protocol on Access and Benefit-Sharing: implications for herbaria and systematics research. (ABSTRACT) In *Mind the Gap: Australasian Systematic Botany Society 2018 Conference, Brisbane Botanic Gardens* p. 21
- Jellinek S, Wilson KS, Hagger V, Mumaw L, Cooke B, Guerrero AM *et al.* [Erickson TE] (2019). Integrating diverse social and ecological motivations to achieve landscape restoration. *Journal of Applied Ecology* **56**, 246-252
- John J (2018). *The Diatom Flora of Australia. Volume 1, Diatoms from Tasmania: Taxonomy and Biogeography*. Koeltz Botanical, Oberreifenberg, Germany. 656 p.
- Johnson GB, Taylor BM, Robbins WD, Franklin EC, Toonen R, Bowen B *et al.* (2019). Diversity and structure of parrotfish assemblages across the northern Great Barrier Reef. *Diversity* **11**:14
- Johnston M, Algar D, Onus M, Desmond G, Tiller C, Fletcher J *et al.* [Hamilton N] (2019). Declaration on Dirk: feral cats eradicated. *Landscape* **34(3)**, 42-46
- Keighery G (2019). Ranking the conservation status of the Proteaceae worldwide. *Kwongan Matters* **8**, 7-16
- Keighery G, Keighery B (2019). *Carpobrotus*: native and weed species on Perth beaches (PAMPHLET). WA Native and Weed Species Pamphlet **1**. G & B Keighery, Perth. 2 p.
- Keighery G, Keighery B (2019). Native *Senecio* species and beach dune weeds in Western Australia (PAMPHLET). WA Native and Weed Species Pamphlet **2**. G & B Keighery, Perth. 2 p.
- Kendrick A (2018). Kimberley coral monitoring. *Landscape* **34(1)**, p. 15
- Kenneally KF (2018). Kimberley tropical monsoon rainforests of Western Australia: perspectives on biological diversity. *Journal of the Botanical Research Institute of Texas* **12**, 149-228
- Kildisheva OA, Erickson TE, Madsen MD, Dixon KW and Merritt DJ (2019). Seed germination and dormancy traits of forbs and shrubs important for restoration of North American dryland ecosystems. *Plant Biology* **21**, 458-469
- Kinloch J, Pitt, G (2019). Fortescue Marsh Feral Herbivore Project: 2018 animal count and movement analysis. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 22 p.
- Knight K (2019). A slime mould named *Leocarpus fragilis*. *Bushland News* **109**, p. 28
- Krauss S, Dixon B, Ayre B, Anthony J (2018). Measuring and managing genetic erosion in plant translocation: lessons from *Grevillea scapigera*. (ABSTRACT) In *APCC12 abstracts: 12th Australasian Plant Conservation Conference 2018, 11-15 November 2018, CSIRO, Canberra* p. 7
- Krauss S, Hufford K, Veneklaas E (2018). Inbreeding and outbreeding depression in *Stylidium hispidum*: implications for mixing seed sources for ecological restoration. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 250

- Krauss SL, Anthony J (2019). Genetic impacts of habitat loss on the rare banded ironstone formation endemic *Ricinocarpos brevis* (Euphorbiaceae). *Australian Journal of Botany* **67**, 183-193
- Krauss SL, Anthony J (2019). The potential impact of mining on population genetic variation in the banded ironstone formation endemic *Tetralochea erubescens* (Elaeocarpaceae). *Australian Journal of Botany* **67**, 172-182
- Krauss SL, Roberts DG, Phillips RD, Edwards C (2018). Effectiveness of camera traps for quantifying daytime and nighttime visitation by vertebrate pollinators. *Ecology and Evolution* **8**, 9304-9314
- Ladd PG, Yates C, Dillon R, Palmer R (2019). Pollination ecology of *Tetralochea* species from isolated, arid habitats (banded iron formations) in Western Australia. *Australian Journal of Botany* **67**, 248-255
- Lane J, Clarke A, Winchcombe Y (2018). SWWMP and the Australasian bittern: modelling likely futures. (ABSTRACT) In *The Australasian Bittern & Its Wetlands: a Symposium, November 21st, 2018* p. 3
- Legge S, Woinarski J, Burbidge AA, Palmer R, Ringma J, Radford J *et al.* [Morris K, Page M] (2018). Havens for threatened Australian mammals: the contributions of fenced areas and offshore islands to the protection of mammal species susceptible to introduced predators. *Wildlife Research* **45**, 627-644
- Leliaert F, Payo DA, Gurgel CFD, Schils T, Draisma SGA, Saunders GW *et al.* [Huisman JM] (2018). Patterns and drivers of species diversity in the Indo-Pacific red seaweed *Portieria*. *Journal of Biogeography* **45**, 2299-2313
- Leseberg NP, Murphy SA, Jackett NA, Greatwich BR, Brown J, Hamilton N *et al.* (2019). Descriptions of known vocalisations of the night parrot *Pezoporus occidentalis*. *Australian Field Ornithology* **36**, 79-88
- Levy E, Byrne M, Huey JA, Hillyer MJ, Firman RC, Ottewill K (2019). Limited influence of landscape on the genetic structure of three small mammals in a heterogeneous arid environment. *Journal of Biogeography* **46**, 539-551
- Lewandrowski W, Elliott C (2019). The blushing tetralochea: out of the rock they emerge: recruitment of the rare *Tetralochea erubescens* from iconic banded ironstone ranges. *For People & Plants* **105**, 27-29
- Llewelyn J, Choyce NC, Phillips BL, Webb JK, Pearson DJ, Schwarzkopf L *et al.* (2018). Behavioural responses of an Australian colubrid snake (*Dendrelaphis punctulatus*) to a novel toxic prey item (the cane toad *Rhinella marina*). *Biological Invasions* **20**, 2507-2516
- Luu R, Butcher R, Llorens T (2018). Dwellingup synaphea (*Synaphea stenoloba*): interim recovery plan. Department of Biodiversity, Conservation and Attractions, Western Australia, Interim Recovery Plan **388**, 31 p.
- Luu R, Casson N, Llorens T (2018). Mallee box (*Eucalyptus cuprea*): interim recovery plan. Department of Biodiversity, Conservation and Attractions, Western Australia, Interim Recovery Plan **387**, 26 p.
- Luu R, Casson N, Llorens T (2018). Silky eremophila (*Eremophila nivea*): interim recovery plan. Department of Biodiversity, Conservation and Attractions, Western Australia, Interim Recovery Plan **386**, 24 p.
- Luu R, Llorens T (2018). *Hypocalymma sylvestre*: interim recovery plan. Department of Biodiversity, Conservation and Attractions, Western Australia, Interim Recovery Plan **384**, 20 p.
- Luu R, Wege J, Llorens T (2018). Quairading triggerplant (*Stylidium coroniforme* subsp. *amblyphyllum*): interim recovery plan. Department of Biodiversity, Conservation and Attractions, Western Australia, Interim Recovery Plan **385**, 19 p.
- Lyons MN (2019). The gypsum flora and plant communities of Western Australia. (ABSTRACT) In *Book of Abstracts and Field Trip Guide: 2nd International Workshop GYPWORLD, 1-4 April 2019, Reggio Calabria (Italy)* (eds CM Musarella, G Spampinato). p. 14
- Ma H, Erickson TE, Merritt DJ (2018). Seed dormancy regulates germination response to smoke and temperature in a rhizomatous evergreen perennial. *AoB Plants* **10**:ply042
- Markey AS, Wilkins CF, Coppen RA, Lyons MN (2018). Targeted rare and priority flora survey: La Grange project area. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 164 p.
- Mason L, Bateman PW, Miller BP, Wardell-Johnson GW (2019). Ashes to ashes: intense fires extinguish populations of urban short-range endemics. *Austral Ecology* **44**, 514-522
- Matusick G, Ruthrof KX, Kala J, Brouwers NC, Breshears DD, Hardy GE St J (2018). Chronic historical drought legacy exacerbates tree mortality and crown dieback during acute heatwave-compounded drought. *Environmental Research Letters* **13**, 1-14
- Mawson P (2018). Animal breeding. *Landscape* **34(1)**, p. 14
- Mawson P, Rafferty C (2019). Bush-stone curlew reintroduction to metropolitan Perth. (ABSTRACT) In *Nature City Seminar: Book of Abstracts* (ed L Commander). p. 14
- Maxwell SM, Broderick AC, Dutton PH, Fossette-Halot S, Fuentes MMPB, Reina RD (2019). Editorial: Advances in the biology and conservation of marine turtles. *Frontiers in Marine Science* **6**:9
- McCaw L (2018). Forest monitoring. *Landscape* **34(1)**, p. 15
- McCaw L (2018). Understanding the changing fire environment of south-west Western Australia. In *Advances in Forest Fire Research 2018* (ed DX Viegas). Imprensa da Universidade de Coimbra, Coimbra. 173-181 p.
- McCaw L, Hollis J (2019). Evaluating fuel and soil moisture indices as a guide to fuel availability in tall open forests. Abstract of presentation at Sixth International Fire Behavior and Fuels Conference, Sydney, April 29-May 3, 2019. p. 1
- McCaw L, Miller B (2018). Fire science. *Landscape* **34(1)**, p. 13
- McClanahan TR, Schroeder RE, Friedlander AM, Vigliola L, Wantiez L, Caselle JE *et al.* [Wilson SK] (2019). Global baselines and benchmarks for fish biomass: comparing remote reefs and fisheries closures. *Marine Ecology Progress Series* **612**, 167-192
- McKenzie NL, Bullen RD, Cowan MA, Milne DJ (2018). Echolocation and distribution of *Saccolaimus saccolaimus* in north-western Australia. *Records of the Western Australian Museum* **33**, 135-144
- McLean AL, Cooper SJB, Lancaster ML, Gaikhorst G, Lambert C, Moseby K *et al.* (2018). Small marsupial, big dispersal? Broad- and fine-scale genetic structure of an endangered marsupial from the Australian arid zone. *Australian Journal of Zoology* **66**, 214-227
- McMahon K, Sinclair EA, Sherman CDH, van Dijk K-J, Hernawan UE, Verduin J (2018). Genetic connectivity in tropical and temperate Australian seagrass species. In *Seagrasses of Australia: Structure, Ecology and Conservation* (eds AWD Larkin, GA Kendrick, PJ Ralph). pp. 155-194. Springer International, Cham, Switzerland
- Millar M, Coates DJ, Byrne M, Krauss SL, Anthony J, Williams MR *et al.* (2018). Is restoration working? An ecological genetic assessment. (ABSTRACT) In *APCC12 abstracts: 12th Australasian Plant Conservation Conference 2018, 11-15 November 2018, CSIRO, Canberra* p. 9
- Millar MA, Coates DJ, Byrne M, Roberts JD (2019). An integrated genetic approach to provenancing and establishment of founding individuals for restoration in the semiarid midwest region of Western Australia. *Australian Journal of Botany* **67**, 218-233
- Miller B, Merritt D, Dixon K, Poschod P (2018). Residual seed banks, and soil seed bank longevity in a fire-prone shrubland in SW WA. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* 303-304

- Miller B, Symonds D, Barrett M (2019). Persistence of rare species depends on rare events: demography, fire response and phenology of two plant species endemic to a semiarid banded iron formation range. *Australian Journal of Botany* **67**, 268-280
- Miller R, Enright N, Fontaine J, Miller B, Merritt D (2018). Seedling recruitment success linked to season of fire in a Mediterranean-climate woodland. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 302
- Mirfakhraei B, Veneklaas E, Stevens J, Krauss S (2018). Seed sourcing for plant restoration: performance of provenances along a climate gradient under water treatments. (POSTER ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 128
- Monks L, Barrett S, Beecham B, Byrne M, Chant A, Coates D *et al.* [Cochrane JA, Crawford A, Dillon R, Yates C] (2019). Recovery of threatened plant species and their habitats in the biodiversity hotspot of the Southwest Australian Floristic Region. *Plant Diversity* **41**, 59-74
- Monks L, Jusaitis M, Dillon R, Freestone M, Taylor D, Commander L *et al.* (2018). Implementing the translocation and ongoing maintenance. In *Guidelines for the Translocation of Threatened Plants in Australia* (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 88-113. Australian Network for Plant Conservation, Canberra
- Moro D, Dunlop J, Williams MR (2019). Northern quoll persistence is most sensitive to survivorship of juveniles. *Wildlife Research* **46**, 165-175
- Moro D, Palmer, R, Greatwich B, Dickinson R, Anderson H (2018). Browse Island: a journey to Western Australia's most remote nature reserve. *Landscape* **34(2)**, 22-27
- Morris K (2018). Dirk Hartog Island fauna reconstruction. *Landscape* **34(1)**, p. 14
- Morris K, Palmer R, Johnson B, Zainiel R (2019). The eradication of black rats on Direction Island, Cocos Keeling group. (ABSTRACT) In *Island Arks, Rottneest Island, Western Australia, 11-15th February 2019* p. 38
- Moustaka M, Langlois TJ, McLean D, Bond T, Fisher, R, Fearn P *et al.* [Evans R] (2018). The effects of suspended sediment on coral reef fish assemblages and feeding guilds of north-west Australia. *Coral Reefs* **37**, 659-673
- Moustaka M, Mohring MB, Holmes T, Evans RD, Thomson D, Nutt C *et al.* [Wilson SK] (2019). Cross-shelf heterogeneity of coral assemblages in northwest Australia. *Diversity* **11**:15
- Moustaka M, Strydom S (2019). Tropical seagrass: small in size but big in nature. *Landscape* **34(4)**, 50-52
- Muñoz-Rojas M (2018). Soil quality indicators: critical tools in ecosystem restoration. *Current Opinion in Environmental Science and Health* **5**, 47-52
- Munoz-Rojas M, Bateman A, Erickson TE, Chua M, Merritt DJ (2018). Innovative soil strategies for addressing knowledge gaps and enhancing training capabilities in post-mining restoration. In *Landcare for the Future: Book of Abstracts: Santiago de Compostela, July 16-18, 2018* p. 81
- Munoz-Rojas M, Bateman A, Erickson TE, Chua M, Merritt DJ (2018). Innovative soil strategies for addressing knowledge gaps to inform post-mining restoration. Video presentation at LandCare for the Future: Santiago de Compostela, Spain, 16-17 July 2018. Available at: <https://www.youtube.com/watch?v=5GyF82Vfh6Q&feature=youtu.b>
- Muñoz-Rojas M, Chilton A, Liyanage GS, Erickson TE, Merritt DJ, Neilan BA *et al.* (2018). Effects of indigenous soil cyanobacteria on seed germination and seedling growth of arid species used in restoration. *Plant and Soil* **429**, 91-100
- Muñoz-Rojas M, Román JR, Roncero-Ramos B, Erickson TE, Merritt DJ, Aguila-Carricondo P *et al.* (2018). Cyanobacteria inoculation enhances carbon sequestration in soil substrates used in dryland restoration. *Science of the Total Environment* **636**, 1149-1154
- Murphy BP, Woolley LA, Geyle HM, Legge SM, Palmer R, Dickman CR *et al.* (2019). Introduced cats (*Felis catus*) eating a continental fauna: the number of mammals killed in Australia. *Biological Conservation* **237**, 28-40
- Nally S, Greeshaw F, Bickerton D, Reiter N, van Leeuwen S (2018). Policy, approvals and translocation proposals. In *Guidelines for the Translocation of Threatened Plants in Australia* (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 60-65. Australian Network for Plant Conservation, Canberra
- Nayyef A, Merritt D, Turner S, Pritchard D (2018). Enhancement of seed germination of wild plant species through priming. (POSTER ABSTRACT) In *The Royal Society of Western Australia Symposium, 2018: Program & Abstracts* p. 60
- Nilsson K, Renwick J, Ottewell K (2019). Genetic analysis of *Petrogale lateralis lateralis* at two sites in Cape Range National Park. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 14 p.
- Northover AS, Elliot AD, Keatley S, Lim Z, Botero A, Ash A *et al.* [Wayne AF] (2018). Debilitating disease in a polyparasitised woylie (*Bettongia penicillata*): a diagnostic investigation. *International Journal for Parasitology: Parasites and Wildlife* **7**, 274-279
- Northover AS, Godfrey SS, Keatley S, Lymbery AJ, Wayne AF, Cooper C *et al.* [Morris K] (2019). Increased *Trypanosoma* spp. richness and prevalence of haemoparasite co-infection following translocation. *Parasites & Vectors* **12**:126
- O'Donnell A, McCaw L, Cook E, Grierson P (2019). Long-term rainfall dynamics of Western Australia's major cropping region reconstructed from tree rings. (ABSTRACT) In *AMOS ICTMO 2019: Abstract Book, Darwin Convention Centre, 11-14 June 2019* p. 122
- Obbens FJ (2018). Three new perennial species of *Calandrinia* (Montiaceae) from southern Western Australia. *Nuytsia* **29 (2018)**, 193-204
- Onton K, Hassell C (2018). Frequent flyers: the epic migration of Kimberley shorebirds. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham *et al.*). pp. 100-117. Kimberley Society, Perth
- Ottewell K, McArthur S, van Leeuwen S, Byrne M (2019). Cave use by the ghost bat (*Macroderma gigas*) at the West Angelas mine site: survey results October 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 13 p.
- Page M (2018). The Western Australian Australasian bittern recovery plan. (ABSTRACT) In *The Australasian Bittern & Its Wetlands: a Symposium, November 21st, 2018* p. 5
- Page M, Vitali S (2018). Advice to veterinarians regarding the treatment of wildlife. *Veterinary Surgeons Board Western Australia Newsletter* **Jul**, 3-5
- Palmer R, Anderson H, Richards B (2019). Predator control baiting and monitoring program, Yarraloola and Red Hill, Pilbara region, Western Australia: 2018 annual report, year 4. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 59 p.
- Palmer R, Rose AB, Debus SJS (2019). Diet of the peregrine falcon *Falco peregrinus* in inland south-western Australia. *Australian Field Ornithology* **36**, 36-39
- Pearson D, Paxman M, Desmond A, Lindley J, Renwick J (2018). Rebounding rock-wallabies: a translocation success story. *Landscape* **34(2)**, 43-48
- Pedrini S, Lewandowski W, Stevens JC, Dixon KW (2019). Optimising seed processing techniques to improve germination and sowability of native grasses for ecological restoration. *Plant Biology* **21**, 415-424

- Pennells J, Yu Lin T, Schmidt S, Gamage H, Godwin ID, Erickson TE *et al.* (2018). Effects of the growth environment on the yield and material properties of nanocellulose derived from the Australian desert grass *Triodia*. *Industrial Crops and Products* **126**, 238-249
- Penniford M (2019). Changes in aquatic communities in south-western Australia and conservation status of some aquatic invertebrates. (ABSTRACT) In *Program, 15th annual WA Wetland Management Conference, 2019* 12-13
- Penniford M, Pinder A (2018). Aquatic invertebrates in forests. Available at <https://southwestsnapshot.com.au/profiles/aquatic-invertebrates-in-forests/>. South West Catchments Council, Bunbury. 1 p.
- Percy-Bower JM, Parker CM (2019). Updates to Western Australia's vascular plant census for 2018. *Nuytsia* **30**, 1-18
- Pereira P, Bogunovic I, Muñoz-Rojas M, Brevik EC (2018). Soil ecosystem services, sustainability, valuation and management. *Current Opinion in Environmental Science and Health* **5**, 7-13
- Perkins AJ (2018). *Hydrocotyle asterocarpa*, *H. decorata* and *H. perforata* (Araliaceae), three new Western Australian species with spicate inflorescences. *Nuytsia* **29**, 205-215
- Perkins AJ (2018). *Hydrocotyle eichleri*, *H. papilionella* and *H. tuberculata* (Araliaceae), three new species from Western Australia. *Nuytsia* **29**, 233-243
- Perkins AJ (2018). *Hydrocotyle spinulifera* and *H. dimorphocarpa* (Araliaceae), two new Western Australian species with dimorphic mericarps. *Nuytsia* **29**, 57-65
- Perring MP, Erickson TE, Brancalion PHS (2018). Rocketing restoration: enabling the upscaling of ecological restoration in the Anthropocene. *Restoration Ecology* **26**, 1017-1023
- Pinder A (2018). Wetland conservation. *Landscape* **34(1)**, p. 16
- Pinder A, Clarke A, Winchcombe Y, Gale D, Coote M (2019). Surveys of waterbirds using the Lake Warden and Lake Gore Ramsar sites in November 2018 and February 2019, with exploratory analyses of the 2006 to 2019 dataset. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 62 p.
- Pinder A, McMurtrie S, James A (2018). A surprising diversity of aquatic oligochaetes from a subantarctic island. (ABSTRACT) In *Book of Abstracts: 14th International Symposium on Aquatic Oligochaeta, 2018, Japan* p. 32
- Pinder A, Penniford M, Rutherford J, Lane J (2018). Muir-Byenup wetlands acidification case-study. Available at: <https://southwestsnapshot.com.au/aquatic-biodiversity/>. South West Catchments Council, Bunbury. 3 p.
- Pinder A, Swann G (2019). A survey of waterbirds using the Parry Lagoons area of the Ord River Floodplain Ramsar site in May 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 25 p.
- Pink C, Algar D, Green P (2019). Diet of introduced black rats (*Rattus rattus*) on Christmas Island: setting the scene with stomach and stable isotope analysis. (ABSTRACT) In *Island Invasives: Scaling up to Meet the Challenge: Proceedings of the International Conference on Island Invasives 2017* (eds CR Veitch, MN Clout, AR Martin *et al.*). p. 720. IUCN, Gland
- Quinlan K, Pinder A (2019). Science project summary: Getting on board the Aquatic Invertebrates of Australia (AIA) BOLD barcoding project. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 7 p.
- Radford I, Gallagher J, Weier A, Fairman R, Alberts W, Mitchell P *et al.* (2018). Balangarra "right way fire" in the conservation management of threatened Gouldian finches. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 229
- Radford I, Woolley L-A, Corey B, Vigilante T, Wunambal Gaambera Aboriginal Corporation, Hatherley E *et al.* [Fairman R, Carnes K, Start AN] (2019). Prescribed burning benefits threatened mammals in northern Australia. Abstract of presentation at North Australian Savanna Fire and Carbon Forum 2019, 13-14 February 2019 Charles Darwin University, Casuarina Campus. p. 1
- Radford JQ, Woinarski JCZ, Legge S, Baseler M, Bentley J, Burbidge AA *et al.* [Morris K, Page M] (2018). Degrees of population-level susceptibility of Australian terrestrial non-volant mammal species to predation by the introduced red fox (*Vulpes vulpes*) and feral cat (*Felis catus*). *Wildlife Research* **45**, 645-657
- Raudino H, Douglas C, D'Cruz E, Waples K (2019). Snubfin dolphin census in Yawuru Nagulagan/Roebuck Bay. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 15 p.
- Raudino HC, Hunt TN, Waples KA (2018). Records of Australian humpback dolphins (*Sousa sahulensis*) from an offshore island group in Western Australia. *Marine Biodiversity Records* **11**:14
- Rayner K, Lohr C, Speldewinde P, Garretson S, Morris K (2019). Predictive modelling during planning: a retrospective case study of two species translocated to Doole Island in the Exmouth Gulf of Western Australia. (ABSTRACT) In *Island Arks, Rottnest Island, Western Australia, 11-15th February 2019* p. 52
- Ringma J, Legge S, Woinarski J, Radford J, Wintle B, Bentley J *et al.* [Morris K, Page M, Palmer R] (2019). Systematic planning can rapidly close the protection gap in Australian mammal havens. *Conservation Letters* **12**:e12611
- Ritchie A, Svejcar LN, Fontaine JB (2019). Banksia woodlands 30 years in review. (ABSTRACT) In *Nature City Seminar: Book of Abstracts* (ed L Commander). p. 18
- Ritchie AL, Dyer RJ, Nevill PG, Sinclair EA, Krauss SL (2019). Wide outcrossing provides functional connectivity and resilience to habitat fragmentation for old and new *Banksia* populations. *Oecologia* **190**, 255-268
- Robinson JPW, Wilson SK, Robinson J, Gerry C, Lucas J, Assan C, *et al.* (2019). Productive instability of coral reef fisheries after climate-driven regime shifts. *Nature Ecology and Evolution* **3**, 183-190
- Robinson NM, Scheele BC, Legge S, Southwell DM, Carter O, Lintermans M *et al.* [Wayne AF] (2018). How to ensure threatened species monitoring leads to threatened species conservation. *Ecological Management and Restoration* **19**, 222-229
- Robson T, Golos PJ, Stevens J, Reid N (2018). Enhancing tailings revegetation using shallow cover systems in arid environments: hydrogeochemical, nutritional and ecophysiological constraints. *Land Degradation and Development* **29**, 2785-2796
- Rosauer DF, Byrne M, Blom MPK, Coates DJ, Donnellan S, Doughty P, Keogh JS *et al.* (2018). Real-world conservation planning for evolutionary diversity in the Kimberley, Australia, sidesteps uncertain taxonomy. *Conservation Letters* **11**:e12438
- Rutherford J (2019). Identifying water sources that sustain mound springs in the Walyarta Conservation Park. Available at <https://www.dpaw.wa.gov.au/about-us/science-and-research/publications-resources/111-science-division-information-sheets>. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **93/2019**. DBCA, Kensington, WA. 2 p.
- Rutherford J, Cendón DI, Soerenson C, Batty S, Huntley B, Bourke L, *et al.* [Pinder A, Quinlan K, English V, Coote M] (2018). Hydrological conceptualisation of the Walyarta mound springs. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 229 p.
- Ruthrof K (2018). Ecological impacts of extreme climate events. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 253

- Ruthrof K (2018). Prescribed burning in Perth's bushlands: where, when and how much? *Bushland News* **107**, p. 12
- Ruthrof K, Miller B, Fontaine J, Enright N, Miller R, Tangney R (2018). Prescribed burning in Perth's bushlands: where, when and how much? *Murdoch University School of Veterinary and Life Sciences Bulletin* **5.17**, 2 p.
- Ruthrof KX, Breshears DD, Fontaine JB, Froend RH, Matusick G, Kala J *et al.* [Miller BP, Wilson SK] (2018). Subcontinental heat wave triggers terrestrial and marine multi-taxa responses. *Scientific Reports* **8**:13094
- Rycken S, Warren KS, Yeap L, Jackson B, Riley K, Page M *et al.* [Dawson R, Smith K, Mawson P] (2019). Assessing integration of black cockatoos using behavioural change point analysis. *Journal of Wildlife Management* **83**, 334-342
- Rye BL (2018). Placement of three names in *Cyathostemon*, *Hysterobaeckea* and *Oxymyrrhine* (Myrtaceae: Chamelaucieae). *Nuytsia* **29**, 269-270
- Rye BL (2019). An update to the taxonomy of some Western Australian genera of Myrtaceae tribe Chamelaucieae. 6, *Scholtzia*. *Nuytsia* **30**, 33-86
- Saatkamp A, Cochrane A, Commander L, Guja L, Jimenez-Alfaro B, Larson J *et al.* [Dalziel EL, Erickson TE, Golos PJ, Lewandowski W, Merritt D, Miller BP, Miller RG, Tangney R, Tomlinson S, Turner S] (2019). A research agenda for seed-trait functional ecology. *New Phytologist* **221**, 1764-1775
- Saeed A, Huang P, Trayler K, Oldham C, Wang B, Hipsey MR (2018). Integration of routine and high-frequency data to improve 3-D water quality model predictions. (POSTER ABSTRACT) In *Poster Session Abstract Book: GLEON 20, Rottnest Island, 2018* p. 42
- Salgado Kent C, Waples K, Bowles A, Raudino H (2018). Monitoring of humpback whales (Megaptera novaeangliae) at Pender Bay, south Kimberley region. In *Humpback whale use of the Kimberley: understanding and monitoring spatial distribution: WAMSI Kimberley Marine Research Program, KMRP report, Project 1.2.1* pp. 37-59. Western Australian Marine Science Institution, Perth
- Salmon M, Wyneken J, Hamann M, Whiting S (2019). Is juvenile growth pattern and morphology shaped by predation risk? Hypothesis testing through comparisons between flatbacks (*Natator depressus*) and green turtles (*Chelonia mydas*). (ABSTRACT) In *Proceedings of the Thirty-Sixth Annual Symposium on Sea Turtle Biology and Conservation, 29 February to 4 March 2016, Lima, Peru* (comps JC Mangel, A Rees, M Pajuelo *et al.*). p. 29
- Sansom J, Blythman M, Dadour L, Rayner K (2019). Deployment of novel nest-shelters to increase nesting attempts in a small population of rock parrots *Neophema petrophila*. *Australian Field Ornithology* **36**, 74-78
- Sato CF, Westgate MJ, Barton PS, Foster CN, O'Loughlin LS, Pierson JC *et al.* [Chapman J] (2019). The use and utility of surrogates in biodiversity monitoring programmes. *Journal of Applied Ecology* **56**, 1304-1310
- Saunders DA, White NE, Dawson R, Mawson PRM (2018). Breeding site fidelity and breeding pair infidelity in the endangered Carnaby's cockatoo, *Calyptorhynchus latirostris*. *Nature Conservation* **27**, 59-74
- Shedrawi G, Bertram A, Evans M, Kendrick A, Clitheroe E, Bancroft K (2018). Engaging the community: a little penguin citizen science project. Available at <https://www.dpaw.wa.gov.au/about-us/science-and-research/publications-resources/111-science-division-information-sheets>. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **92/2018**. DBCA, Kensington, WA. 2 p.
- Shepherd K, Jabaily R (2018). Vale *Velleia* (and others): the final chapter of our *Goodenia s.l.* saga. (ABSTRACT) In *Mind the Gap: Australasian Systematic Botany Society 2018 Conference, Brisbane Botanic Gardens* p. 48
- Shepherd KA, Wilkins CF (2018). A taxonomic revision of species with a petaloid epicalyx bract allied to *Lasiopetalum bracteatum* (Malvaceae: Byttnerioideae). *Nuytsia* **29**, 161-179
- Shepherd KA, Wilkins CF (2018). Typification of *Lasiopetalum* and an interim key to the Western Australian species of the genus (Malvaceae: Byttnerioideae). *Nuytsia* **29**, 181-192
- Silcock J, Coates D, Commander L, Broadhurst L (2018). Introduction. In *Guidelines for the Translocation of Threatened Plants in Australia* (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 9-14. Australian Network for Plant Conservation, Canberra
- Sims C, Cowen S, Friend T (2019). Monitoring source populations of fauna for the Dirk Hartog National Park Ecological Restoration Project, 2018. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 48 p.
- Sinclair EA, Cambridge ML, Kendrick GA (2019). First report of hybridization in the seagrass genus *Posidonia* (Posidoniaceae). *Aquatic Botany* **156**, 10-13
- Sinclair EA, Ruiz Montoya L, Krauss SL, Anthony JM, Hovey RK, Lowe RJ *et al.* (2018). Seeds in motion: genetic assignment and hydrodynamic models demonstrate concordant patterns of seagrass dispersal. *Molecular Ecology* **27**, 5019-5034
- Skates LM, Paniw M, Cross AT, Ojeda F, Dixon KW, Stevens JC *et al.* (2019). An ecological perspective on plant carnivory beyond bogs: nutritional benefits of prey capture for the Mediterranean carnivorous plant *Drosophyllum lusitanicum*. *Annals of Botany* **124**, 65-76
- Smith K, Burbidge A, King R (2018). Menacing or misunderstood? Understanding magpies. *Landscape* **34(1)**, 37-39
- Sokoloff DD, Marques I, Macfarlane TD, Remizowa MV, Pellicer J, Hidalgo O *et al.* (2019). Cryptic species in an ancient flowering-plant lineage (Hydatellaceae, Nymphaeales) revealed by molecular and micromorphological data. *Taxon* **68**, 1-19
- Southgate R, Dziminski MA, Paltridge R, Schubert A, Gaikhorst G (2019). Verifying bilby presence and the systematic sampling of wild populations using sign-based protocols: with notes on aerial and ground survey techniques and asserting absence. *Australian Mammalogy* **41**, 27-38
- Stack G (2018). Felixer: feral cat control development. *Western Wildlife: Land for Wildlife Newsletter* **22**, p. 11
- Stack G (2018). Rodenticide impact: chuditch research. *Western Wildlife: Land for Wildlife Newsletter* **22**, p. 20
- Statton J, Dixon KW, Irving AD, Jackson EL, Kendrick GA, Orth RJ *et al.* [Sinclair EA] (2018). Decline and restoration ecology of Australian seagrasses. In *Seagrasses of Australia: Structure, Ecology and Conservation* (eds AWD Larkin, GA Kendrick, PJ Ralph). pp. 665-704. Springer International, Cham, Switzerland
- Stevens J, Webb M, Byrne M (2018). Science partnerships can deliver restoration solutions, but urban spaces provide other challenges. Abstract of presentation at 4th public symposium and annual meeting of the Ecological Restoration Alliance of Botanic Gardens, 3-5 October, Ontario, Canada. p. 1
- Stevens J, Yates C (2018). Restoration science. *Landscape* **34(1)**, p. 14
- Stevens J, Yates C (2018). Seed banking, tissue culture and cryostorage. *Landscape* **34(1)**, p. 16
- Streczynski R, Clark H, Whelehan LM, Ang S-T, Hardstaff LK, Funnekotter B, Bunn E *et al.* (2019). Current issues in plant cryopreservation and importance for *ex situ* conservation of threatened Australian native species. *Australian Journal of Botany* **67**, 1-15
- Sukhorukov AP, Nilova MV, Krinitsina AA, Zaika MA, Erst AS, Shepherd KA (2018). Molecular phylogenetic data and seed coat anatomy resolve the generic position of some critical Chenopodiaceae (Chenopodiaceae-Amaranthaceae) with reduced perianth segments. *Phytokeys* **109**, 103-128

- Sukhorukov AP, Nilova MV, Krinitsina AA, Zaika MA, Shepherd KA (2018). Molecular phylogenetic data and seed coat morphology resolve the generic position of some critical Chenopodiaceae (Chenopodiaceae-Amaranthaceae) with reduced perianth segments. (ABSTRACT) In *Caryophyllales 2018: Instituto de Biología, UNAM* (comp H Ochoterena). p. 20
- Surtees C, Calver MC, Mawson PR (2019). Measuring the welfare impact of soft-catch leg-hold trapping for feral cats on non-target by-catch. *Animals* **9**:217
- Svejar L, Standish R, Miller B, Stevens J, Fontaine J (2018). Does spatial patterning determine survival of seedlings in ecological restoration after sand mining? (POSTER ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 107
- Swarts N, Hancock N, Beaumont L, Moore JL, van Leeuwen S, Byrne M (2018). Selecting source and recipient sites. In *Guidelines for the Translocation of Threatened Plants in Australia* (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 46-59. Australian Network for Plant Conservation, Canberra
- Swiatek P, Pinder A, Gajda L (2018). Oogenesis and ovary organization in a phreodrilid annelid: *Insulodrilus bifidus*. (ABSTRACT) In *Book of Abstracts: 14th International Symposium on Aquatic Oligochaeta, 2018, Japan* p. 37
- Tangney RJ (2018). Fire intensity, seasonal variation and seeds traits may influence seed fates in banksia woodlands. Thesis (Ph.D.) Curtin University, 2018. 212 p.
- Tangney R (2018). Seed traits shape seed survival of fire of varying intensity and season. (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* p. 303
- Tangney R, Merritt DJ, Fontaine JB, Miller BP (2019). Seed moisture content as a primary trait regulating the lethal temperature thresholds of seeds. *Journal of Ecology* **107**, 1093-1105
- Tarszisz E, Tomlinson S, Harrison ME, Morrogh-Bernard HC, Munn AJ (2018). An ecophysiological model of seed dispersal by orangutans: linking animal movement with gut passage across time and space. *Conservation Physiology* **6**:coy013
- Tay NE, Hopkins AJM, Ruthrof KX, Burgess T, Hardy GESJ, Fleming PA (2018). The tripartite relationship between a bioturbator, mycorrhizal fungi, and a key Mediterranean forest tree. *Austral Ecology* **43**, 742-751
- Teixeira da Silva JA, Kher MM, Soner D, Nataraj M, Dobránszki J, Millar MA (2018). *Santalum* molecular biology: molecular markers for genetic diversity, phylogenetics and taxonomy, and genetic transformation. *Agroforestry Systems* **92**, 1301-1315
- Tejero P, Moore M, Ochoterena H, Martín-Bravo S, Martín-Hernanz S, Fernández-Mazuecos M *et al.* [Lyons M, van Leeuwen S] (2019). Tracking gypsophily across the phylogeny: 3 study cases. (ABSTRACT) In *Book of Abstracts and Field Trip Guide: 2nd International Workshop GYPWORLD, 1-4 April 2019, Reggio Calabria (Italy)* (eds CM Musarella, G Spampinato). p. 26
- Thomas A, Comer S, Pinder J, Berryman A, Burbidge A (2018). Parks and Wildlife update: South West Fauna Recovery Project (SWFRP). *Friends of the Western Ground Parrot Newsletter* **80**, 3-4
- Threatened Species Recovery Hub (2019). Protecting Australian mammals from introduced cats and foxes: the current status and future growth of predator-free havens. Threatened Species Recovery Hub, St Lucia. 16 p.
- Thums M, Jenner C, Newland C, Ferreira L, Waples K, Meekan M (2018). Detecting humpback whales from high resolution satellite imagery. In *Humpback whale use of the Kimberley: understanding and monitoring spatial distribution: WAMSI Kimberley Marine Research Program, KMRP report, Project 1.2.1* pp. 27-36. Western Australian Marine Science Institution, Perth
- Thums M, Jenner C, Udyawer V, Ferreira L, Waples K, Jenner M *et al.* (2018). Modelling the movement and spatial distribution of humpback whales in the nearshore waters of the Kimberley. In *Humpback whale use of the Kimberley: understanding and monitoring spatial distribution: WAMSI Kimberley Marine Research Program, KMRP report, Project 1.2.1* pp. 1-26. Western Australian Marine Science Institution, Perth
- Thums M, Jenner C, Waples K, Salgado-Kent C, Jenner M, Meekan M (2018). Strengths and weaknesses of humpback whale survey techniques in the Kimberley and recommendations for future monitoring. In *Humpback whale use of the Kimberley: understanding and monitoring spatial distribution: WAMSI Kimberley Marine Research Program, KMRP report, Project 1.2.1* pp. 60-68. Western Australian Marine Science Institution, Perth
- Thums M, Jenner C, Waples K, Salgado-Kent C, Meekan M (2018). Humpback whale use of the Kimberley: understanding and monitoring spatial distribution: WAMSI Kimberley Marine Research Program, KMRP report, Project 1.2.1. Western Australian Marine Science Institution, Perth. 79 p.
- Tomlinson S (2018). Some seriously fishy research puts holes in movement barriers. *Conservation Physiology* **6**, p. 1
- Tomlinson S (2019). The mathematics of thermal sub-optimality: nonlinear regression characterization of thermal performance of reptile metabolic rates. *Journal of Thermal Biology* **81**, 49-58
- Tomlinson S, Rummer JL, Hultine KR, Cooke SJ (2018). Crossing boundaries in conservation physiology. *Conservation Physiology* **6**:coy015
- Townsend RA, Huisman JM (2018). Transfer of *Oztralia gabrielsonii* and *Oztralia orbiculata* to *Dawsoniolithon* (Corallinales: Rhodophyta). *Notulae Algarum* **78**, 1-2
- Traylor K (2018). Restocking western school prawn. *Landscape* **34**(1), p. 17
- Tucker T, Pendoley K, Whiting S (2018). Distribution and abundance of nesting marine turtles in the Kimberley: pairing the landscape and local perspectives. In *Marine turtles in the Kimberley: key biological indices required to understand and manage nesting turtles along the Kimberley coast: WAMSI Kimberley Marine Research Program, final report, Project 1.2.2* pp. 11-34. Western Australian Marine Science Institution, Perth
- Tucker A, Whiting S, Pendoley K, FitzSimmons N, Berry O, Mitchell N *et al.* (2018). Questions of scale: collaborative turtle research along the Kimberley's remotest coasts. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham *et al.*). pp. 164-181. Kimberley Society, Perth
- Turner S, Lewandowski W, Dixon KW (2018). A hard nut to crack: germination of the Australian boab. In *The Natural World of the Kimberley* (comps H McGlashan, K Coate, J Gresham *et al.*). pp. 36-37. Kimberley Society, Perth
- Udyawer V, Barnes P, Bonnet X, Brischoux F, Crowe-Riddell J, D'Anastasi B *et al.* [Kendrick A] (2018). Future directions in the research and management of marine snakes. *Frontiers in Marine Science* **5**:399
- Valentine L, Ruthrof K (2018). Scratching below the surface with the quenda. *Bushland News* **107**, 17-19
- Valentine L, Ruthrof K (2019). Scratching below the surface with Australia's digging mammals. Available at <https://www.globalsoil-biodiversity.org/blog>. 7 p.
- Valentine L, Ruthrof K, Hobbs R (2018). Scratching below the surface with marsupial diggers: seedlings grow bigger in the spoils of quenda-dug soils. *Decision Point* **106**, 16-17
- Valentine LE, Ruthrof KX, Fisher R, Hardy G E St J, Hobbs RJ, Fleming PA (2018). Bioturbation by bandicoots facilitates seedling growth by altering soil properties. *Functional Ecology* **32**, 2138-2148

- Van Dongen R, Huntley B (2018). Vegetation cover change assessment on Yarraloola and Red Hill remote sensing monitoring program report, 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 61 p.
- van Dongen RJ, Huntley BG, Keighery GJ (2019). Monitoring vegetation cover using high temporal frequency Landsat imagery on Dirk Hartog Island, Western Australia. (ABSTRACT) In *Island Arks, Rottneest Island, Western Australia, 11-15th February 2019* p. 18
- Van Etten EJB, Burrows ND (2018). On the ecology of Australia's arid zone: fire regimes and ecology of arid Australia. In *On the Ecology of Australia's Arid Zone* (ed H Lambers). pp. 243-282. Springer, Cham
- Van Lier JR, Wilson SK, Depczynski M, Wenger LN, Fulton CJ (2018). Habitat connectivity and complexity underpin fish community structure across a seascape of tropical macroalgae meadows. *Landscape Ecology* **33**, 1287-1300
- Varga T, Krizsán K, Földi C, Dima B, Sánchez-García M, Sánchez-Ramírez S et al. [Bougher NL] (2019). Megaphylogeny resolves global patterns of mushroom evolution. *Nature Ecology and Evolution* **3**, 668-678
- von Senger D (2019). Return to 1616: engaging with the community. (ABSTRACT) In *Island Arks, Rottneest Island, Western Australia, 11-15th February 2019* p. 20
- Waayers D, Tucker T, Whiting S, Groom R, Vanderklift M, Pilans R et al. (2019). Satellite tracking of marine turtles in south-eastern Indian Ocean: a review of deployments spanning 1990-2016. *Indian Ocean Turtle Newsletter* **29**, 23-37
- Walden L, Fontaine J, Ruthrof K, Matusick G, Harper R (2018). Wild-fire plus climate change-type drought: how much can a forest stand? (ABSTRACT) In *Book of Abstracts: Annual Conference, Ecological Society of Australia, 2018, Brisbane* 23-24
- Walden LL, Fontaine JB, Ruthrof KX, Matusick G, Harper RJ, Hardy GESTJ (2019). Carbon consequences of drought differ in forests that resprout. *Global Change Biology* **25**, 1653-1664
- Walker D, Huisman J, Kilminster K, Kuo J (2018). New perspectives on seagrass and macro algal biogeography. (ABSTRACT) In *The Royal Society of Western Australia Symposium, 2018: Program & Abstracts* p. 17
- Wallace MJ, Krauss SL, Barrett MD (2019). Complex genetic relationships within and among cytotypes in the *Lepidosperma costale* species complex (Cyperaceae) on rocky outcrops in Western Australia. *Australian Journal of Botany* **67**, 205-217
- Waples K, Field S, Kendrick A, Johnston A, Twomey L (2019). Strategic integrated marine science for the Kimberley region: new knowledge for better decisions and outcomes: WAMSI Kimberley Marine Research Program, a synthesis of research 2012-2018. Western Australian Marine Science Institution, Perth. 180 p.
- Waples K, Raudino H (2018). Setting a course for marine mammal research in Western Australia. *Pacific Conservation Biology* **24**, 289-303
- Ward BG, Bragg TB, Hayes BA (2018). Effects of chaining and burning in *Acacia ramulosa* shrublands of the Peron Peninsula, Shark Bay, Western Australia. *International Journal of Wildland Fire* **27**, 623-635
- Watkins GE, Willers N, Raudino H, Kinloch J, van Dongen R (2018). Success criteria not met, but valuable information gained: monitoring a reintroduction of the tammar wallaby. *Wildlife Research* **45**, 421-435
- Wayne A (2018). Upper Warren: home of threatened fauna. Available at <https://www.dpaw.wa.gov.au/about-us/science-and-research/animal-conservation-research/535-upper-warren-home-of-threatened-fauna%2%A0>. 6 p.
- Wayne AF, Maxwell M, Ward C, Quinn J, Virgo M, Cowan M (2019). Mammals of the southern jarrah forest: results from a camera trapping study. Department of Biodiversity, Conservation and Attractions, Manjimup. 124 p.
- Weier A, Radford IJ, Bellairs SM, Lawes MJ (2019). Seed set in *Sorghum stipoides*, and not fire, determines the timing of breeding by Gouldian finches (*Erythrura gouldiae*). *Austral Ecology* **44**, 151-162
- Weier A, Radford IJ, Woolley L-A, Lawes MJ (2018). Fire regime effects on annual grass seeds as food for threatened grass-finch. *Fire Ecology* **14**:8
- Whelehan L (2019). Magnificent mitochondria may hold conservation key. *For People & Plants* **106**, 27-28
- Whiteley S (2018). Conserving the rare and threatened *Androcalva perlaria*. *For People & Plants* **103**, 24-26
- Whitford KR, McCaw WL (2019). Coarse woody debris is affected by the frequency and intensity of historical harvesting and fire in an open eucalypt forest. *Australian Forestry* **82**, 56-69
- Whiting S, Tucker T (2018). Indigenous engagement, collaboration and knowledge exchange for the Kimberley Node Turtle Project. In *Marine turtles in the Kimberley: key biological indices required to understand and manage nesting turtles along the Kimberley coast: WAMSI Kimberley Marine Research Program, final report, Project 1.2.2* pp. 86-92. Western Australian Marine Science Institution, Perth
- Whiting S, Tucker T, Pendoley K, Mitchell N, Bentley B, Berry O et al. (2018). Background and implementation of the WAMSI Kimberley Node Turtle Project. In *Marine turtles in the Kimberley: key biological indices required to understand and manage nesting turtles along the Kimberley coast: WAMSI Kimberley Marine Research Program, final report, Project 1.2.2* pp. 1-10. Western Australian Marine Science Institution, Perth
- Whiting S, Tucker T, Pendoley K, Mitchell N, Bentley B, Berry O et al. (2018). Marine turtles in the Kimberley: key biological indices required to understand and manage nesting turtles along the Kimberley coast: WAMSI Kimberley Marine Research Program, final report, Project 1.2.2. Western Australian Marine Science Institution, Perth. 146 p.
- Williams AAE, Coppen RAM, Williams MR (2018). A method for conducting mark-release-recapture studies of the graceful sun-moth *Synemon gratiose* (Lepidoptera: Castniidae). *Records of the Western Australian Museum* **33**, 181-186
- Wills A (2019). Defoliation of *Melaleuca raphiophylla* by native sawflies on Peaceful Bay Road, 28 February 2019. Department of Biodiversity, Conservation and Attractions, Manjimup. 5 p.
- Wilson P, Thums M, Pattiaratchi C, Meekan M, Pendoley K, Fisher R et al. [Whiting S] (2018). Artificial light disrupts the nearshore dispersal of neonate flatback turtles *Natator depressus*. *Marine Ecology Progress Series* **600**, 179-192
- Wilson S (2018). Department of Biodiversity, Conservation and Attractions. *Lateral Lines: Australian Society for Fish Biology Newsletter* **48(2)**, 73-74
- Wilson S, Kendrick A, Wilson B (2018). The north-western margin of Australia. In *World Seas. Volume II, The Indian Ocean to the Pacific: an Environmental Evaluation. Second edition* (ed C Sheppard.). pp. 303-331. Academic Press, London
- Wu S, Liu Y, Southam G, Robertson L, Chiu TH, Cross AT et al [Stevens JC] (2019). Geochemical and mineralogical constraints in iron ore tailings limit soil formation for direct phytostabilization. *Science of the Total Environment* **651**, 192-202
- Wyneken J, Salmon M, Hamann M, Tucker A, Whiting S (2019). Successful and unsuccessful adhesives for use on neonate flatback turtles (*Natator depressus*): what works and doesn't work on the teflon turtles. (ABSTRACT) In *Proceedings of the Thirty-Sixth Annual Symposium on Sea Turtle Biology and Conservation, 29 February to 4 March 2016, Lima, Peru* (comps JC Mangel, A Rees, M Pajuelo et al.). 266-267

Yates C (2018). Threatened plant translocation. *Landscape* **34(1)**, p. 15

Zimmer H, Auld T, Coates D, Moore J, Silcock J, Reiter N, (2018). Translocation monitoring and evaluation. In *Guidelines for the*

Translocation of Threatened Plants in Australia (eds LE Commander, DJ Coates, L Broadhurst *et al.*). pp. 114-139. Australian Network for Plant Conservation, Canberra



Summary of Research Projects

Animal Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Pilbara, Goldfields	Pilbara, Gascoyne, Murchison	Rangelands	Barrow Island threatened and priority fauna species translocation program	18
Midwest	Carnarvon, Yalgoo	Rangelands	Cat eradication on Dirk Hartog Island	9
Pilbara	Pilbara	Rangelands	Conservation and management of the bilby in the Pilbara	14
South Coast, Warren	Jarrah Forest, Esperance Plains, Warren	South West, South Coast	Conservation of south coast threatened birds	21
Goldfields, Swan	Coolgardie, Swan Coastal Plain	Rangelands, Swan	Conservation of the graceful sun-moth	24
Kimberley, Pilbara, Midwest, Goldfields	Tanami, Great Sandy Desert, Pilbara, Carnarvon, Little Sandy Desert, Gibson Desert, Gascoyne, Murchison, Great Victoria Desert	Rangelands	Conservation of the night parrot	3
Pilbara	Pilbara	Rangelands	Decision support system for prioritising and implementing biosecurity on Western Australia's islands	13
Pilbara, Midwest, South Coast	Carnarvon, Desert, Gibson Gascoyne, Murchison	Rangelands, Swan	Development of effective broad-scale aerial baiting strategies for the control of feral cats	26
Midwest	Yalgoo, Shark Bay	Rangelands	Dirk Hartog Island National Park Ecological Restoration Project – fauna reconstruction	6
Pilbara	Pilbara	Rangelands	Ecology and management of the northern quoll in the Pilbara	23
Wheatbelt	Avon Wheatbelt	Avon	Feral cat control and numbat recovery in Dryandra Woodland and other sites	21
Pilbara, Swan	Pilbara, Swan Coastal Plain, Jarrah Forest	Rangelands, Swan	Genetic approaches for evaluating the contribution of the reserve system to fauna conservation	17

DBCRA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Kimberley, Pilbara	Northern Kimberley, Central Kimberley, Dampierland, Pilbara	Rangelands	Genetic assessment for conservation of rare and threatened fauna	15
South Coast	Jarrah Forest	South Coast	Gilbert's potoroo recovery plan	27
Kimberley	Victoria Bonaparte, Northern Kimberley, Ord Victoria Plain, Central Kimberley	Rangelands	Impact of cane toads on biodiversity in the Kimberley	25
Pilbara	Pilbara	Rangelands	Improved fauna recovery in the Pilbara – benefitting the endangered northern quoll through broad-scale feral cat baiting.	8
All Regions	Gascoyne	All Regions	Improving the use of remote cameras as a survey and monitoring tool	11
Midwest	Geraldton Sandplains	Rangelands	Monitoring of threatened birds on Dirk Hartog Island	10
Goldfields	Gascoyne	Rangelands	Rangelands restoration: reintroduction of native mammals to Matuwa (Lorna Glen)	19
South West	Jarrah Forest	South West, South Coast	South West Threatened Fauna Recovery Project: Southern Jarrah Forest	5
South Coast	Warren	South Coast	Understanding and reducing python predation of the endangered Gilbert's potoroo	4

Plant Science and Herbarium

DBCRA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions	All Regions	Biodiversity informatics at the Western Australian Herbarium	36
Wheatbelt	Avon Wheatbelt, Swan Coastal Plain	Northern Agricultural, Avon, Swan, South Coast	Genetic and ecological viability of plant populations in remnant vegetation	45
Midwest, Goldfields, Wheatbelt, Swan, South Coast	Yalgoo, Murchison, Geraldton Sandplains, Avon Wheatbelt, Coolgardie, Swan Coastal Plain, Mallee, Esperance Plains	Rangelands, Northern Agricultural, Avon, Swan, South West, South Coast	Genetics and biosystematics for the conservation, circumscription and management of the Western Australian flora	50
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Herbarium collections management	35
All Regions	All IBRA Regions	All Regions	Interactive key and taxonomic studies of Myrtaceae tribe Chamelaucieae	31
South Coast	Esperance Plains	South Coast	Is restoration working? An ecological genetic assessment	30
Midwest, Wheatbelt, Swan, South Coast, South West, Warren	Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains	Rangelands, Northern Agricultural, Avon, Swan, South West, South Coast	Mating system variation, genetic diversity and viability of small fragmented populations of threatened flora, and other key plants of conservation importance	47
Pilbara	Pilbara	Rangelands	Molecular characterisation of stinking passionflower (<i>Passiflora foetida</i>)	29

DBCRA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Kimberley, Pilbara	Victoria Bonaparte, Northern Kimberley, Ord Victoria Plain, Central Kimberley, Dampierland, Great Sandy Desert, Carnarvon, Little Sandy Desert, Gibson Desert, Gascoyne, Central Ranges	Rangelands	Resolving the systematics and taxonomy of <i>Tephrosia</i> in Western Australia	39
All Regions	All IBRA Regions	All Regions	Seed biology, seedbank dynamics and collection and storage of seed of rare and threatened Western Australian taxa	49
All Regions	All IBRA Regions	All Regions	Strategic taxonomic studies in families including Amaranthaceae and Fabaceae (<i>Ptilotus</i> , <i>Gomphrena</i> , <i>Swainsona</i>) and other plant groups	32
All Regions	All IBRA Regions	All Regions	Systematics of the triggerplant genus <i>Stylidium</i>	41
All Regions	All IBRA Regions	All Regions	Taxonomic resolution and description of new plant species, particularly priority flora from those areas subject to mining in Western Australia	44
Kimberley, Pilbara, Swan, South Coast, South West, Warren	Victoria Bonaparte, Northern Kimberley, Central Kimberley, Dampierland, Gascoyne, Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Esperance Plains, Warren	Rangelands, Northern Agricultural, Swan, South West, South Coast	Taxonomic review and floristic studies of the benthic marine algae of north-western Australian and floristic surveys of Western Australian marine benthic algae	42
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Taxonomy of selected families including legumes, grasses and lilies	40
All Regions	All IBRA Regions	All Regions	Taxonomy of undescribed taxa in the Ericaceae subfamily Styphelioideae, with an emphasis on those of conservation concern	38
All Regions	All IBRA Regions	All Regions	The Western Australian Herbarium's specimen database	34
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	The Western Australian Plant Census and Australian Plant Census	33
Kimberley, Pilbara, Midwest, Swan, South Coast, South West, Warren	Victoria Bonaparte, Northern Kimberley, Central Kimberley, Dampierland, Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Esperance Plains, Warren	Rangelands, Northern Agricultural, Swan, South West, South Coast	The Western Australian marine benthic algae online and an interactive key to the genera of Australian marine benthic algae	43
Midwest, Goldfields, Wheatbelt, Swan, South Coast, South West	Gascoyne, Geraldton Sandplains, Avon Wheatbelt, Jarrah Forest, Esperance Plains	Rangelands, Northern Agricultural, Avon, Swan, South West, South Coast	The population ecology of critically endangered flora	48
Midwest, Wheatbelt, South Coast, South West	Gascoyne, Murchison, Avon Wheatbelt, Coolgardie, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren	Northern Agricultural, Avon, Swan, South West, South Coast	Translocation of critically endangered plants	46

Ecosystem Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Wheatbelt	Avon Wheatbelt	Avon	Advancing the hydrological understanding of key Wheatbelt catchments and wetlands to inform adaptive management	59
Wheatbelt, Swan, South Coast, South West, Warren	Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Esperance Plains, Warren	Northern Agricultural, Avon, Swan, South West, South Coast	Do hotter and drier regions harbour adaptive variation for climate change?	54
Swan, South West, Warren	Jarrah Forest, Warren	Swan, South West	FORESTCHECK: Integrated site-based monitoring of the effects of timber harvesting and silviculture in the jarrah forest	71
Pilbara, Midwest, Goldfields, Wheatbelt, South Coast, South West, Warren	Murchison, Geraldton Sandplains, Avon Wheatbelt, Coolgardie, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren	Wheatbelt, Rangelands, Northern Agricultural, South West, South Coast	Genetic analysis for the development of vegetation services and sustainable environmental management	73
South West	Swan Coastal Plain, Jarrah Forest	South West	Hydrological function of critical ecosystems	56
Swan	Jarrah Forest	Swan, South West	Hydrological response to timber harvesting and associated silviculture in the intermediate rainfall zone of the northern jarrah forest	72
South West, Warren	Jarrah Forest	Swan, South West	Identification of seed collection zones for rehabilitation	70
South West	Jarrah Forest		Investigating the causes of change in forest condition	53
Swan, Warren	Jarrah Forest, Warren	Swan, South West	Long-term stand dynamics of regrowth forest in relation to site productivity and climate	66
South West	Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren	Swan, South West, South Coast	Management of invertebrate pests in forests of south-west Western Australia	67
Wheatbelt, South Coast, Warren	Geraldton Sandplains, Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren	Wheatbelt, Northern Agricultural, Swan, South West, South Coast	Protecting the safe havens: will granite outcrop environments serve as refuges for flora threatened by climate change?	69
South West	Jarrah Forest, Warren	Swan, South West	Responses of aquatic invertebrate communities to changing hydrology and water quality in streams and significant wetlands of the south-west forests of Western Australia	57
Warren	Jarrah Forest, Warren	South West	Responses of terrestrial vertebrates to timber harvesting in the jarrah forest	64
Warren	Warren	South West	Restoring natural riparian vegetation systems along the Warren and Donnelly Rivers	62
Midwest, Wheatbelt, Swan, South Coast, South West, Warren	Murchison, Geraldton Sandplains, Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren, Leeuwin-Naturaliste	Wheatbelt, Northern Agricultural, Avon, Swan, South West, South Coast	South-west wetlands monitoring program	58
Goldfields, Wheatbelt, South Coast, Warren	Murchison, Avon Wheatbelt, Jarrah Forest, Mallee, Esperance Plains	Wheatbelt, Rangelands, South Coast	South-western Australia transitional transect	63

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions	All Regions	Taxonomy, zoogeography and conservation status of aquatic invertebrates	60
Warren	Warren	South West	Understanding peat wetland resilience: evaluating the impact of climate and land-use change on the hydrodynamics and hydrogeochemistry of peat wetlands in the Warren (Muir-Byenup) District	61
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Western Australian flora surveys	65
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Western Australian wetland fauna surveys	68

Marine Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Kimberley	Bonaparte Gulf, Kimberley, Northwest Shelf, Cambridge-Bonaparte, Canning, King Sound	Rangelands	Distribution and abundance estimate of Australian snubfin dolphins at a key site in the Kimberley region, Western Australia	76
Pilbara	Pilbara, Ningaloo	Rangelands	Effects of Gorgon project dredging on the marine biodiversity of the Montebello/Barrow Islands marine reserves	84
Pilbara	Pilbara, Pilbara (Off-shore)	Rangelands	Habitat use, distribution and abundance of coastal dolphin species in the Pilbara	75
Pilbara	Pilbara, (Nearshore) Pilbara	Rangelands	Improving the understanding of West Pilbara marine habitats and associated taxa: their connectivity and recovery potential following natural and human induced disturbance	78
Pilbara	Ningaloo	Rangelands	Interactive effects of fishing and climate change on coral reef fish populations	86
Pilbara	Pilbara, (Nearshore) Pilbara	Rangelands	Long-term monitoring in the area of the proposed Dampier Archipelago marine reserves	74
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Marine monitoring program	81
Kimberley, Pilbara	Northwest Shelf	Rangelands	North West Shelf Flatback Turtle Conservation Program	82
Warren	WA South Coast	South Coast	Spatial and temporal patterns in benthic invertebrate communities of the Walpole and Nornalup Inlets Marine Park	85
Swan	Central West Coast	Swan	Spatial and temporal patterns in the structure of intertidal reef communities in the marine parks of south-western Australia	87
Pilbara	Carnarvon, (Nearshore) Pilbara	Rangelands	The influence of macroalgal fields on coral reef fish	79
Pilbara	Oceanic Shoals, Kimberley, Northwest Shelf, Eighty Mile Beach, Pilbara (Offshore), Pilbara (Nearshore), Shark Bay	Rangelands	Understanding movements and identifying important habitats of sea turtles in Western Australia	80

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Kimberley	Oceanic Shoals, Bonaparte Gulf, Kimberley, Northwest Shelf, Cambridge-Bonaparte, Canning, King Sound, Eighty Mile Beach	Rangelands	WAMSI 2: Kimberley Marine Research Program	83

Fire Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Warren	Jarrah Forest	South West	Burning for biodiversity: Walpole fine-grain mosaic burning trial	95
Swan	Geraldton Sandplains, Swan Coastal Plain	Northern Agricultural, Swan	Evaluation of synergies among fire and weed management in urban biodiversity and fire management	89
Goldfields, Wheatbelt, South Coast	Yaloo, Avon Wheatbelt, Coolgardie, Mallee	Wheatbelt, Rangelands	Fire regimes and impacts in transitional woodlands and shrublands	93
	Jarrah Forest	South West	Long term response of jarrah forest understorey and tree health to fire regimes	91
Kimberley	Northern Kimberley	Rangelands	North Kimberley Landscape Conservation Initiative: monitoring and evaluation	92
Midwest, Wheatbelt, Swan, South Coast, South West	Jarrah Forest, Mallee, Warren	Northern Agricultural, South West, South Coast	Understanding the changing fire environment of south-west Western Australia	90

Kings Park Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Conservation biotechnology	101
All Regions	All IBRA Regions	All Regions	Conservation genetics	99
Wheatbelt, Swan, South Coast, South West, Warren	Geraldton Sandplains, Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren	Northern Agricultural, Avon, Swan, South West, South Coast	Orchid conservation and recovery	100
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Restoration science	97
All Regions	All IBRA Regions	All Regions	Seed science	96

Perth Zoo Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Swan, South West	Swan Coastal Plain, Jarrah Forest	Swan, South West	<i>Geocrinia</i> frog breed and rear for release program	107
Swan	Swan Coastal Plain	Swan	Behavioural observations of Perth Zoo collection animals for animal welfare purposes and establishment of baseline data	106

DBCAs Region	IBRA/IMCRA	NRM Region	Project Title	Page
Midwest, Swan, South Coast	Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Esperance Plains	Northern Agricultural, Swan, South Coast	Dibbler breed for release program	109
Swan	Swan Coastal Plain	Swan	Memory of recent actions in large-brained mammals (<i>Elephas maximus</i>).	105
Wheatbelt, Swan, Warren	Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Warren	Northern Agricultural, Swan, South West	Numbat breed for release program	110
Swan	Swan Coastal Plain	Swan	Olfactory and auditory based behavioural enrichment for Perth Zoo's Asian elephants.	105
Midwest, Swan, South Coast	Gascoyne, Murchison, Geraldton Sandplains, Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren	Wheatbelt, Northern Agricultural, South West, South Coast	Survival and dispersal of black cockatoos in south-west Western Australia	110
Swan	Swan Coastal Plain	Swan	Using dataloggers to determine the effects of handling and temperature on packages travelling along Australian postage routes used to illegally transport native fauna	104
Swan, South Coast	Swan Coastal Plain, Mallee, Esperance Plains	Swan, South Coast	Western ground parrot husbandry	103
Swan, Warren	Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Warren	Swan, South West	Western swamp tortoise breed for release program	108

Rivers and Estuaries Science

DBCAs Region	IBRA/IMCRA	NRM Region	Project Title	Page
Swan	Swan Coastal Plain	Swan	Alfred Cove eutrophication investigation: gaining insights to apparent eutrophication-related stress exhibited by seagrass in the Swan Estuary Alfred Cove Marine Park	115
Swan	Swan Coastal Plain	Swan	Algal blooms: investigations and control	114
Swan	Swan Coastal Plain	Swan	Application of FlowCAM® to biological monitoring in the Swan Canning Riverpark	118
Swan	Swan Coastal Plain	Swan	Assessment of multi-wavelength fluorometer technology for chlorophyll <i>a</i> and gross phytoplankton composition estimation	116
Swan	Swan Coastal Plain	Swan	Dolphin health - toxicogenomics and pathology investigations	121
Swan	Swan Coastal Plain	Swan	Explaining foreshore vegetation die-off	117
Swan	Swan Coastal Plain	Swan	Incident investigations and response	112
Swan	Swan Coastal Plain	Swan	Investigating fish communities as an indicator of estuarine condition	115
Swan	Swan Coastal Plain	Swan	Model frameworks for estuarine reporting	120
Swan	Swan Coastal Plain	Swan	Seagrass monitoring and evaluation	113
Swan	Swan Coastal Plain	Swan	Stock enhancement of western school prawn: evaluation recruitment limitation, environment and release strategies	119

Remote Sensing and Spatial Analysis

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Midwest	Yalgoo, Shark Bay	Rangelands	Dirk Hartog Island vegetation monitoring	129
All Regions	All IBRA Regions	Rangelands, Northern Agricultural, Swan, South West, South Coast	Remote sensing and spatial analysis for fire management	125
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Remote sensing monitoring	127
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Spatial analysis and modelling	126
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Spatial data management	123

Species and Communities

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Ecological communities conservation and recovery	131
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Fauna conservation and recovery	136
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Flora conservation and recovery	134
All Regions	All IBRA Regions	All Regions	Off-reserve conservation	133
All Regions	All IBRA Regions	All Regions	Wetland conservation	130

Ecoinformatics

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	BioSys – the Western Australian Biological Survey Database	139
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Online GIS biodiversity mapping (<i>NatureMap</i>)	141
All Regions	All IBRA Regions, All IM-CRA Regions	All Regions	Provision of authoritative names of Western Australian taxa	140

