


GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Biodiversity and **Conservation Science**

Biodiversity and Conservation Science Annual Report **2020-2021**

Acknowledgement to Country

Our science is undertaken on the traditional lands of Aboriginal people. The Department of Biodiversity, Conservation and Attractions acknowledges the traditional owners of country throughout Western Australia and their continuing connection to the land, waters and community. We pay our respects to them, their culture and to their Elders past and present.

Publication details

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Images

Front cover main photo:
A biological survey of Lake Carnegie was undertaken to inform assessment of biodiversity values as part of Western Australia's Government Plan for our Parks initiative.
Photo – Adrian Pinder/DBCA

Front cover top photos left to right:
Fire research. *Photo – Ben Miller/DBCA*
Geleznowia amabilis. Photo – Kelly Shepherd/DBCA
Dirk Hartog Island dibbler. *Photo – Jason McDonnell/DBCA*
Swan Canning Riverpark monitoring. *Photo – Kerry Trayler/DBCA*

Back cover top photos left to right:
Seagrass sampling. *Photo – Jan Ranson/DBCA*
Caladenia busseliana. Photo – Belinda Davis/DBCA
Dirk Hartog Island. *Photo – Ricky Van Dongen/DBCA*
Banksia heath fieldwork. *Photo – Carl Gosper/DBCA*

Department of

Biodiversity, Conservation and Attractions

Biodiversity and Conservation Science

Annual Report

2020–2021

Department of **Biodiversity, Conservation and Attractions**

Biodiversity and **Conservation Science**

Executive Director's Message

I am pleased to present our Biodiversity and Conservation Science report for 2020-21 as we continue to deliver on the government's commitment to build and share biodiversity knowledge for Western Australia. In accordance with our Science Strategic Plan and Program Plans, we deliver excellent science that informs conservation and management of our diverse 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.

Despite the challenges due to the coronavirus global pandemic, we have maintained delivery of a high level of quality science to inform conservation management. I thank all our Biodiversity and Conservation Science staff for their commitment and perseverance during a time of significant change. The strength of Biodiversity and Conservation Science resides in our people and our capability to provide innovative science that informs current and future conservation initiatives. Our great science work is facilitated by the excellent support of our administration staff. I am immensely proud of the Biodiversity and Conservation Science team and what we achieve together and with our partners.

We have had another very productive year. A major achievement has been the establishment of the Biodiversity Information Office. This initiative is a State Commonwealth partnership to collate, curate and make available biodiversity data to support environmental management and conservation in Western Australia. To ensure our biodiversity knowledge is applied most effectively, we have developed a strategic risk-based approach to provision of scientific advice and assessment of impacts. The year 2020 was the 50th anniversary of our Herbarium journal *Nuytsia* and we celebrated with the publication of names and descriptions for 50 new plant species throughout the year. Other highlights of our scientific research include: the development of innovative monitoring tools using remote sensing; audio recording and camera units in terrestrial and aquatic environments; trialing eDNA techniques for monitoring and assessing plants, animals and ecological condition; development of non-invasive faecal DNA approaches for monitoring selected animals; implementation of a fire severity mapping tool; a biological survey of Lake Carnegie to inform assessment of biodiversity values; integrated quantification of impacts, banking of germplasm and establishment of seed production areas for threatened flora affected by the 2018-19 Stirling Ranges bushfires; completion of a review of wetland values across the Swan Coastal Plain; producing plants of a threatened orchid for translocation; and breeding of dibblers for release on Dirk Hartog Island.

As we continue to deliver excellent science to underpin effective biodiversity conservation in Western Australia, we remain active in pursuing new opportunities and seeking innovative ways for delivering science to support conservation. We are looking to strengthen communication of our scientific 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.

We value our collaborations and partnerships both internally and externally. We strive to work effectively with conservation staff in the Parks and Wildlife Service, and at Kings Park and Botanic Garden, Perth Zoo and Rottnest Island. We continue to engage with a wide range of external partners at universities, CSIRO, NGOs, WABSI, WAMSI and the newly established National Environmental Science Program hubs. We value the large number of active science partnerships and our engagement in the co-supervision of many Honours, Masters and PhD students.

I look forward to continuing to work effectively with all our partners to provide scientific excellence to support the Departments operations and contribute to the delivery of the biodiversity science priorities for Western Australia. The scientific information we generate and the biodiversity knowledge we apply is fundamental to ensuring the unique biodiversity we have around us is conserved and valued.

Dr Margaret Byrne
Executive Director, Biodiversity and Conservation Science
November 2021

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Service Delivery Structure

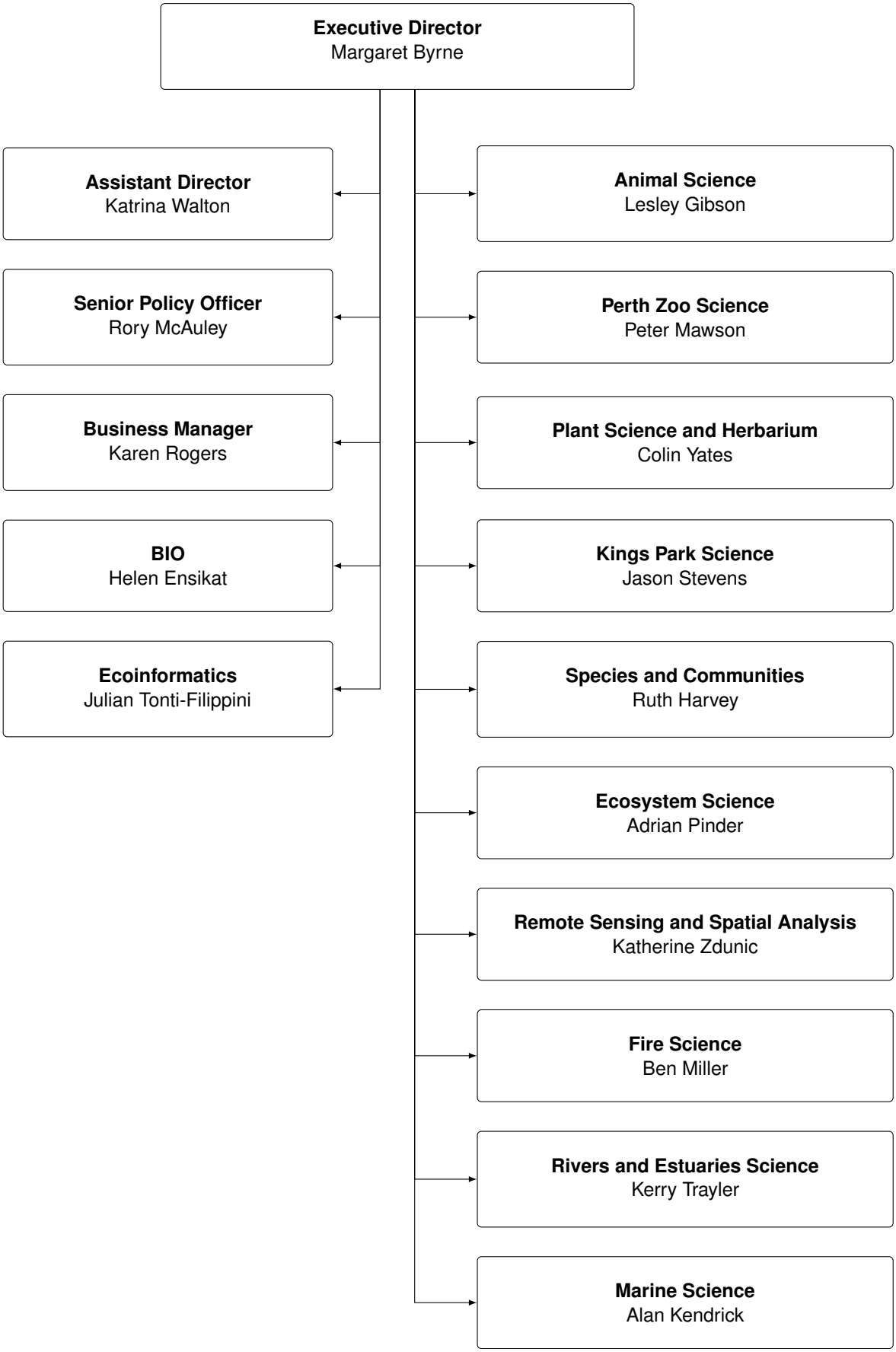
Science in the Department of Biodiversity, Conservation and Attractions is undertaken in accordance with the departmental Science Policy, where science refers to scientific research, scientific monitoring and science communication undertaken in relation to the biological, physical and social environments.

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.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Katherine Zdunic
Fire Science
Ben Miller
Rivers and Estuaries Science
Kerry Trayler
Marine Science
Alan Kendrick

Biodiversity Information Office

Program Leader: Helen Ensikat The Biodiversity Information Office (BIO) has been established as custodian and manager of the Biodiversity Data Repository for the biodiversity data collected and used by the Western Australian community. BIO will mobilise biodiversity data from all environment-related sectors, including government, industry, and community organisations, promoting a culture of collaboration and seamless data sharing across government, industry, research and the community. Greater access to biodiversity data will increase knowledge of our biodiversity and support informed decision making. BIO enhances the capability of the WA public sector to deliver services to a diverse range of stakeholders, leading to the delivery of sound policy outcomes and evidence-based decision-making. BIO is a core component of the WA digital transformation initiative delivering data services for digital transformation of environmental assessment and approvals system (Environment Online) that is led by the Department of Water and Environmental Regulation (DWER). BIO will provide seamless integration with Environment Online to ensure access to the best available information to inform decision making. BIO is part of the partnership between WA and the Commonwealth Department of Agriculture, Water and the Environment (DAWE) to deliver the Digital Environmental Assessment Program as an integrated digital environmental assessment system and biodiversity data repository.

BIO data collation program

CF 2021-045

H Ensikat, N Panine, R Cechner

Context

The data collation program of the Biodiversity Information Office (BIO) will bring together data from a range of data sources and providers across industry, the public, research sectors and community organisations. BIO will initially focus on high volume, high quality datasets – particularly those that are not easily accessible at present, driving a step-change in the availability of biodiversity data in Western Australia. The data will be ingested into the platform after passing automated quality assurance checks, where it will be mapped to a range of common data standards and undergo a human-mediated quality control process before being released to users.

The initial data for the launch of the BIO platform will be sourced directly from industry, from DBCA repositories, and regulators such as the Department of Water and the Environment (DWER). However, new data will continually be ingested, through automated delivery from regulators and a rolling program to identify and source other valuable datasets. This data collation program will involve outreach to data custodians across all sectors, exploration of technologies to unlock data in pre-digital documents and ongoing monitoring of existing data to

identify temporal and spatial gaps.

Aims

- Provide users with access to a rich collection of high-quality datasets.
- Ingest new and up-to-date data over time.
- Enable access to previously undiscoverable and inaccessible datasets held by government and by other sectors.

Progress

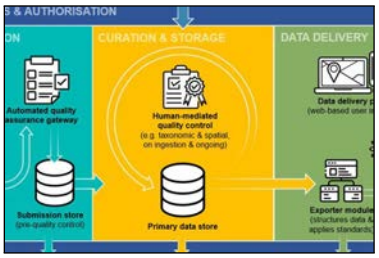
- BIO has negotiated in-principle agreement with major industry proponents to share data via the BIO platform and has received sample data from some proponents.
- BIO is working with peak industry bodies to promote opportunities for data sharing more broadly across member organisations.
- BIO has consulted with DWER on the one-off ingestion of historical environmental assessment data and re-engineering regulatory processes to allow for the automated ingestion of new data into the BIO platform.
- Existing DBCA-managed biodiversity data sets have been identified and reviewed for priority ingestion into the platform.

Management implications

- Access to a greater range of high-quality biodiversity data, including datasets that have not been available in the past, will support better-informed research and decision-making.
- Availability of up-to-date environmental assessment data, mapped to common standards and validated via the curation process, will ensure that environmental decisions are based on current and accurate information.

Future directions

- Finalise the initial datasets to be ingested for the launch of the BIO biodiversity platform and their transfer from data custodians.
- Finalised standards to be included in the BIO information model and map the initial data sets to these standards.
- Co-design environmental assessment processes with DWER to embed data ingestion into the BIO platform with pre-planning and application workflows for industry proponents.
- Further outreach to potential data providers across all sectors to secure and schedule the delivery of new data sets over time.



BIO biodiversity data platform

CF 2021-044

H Ensikat, N Panine, R Cechner

Context

The Biodiversity Information Office (BIO) is developing a central platform for Western Australian biodiversity data, unlocking the value in this data by making it easily discoverable, searchable, and accessible. The platform will mobilise biodiversity data from all environment-related sectors, including government, industry and community organisations, and will establish the digital infrastructure required to enable seamless data sharing across the public, private and research sectors and the broader community.

This work will drive improved regulatory decision-making, providing data for the State's forthcoming Environment Online portal to support digital transformation of environmental assessment and approval. It will facilitate the exchange of biodiversity data between jurisdictions via integrating the BIO platform with the federated national

Biodiversity Data Repository being developed by Department of Agriculture, Water and the Environment (DAWE). Upon launch, the platform will deliver point, plot and polygon biodiversity data to users, via a geospatial web interface and an Application Programming Interface for developers.

Aims

- Allow users to easily discover, search, and access a range of Western Australian biodiversity data via a single platform.
- Provide streamlined access to biodiversity data for government agencies, including regulators, to enhance the quality and timeliness of decision-making.
- Develop a model that can be deployed in other States and Territories to automate the contribution of biodiversity data to an Australia-wide repository.

Progress

- BIO has been established as a new function within DBCA and key staff have been recruited.
- Initial consultation with key stakeholders has been undertaken, including industry proponents, environmental consultants, researchers and government agencies, to prepare for development of the BIO platform.
- The high-level design and technical architecture for the BIO platform has been finalised and has begun co-design work with DAWE to plan for integration with the national Biodiversity Data Repository.
- Collaboration is underway with the Western Australian Museum, Western Australian Herbarium and other DBCA experts to ensure data in the platform will remain up-to-date and robustly curated and is drawing on the expertise of existing biodiversity data management organisations, including the Terrestrial Ecosystem Research Network and the Atlas of Living Australia, to build on previous government investment in this area.

Management implications

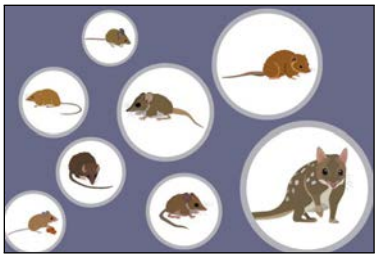
- Increased data availability for industry and government will support more sustainable development proposals and drive transparent and evidence-based environmental decisions.
- Access to a broader range of high-quality biodiversity data will expand research opportunities for research and enhance the quality of research outputs.

Future directions

- Completion and launch of the first iteration of the BIO biodiversity data platform in mid-2022.
- Consultation with data users and data custodians across all sectors to prioritise future enhancements and refinements of the platform in 2022-23.

Animal Science

Program Leader: Lesley Gibson Applied research undertaken by the Animal Science Program seeks to understand the factors and processes critical for conserving 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.



Building resilience to change for mammals in a multi-use landscape: identifying refugia and landscape connectivity for small mammals in the Pilbara

SP 2021-008

K Ottewell, L Gibson, M Byrne, S McArthur, J Kinloch, K Zdunic, B Huntley

Context

To promote species' resilience over vast landscapes, long time-scales and given current rates of environmental change, it is essential for best-practice conservation strategies to: (i) identify historical refugia, areas that offer temporally and climatically stable habitat that species can retreat to, persist in and expand from under changing environmental conditions; (ii) protect key habitat in species' current distributions; and (iii) promote population connectivity to maintain metapopulation viability and to retain species' evolutionary potential.

Spatio-temporal landscape genetics, combined with Species Distribution Modelling (SDM), offers a novel approach to multi-species conservation planning. This project will provide current and historical insight into how small-medium sized mammals use the Pilbara landscape, providing information for conversation actions and habitat management. Therefore this project is significant in bringing together key government and industry stakeholders engaged in conservation management in the Pilbara. Furthermore, the framework developed for integrating these findings into conservation priorities will be applicable for conservation management globally.

Aims

- Locate core habitat and connectivity pathways (corridors) for species under current environmental conditions by modelling habitat suitability and contemporary gene flow.
- Locate key areas for persistence under changing climates by inferring locations of evolutionary refugia from population genomic data and spatial modelling of range dynamics under historical and predicted

future environments.
- Identify conservation strategies to enhance and protect these areas for optimal combinations of threatened and non-threatened species.

Progress
- Analysis of genetic diversity in small mammals of the Pilbara, identified landscape connectivity in three species, and evolutionary refugia and population expansion characteristics across eight species.
- Pipelines for SNP filtering, species distribution modelling and landscape genetics analyses have been developed.
- Population genetic analyses, including genetic clustering analyses, tests for isolation-by-distance, estimates of genetic diversity and fine-scale relatedness patterns have been completed for *Dasykaluta rosamondae, Dasyurus hallucatus, Ningaui timealeyi, Planigale sp. 1, Pseudomys chapmani, P. hermannsburgensis, Sminthopsis macroura and S. youngsoni.*
- The complete workflow for landscape genetics and species distribution modelling for northern quolls (*D. hallucatus)*, including decision-making tools for end-users, is in preparation for publication.
- Two genetic clusters were identified for northern quolls in the Pilbara, and genetic turnover is driven by climate and geographic distance. Dispersal is restricted by silt substrates and increasing distance to water, while topographic ruggedness, elevation and distance to water were all key habitat attributes.

Management implications
- Identifying environmental variables underpinning habitat and dispersal requirements will provide insight into the ecology of the arid/semi-arid zone mammal community to inform monitoring efforts and conservation strategies.
- Identifying refugia, core habitat and connectivity pathways across the Pilbara, and developing knowledge products integrating these findings across multiple species will support conservation planning in the Pilbara, and will inform decision making in relation to potential impacts and responses to development.
- Locating refugia will provide insight into areas where species have persisted during periods of historical climate change. This will enable conservation strategies to incorporate climate planning for predicted future environments through maintaining connectivity between populations locally adapted to different climatic conditions.

Future directions
- Complete landscape genetic analyses and SDMs for all species.
- Prepare publications for multi-species SDMs and population/landscape genetics findings.
- Incorporate findings into a Systematic Conservation Planning framework, and elicit/incorporate feedback from DBCA and other stakeholders.
- Create predictions under future climate change scenarios and search for adaptive loci.

Felixer grooming trap trial: Feral cat control for threatened fauna conservation in the southern forests.

SP 2020-023

A Wayne, M Maxwell, C Ward

Context

Feral cats are one of the most significant threats to native terrestrial vertebrate species in Australia. The Felixer™ cat grooming trap is a novel method of controlling feral cats that takes advantage of their compulsive grooming behaviour. The Felixer unit detects the presence of a feral cat and sprays a lethal dose of 1080 toxic gel onto the fur of the feral cat. The feral cat instinctively grooms itself to remove the gel and, in doing so, ingests a lethal dose of the poison. The unit takes a photograph every time the detection beams are crossed, allowing an assessment of the efficacy of the trap in differentiating feral cats from non-target species.

Proper testing of this new technology is essential to validate if the Felixer is an effective and low-risk feral cat management tool and at what scale they are most effective. This project is a research trial to assess the effectiveness of these traps to deliver feral cat control at a meso-spatial scale (around 10,000 ha) for threatened fauna conservation and recovery. The trials are being conducted in high conservation value areas in and around the Tone-Perup Nature Reserve and the Lake Muir-Byenup Ramsar site.

Aims

- Determine the safety of the Felixer™ grooming trap for use in the presence of the native fauna in the Upper Warren area.
- Determine whether Felixer™ grooming traps can reduce feral cat densities by at least 60% at a meso-spatial scale (>10,000 ha) in the southern jarrah forests, Western Australia.
- Improve the efficiency and effectiveness of Felixer™ grooming traps by refining the deployment design through adjusting spatio-temporal factors such as density, duration, mobility and location in the landscape.
- Investigate the timing, frequency and spatial scale of Felixer™ trapping required to overcome recruitment from breeding and immigration. Maintain a reduction in cat densities to allow for the recovery of native prey species.

Progress

- Safety assessment has been completed, involving extensive 'camera only' trials over six months at the Perth Zoo Numbat enclosure, Perup Sanctuary and Tone-Perup Nature Reserve. The Felixer units successfully avoided non-target species in 99.97% of occasions out of more than 3,200 occasions.
- One of 361 tammar detections were misidentified as a target. Given the tolerance of tammar wallabies in WA to 1080, if an individual were to be targeted by a Felixer trap with a dose of 1080 gel, and were it to ingest the maximum amount of toxin from its coat, it would not be lethal: an average-sized adult tammar would need to consume at least eight gel doses within about 24 hours to reach a dose equivalent to the reported LD50 for the species. This would be extremely unlikely to occur.
- Arrays of remote sensor cameras are being used to quantify changes in cat density/abundance/activity associated with the toxic trials of the Felixer traps. These assessments use a 'before/ after, control/ impact' study design and spatially explicit capture recapture modelling methods.
- Trials of the Felixer units in toxic mode were commenced.

Management implications

- Confirmation that the Felixer units are safe to use in the presence of native fauna in the southern jarrah forests of Western Australia.
- Early indications are that these units may be able to remove more than 60% of the cat individuals present at a meso-spatial scale, and therefore could be an important and complementary tool to deliver improved conservation outcomes for threatened species vulnerable to cat and fox predation in the jarrah forest.

Future directions

- Trials in toxic mode will continue at multiple sites in 2021.
- Depending on the results of these trials, the project will investigate optimising and sustaining effective feral cat control using Felixer traps.

Structured decision making for optimal feral herbivore management for biodiversity conservation in the Kimberley

SP 2019-069

M Barnes, J Kinloch

Context

Threatened species have variable exposure and susceptibility to threats and responses to management. Feral herbivore control is a cost-effective threat management strategy for conserving many threatened and endemic species in the Kimberley, particularly its small mammal fauna. It comprises a large part of the Kimberley work program. However, the efficiency and cost-effectiveness of this program could be improved by impact-focused spatial action planning to identify efficient spatially explicit management strategies that balance the conservation needs of multiple species while accounting for other funds and opportunities in that timestep.

Aims

- Apply structured decision making approach to identify cost-effective feral herbivore control strategies.
- Evaluate the costs and benefits of existing and proposed herbivore control strategies.
- Understand and characterise synergies and trade-offs among alternative management strategies for herbivore control.

Progress

- Feral herbivore data have been sourced from the Kimberley Region for the Ord River and Kurriji Pa Yajula Nature Reserves, Walyarta, Miluwindi and Purnululu Conservation Parks, Mitchell River, Prince Regent and Drysdale River National Parks and the Ord River Regeneration Reserve.
- Objectives, relevant metrics, operational constraints were collaboratively developed with regional staff in a workshop for each park and relevant datasets identified and shared.
- Spatial modelling to identify feral herbivore hotspots has been undertaken for all six parks.

Management implications

- The project utilises information and knowledge from recent annual control programs. Identification of feral herbivore hotspots and their likely impacts on threatened species has informed the development of alternative novel management actions. The results of this evaluation will improve the efficiency of future feral herbivore control programs and maximise benefits to key conservation values.

Future directions

- Finalise outcomes from structured decision making.

Structured decision making for animal translocation

SP 2019-067

M Barnes, L Gibson, J Renwick, S Cowen, C Sims, A Wayne

Context

Translocation is a valuable conservation tool that can yield significant benefits and can sometimes be costly and high risk. Decisions on translocations include thorough consideration of potential benefits, weighed against costs and risks of the translocation and alternative options. Western Australia is at the forefront of translocations in Australia and has a number of animal translocation programs identified for implementation over the next five years. Other States and Territories are also using translocation as a conservation tool. The number of requests to source species from Western Australian populations is increasing. These trans-location decisions require consideration of both source populations and release locations. It is important that these translocations maximise conservation outcomes for the species without detrimental consequences for source populations and that the cost is proportional to the benefit. A strategic process for making translocation decisions that captures all relevant information on proposed translocations and that accounts for uncertainty, will support enhanced and transparent decision-making and proper consideration of risk and uncertainty.

Aims

- Develop a framework to support decision making for animal translocations.
- Evaluate the costs, benefits and risks of proposed translocations to ensure efficiency, mitigate risks to source populations and support decision-making that is robust to uncertainty in future conditions.

Progress

- Additional rapid prototyping processes to support the identification of objectives associated with translocations for species with a large number of requests have been undertaken (chuditch, golden bandicoot).
- An ensemble modelling approach that incorporated species interactions was undertaken to help us understand how the order, timing, and location of translocations on Dirk Hartog Island (DHI) may influence the program's success. Model results predict that almost all reintroductions will be successful, regardless of choice of strategy. A manuscript was published in the *Journal of Applied Ecology*.
- Stochastic dynamic programming analysis to identify sustainable harvest thresholds for Bernier and Dorre Islands was conducted and presented to recovery teams.
- Quantitative analysis to support more robust assessment of translocation proposals was identified as a key need for target species.
- Population viability analysis using vortex for a range of alternative harvest strategies is underway for both woylies and boodies.
- Draft decision tree was compiled and is currently being reviewed for application for boodies.

Management implications

- A robust and transparent process that supports decision-making allows for the value of the translocation for improved species conservation outcomes relative to the potential impact and cost of harvest for source populations.
- Evaluation methods that allow a comparative assessment of translocations will assist with planning sequence of harvest and meeting demands for translocation requests.
- Relative factors influencing order of translocations can be used to effectively plan multi-species programs such as translocation to DHI.
- The thresholds for sustainable harvest of boodies are influenced by abundance and productivity and knowledge of these factors enables better prediction of conditions for sustainable harvest.
- Stochastic dynamic programming is a robust quantitative tool that has scope for broader application for identifying appropriate harvest thresholds given specified uncertainties.
- The use of the decision frameworks will result in reduced risks, improved translocation outcomes, and increased efficiency in setting and evaluating objectives and delivering conservation outcomes.

Future directions

- Elicit and integrate risk preferences into stochastic dynamic programming work.
- Publish stochastic dynamic programming work.
- Incorporate genetic data into population modelling for boodies and woylies.

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, surrounding areas, and 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 surveys for night parrots and culturally sensitive management for the species.

Progress

- Further acoustic data have been gathered from remotely deployed audio recording units.
- Analyses of historical occurrences, which will assist in planning future survey work, were published in *Emu-Austral 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

- Investigate development of robust software recognition algorithms.

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

SP 2017-001

D Pearson

Context

Carpet pythons are predators of multiple threatened mammal fauna, including the critically 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. Python predation may be 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

- Radio-tracking of male carpet pythons continued during the spring mating season but was less successful than previous years despite greater effort. Males that had bred in the previous year did not display mate-searching behaviour. This suggests that either males do not breed every year, in contrast to other populations, or the removal of reproductive females from the Waychiniup enclosure had resulted in limiting male reproductive stimulus.
- Searching techniques for locating pythons were further evaluated, including the employment of experienced biologists to assist with radio-tracking and the involvement of volunteers from the Gilbert's Potoroo Action Group.
- A total of five pythons were captured within the enclosure and relocated to other parts of Waychinicup National Park.

Management implications

- Carpet pythons are significant predators of Gilbert's potoroo and constrain the growth of the population in the Waychinicup enclosure, and by inference, the recovery of the wild population on Mt Gardner.
- The location and removal of carpet pythons from the Waychinicup potoroo enclosure and Mt Gardner could be used to significantly reduce predation. Night head-torching was the most successful search method to initially locate pythons. Radio-tracking males in the mating season (with the chance of opportunistically finding other pythons) was the best technique for locating reproductive female pythons in the Waychinicup enclosure.
- Adult females in the months before the breeding season (June-October) and during the breeding season (November-March) do not feed, so telemetered reproductive females can be left in the enclosure to attract males and lead to more python captures. They should be removed from the enclosure at the conclusion of the mating season (December).
- Females should be relocated further than 2 km from the enclosure to prevent them returning. Those located 8-10 km from the enclosure did not return.
- No evidence was found that the smaller male pythons ate potoroos so telemetered males could be left within the compound and followed to locate other pythons in the breeding season.

Future directions

- Field work for the project is complete, and papers on the threat that carpet pythons pose to Gilbert's Potoroo and survey techniques for pythons are currently being prepared.

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-west 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, by developing effective integration of feral cat control with existing fox control in the southern jarrah forest.
- Evaluate the efficacy of *Eradicat*® baiting under current operational delivery methods (aerial and ground) and time of year.
- Quantify the risk to potentially vulnerable non-target native mammals in the southern jarrah forest from operational use of *Eradicat*®.
- Improve live capture of feral cats in the southern jarrah forest by minimising non-target captures.
- Engage effectively with neighbours about the control of introduced predators and the recovery of native species.

Progress

- A paper, 'Improving *Eradicat*® bait efficiency and effectiveness for fauna conservation in the southern jarrah forest, Western Australia', has been submitted. This paper provides recommendations for improvements within an integrated and holistic invasive animals management framework to deliver better biodiversity conservation outcomes.
- A second paper is in preparation on 'Fire effects on introduced predator control using *Eradicat*® baits and native fauna behaviour in the southern jarrah forest, Western Australia'. Compared to the reference sites, there were no significant differences in encounter rates or bait removals by cats or foxes immediately after autumn burns.

Management implications

- Controlling feral cats in the southern jarrah forest is challenging and the effectiveness of *Eradicat*® baiting using existing protocols has been demonstrated.
- The *Eradicat*® baits can be effective at controlling foxes and are a low risk to threatened species, such that they can complement other methods. Additional introduced predator threat abatement may be needed to conserve and recover many threatened native mammals in the southern jarrah forests.
- Feral cat baiting is most effective when conducted within an integrated and holistic invasive animal management system.

Future directions

- Complete analyses and manuscripts for publication, including baiting efficiency in relation to proximity to tracks, bait longevity, non-target bait interactions, and spatial ecology of feral cats.

Dirk Hartog Island National Park Ecological Restoration Project – fauna reconstruction

SP 2016-030

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

Context

The Dirk Hartog Island National Park Ecological Restoration Project 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 and one bird species on Dirk Hartog Island (DHI) over a 12-year period is a key part of this project. Of these species, one is listed as critically endangered, one as endangered, six as vulnerable, two as conservation dependent, and one as near threatened under the *Biodiversity Conservation Act 2016*. Their successful re-establishment will contribute to improving the conservation status. 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. For successful re-establishment to occur, sheep, feral goats, and feral cats have been removed. The eradication of feral cats represents the most extensive eradication program

achieved globally. Genetic information on source populations is being used to inform founder selection, genetic monitoring of released animals, and 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 bird 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

- Translocations of four species to DHI took place: supplementation of dibblers and Shark Bay bandicoots (SBB) and the first translocations of Shark Bay mice (SBM) and greater stick-nest rats (GSNR).
- Source population monitoring took place for these species, as well as boodies on Bernier Island.
- Initial post-release monitoring was undertaken through radio-tracking, and survival rates of 67% (SBM), 87% (GSNR) and 100% (SBB) were achieved.
- Radio-tracking of dibblers was more successful than in 2019 but has been discontinued due to welfare concerns regarding collars.
- Monitoring of SBB and banded and rufous hare-wallabies showed increases in abundance and/or extent of occurrence.
- Reproduction of dibblers was noted for the first time on DHI.
- Scat surveys for hare-wallabies were undertaken with over 400 samples collected and genetic analysis is underway.
- Results of captive trials to optimise collar-fit on SBB were published in *Australian Mammalogy*.
- Captive breeding of dibblers at Perth Zoo continues, with further supplementation planned.
- Monitoring of small extant vertebrates on DHI showed a decrease in rodent abundance but an increase in overall captures of other taxa.
- Genetic work was initiated for chuditch and is ongoing for boodies, SBM and hare-wallabies, as is the development of faecal DNA monitoring for SBB and hare-wallabies.

Management implications

- The successful translocation and establishment of large self-sustaining populations of these six species on DHI is likely to have beneficial outcomes for their conservation and for the ecosystems they inhabit.
- The development of innovative techniques to enhance translocation and post-release monitoring success will, not only be beneficial to this project, but may also improve translocation outcomes at other locations.
- The development of non-invasive approaches to effectively monitor fauna species will provide an effective solution that can be implemented to reduce time in the field and with no requirement for Animal Ethics Committee approval.
- Genomics analysis informs population management strategies and provides a suite of novel, affordable monitoring tools to ensure ongoing adaptive management of these populations.

Future directions

- Further supplementation translocation of dibblers is scheduled for spring 2021, and supplementation of GSNR and SBM are planned for autumn 2022.
- Monitoring of source populations of these species will be undertaken.
- Monitoring of all translocated species on DHI will be undertaken.
- Surveys to locate populations of heath mice will be undertaken.
- Population genomic analyses for several species will be progressed, high-throughput SNP arrays will be developed for SBB, RHW & BHW and non-invasive sampling trialled for dibblers.

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

SP 2015-016

R Palmer, A Johnson

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 south-west 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 hectares 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 and 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 and the neighbouring unbaited reference site on Red Hill pastoral lease.

Progress

- A final report was published on the baiting trial and how northern quolls expanded their range in response.
- A paper was published in *PLOS One* demonstrating the positive benefits provided to northern quolls by controlling feral cats using the aerial application of the *Eradicat*® bait.

Management implications

- The evidence that *Eradicat*® baiting has no harmful impact on northern quolls indicates that quolls benefit both directly and indirectly from landscape-level control of feral cats and that operational use of the *Eradicat*® feral cat bait in the Pilbara can protect northern quolls and other native fauna from feral cat predation.
- The unpredictable behaviour of feral cats indicates that an adoptive management approach is likely to be needed to enhance effectiveness of control programs.

Future directions

- This project has been 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 plant and animal communities of the island 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 the 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

- Further analysis of variation in fieldwrens indicates that the currently recognised subspecies arrangements are not valid and a taxonomic revision is required. The western fieldwren is not a valid species and should be viewed as being synonymous with the rufous fieldwren. The rufous fieldwren consists of only three (previously about eight) subspecies: an eastern and a western subspecies, plus *Calamanthus campestris hartogi* that is endemic to Dirk Hartog Island and listed as Vulnerable.
- A paper describing genetic, morphological, plumage and vocal variation across the range of the species was recently published in *Emu-Austral Ornithology*.

Management implications

- Clarification of taxonomic relationships indicates that the Bernier Island fieldwren subspecies should be removed from the list of threatened species.
- As all three threatened taxa (fieldwren, emu-wren and fairy-wren) are more abundant and widespread on the island than previously thought, localised management actions will have limited impacts, and monitoring will not need to be undertaken as frequently or as intensively as previously anticipated.

Future directions

- Publish accounts of the modelling of species distribution across the island and the population estimates of the species.
- 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

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 limited the usefulness of data 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. Further research is required to validate and test different survey designs (temporal and spatial components) and methods of deploying camera traps and interpret the results to determine how best to use remote cameras to provide rigorous data on species detectability and species richness and density.

Aims

- Investigate methodologies for the use of camera traps to examine the temporal and spatial occurrence of native and introduced mammal species in the south-west of Western Australia.
- Investigate and assess the most appropriate methods of image analysis and data storage.
- Develop analytical tools for the interpretation of camera trap data.
- Run comparative trials on new models of cameras and trapping array designs to assess effectiveness and suitability for different monitoring and survey programs.

Progress

- Improved techniques for monitoring arboreal mammals with camera traps through tree mounted cameras have been developed.
- Different models of Reconyx cameras (PC900 & HP2X) and Swift cameras (3C wide angle and standard angle) have been compared for monitoring critical weight range mammals.
- Detection rates for *Phascogale calura* with and without bait-based lures were tested.
- A workshop on camera trap monitoring for NRM, Indigenous ranger and community groups was developed and delivered.
- Support was provided for data analysis of over 25 long term camera trapping datasets including monitoring of feral predators, recovery of threatened species, experimental investigations on bait uptake trials by non-target species, and monitoring of translocated fauna.
- Standardised analysis and reporting continued to inform several threatened species recovery teams on the status of fauna within specific reserves.
- A peer-reviewed paper focusing on methods to improve remote camera trap designs for monitoring critical weight range mammals and introduced predators at Dryandra is ready for publication.

Management implications

- Assessment of variation in detection rates over time for all critical weight range species from this project provides essential data on population stability and trends and the effectiveness of control measures on introduced predators.
- The camera array at Dryandra now forms a reference location against which other sites can be compared for assessment of effects of management actions.
- It appears that detection rates for most of the 13 target species monitored at Dryandra are significantly correlated with ambient temperatures. Winter months have been shown to have the highest detection rates apart from one species, the numbat, which has increased detection during hotter conditions. This has implications for the use of cameras in that surveying in warmer months may require increased effort to produce similar results to cooler times. Monitoring data under warm conditions may result in a perceived reduction in relative abundances compared to cooler periods.
- Careful consideration is essential regarding the specific species being targeted, questions being addressed, and the 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 have been among the most effective and reliable commercially available models for departmental requirements and the current model, HP2X, is recommended for use, though differences in model performance may have ramifications for comparative data.

Future directions

- Continue to assess improvements and changes in camera trap technology against benchmark sites and camera models to help inform best practice.

- Trials of a wireless network of camera traps (up to 15) will begin to assess the effectiveness and the potential for reducing time associated with managing cameras in the field.
- Investigate and maintain knowledge of improvements in data capture, storage and analytical techniques and disseminate information to DBCA staff and external partners working with camera traps.
- Develop standalone software for camera trap data analysis for internal and external projects that generate long term camera trap monitoring data.
- Compare conventional Western Shield trapping data to that from cameras where available data overlap.

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

SP 2013-001

C Lohr, K Zdunic, K Morris, L Gibson

Context

The goal of this project is to prioritise island management actions to 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, are 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 extraction industries, means an increased likelihood that invasive species will colonise pristine islands. This project will develop: 1) 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 2) an island biosecurity model for prioritising biosecurity actions. The project will focus on the islands along the Pilbara coast.

Aims

- Develop a 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 to prioritise surveillance tasks for non-indigenous species on Pilbara islands [biosecurity Bayesian belief network (BBN) software].

Progress

- The development of the Islands DSS software and biosecurity BBN are complete.
- A manuscript discussing the prediction of habitat types on remote Pilbara islands is in preparation.
- Software manuals and a comprehensive report of all research used in the development of the Islands DSS and biosecurity BBN has been submitted to the Net Conservation Benefits Advisory Board.

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

- The project is now complete.

Conservation and management of the bilby in the Pilbara

SP 2012-035

M Dziminski, F Carpenter, L Gibson

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 a greater understanding of the distribution, abundance and ecology of the bilby is necessary to ensure appropriate conservation and management measures are implemented. This project aims to increase our knowledge of the bilby in the Pilbara bioregion of Western Australia, and develop 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 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

- A collaborative project with the Warralong Community, Roy Hill, and Greening Australia continued with a report describing the results of remote camera and sign plots for predator, feral herbivore and bilby occupancy finalised. Feral cat occupancy was high, measured at 0.79 from sign plots to 0.92 from remote cameras and a single fox was detected.
- A paper describing the application of the abundance monitoring approach developed in the Pilbara but applied to a translocated population in the Goldfields was published in *Rangelands Ecology & Management*.
- Diet analysis of bilbies using 144 scats from 17 populations across Western Australia was completed. Initial results indicate cossid moth larvae were common in the diet of bilbies in Pilbara populations, and the ratio of invertebrate to plant items was higher in Pilbara populations compared to Kimberley populations.
- Information on bilby occupancy survey, abundance monitoring and management has been provided to mining and consultancy companies.

Management implications

- Recommendations regarding standardised survey and monitoring techniques for bilbies in the Pilbara bioregion will maximise comparability across sites to better inform conservation management.
- Improved understanding of the conservation status of bilbies in the Pilbara and elsewhere in Western Australia, including preferred habitat, will inform future management of bilby populations and assist in the assessment of mining and development proposals.
- Geographically isolated and small populations of bilbies in the Pilbara highlight the importance of threat managements such as for unmanaged fire regimes.
- Surveys using remotely piloted aircraft show future potential but require refinement.
- Knowledge of bilby diet preferences will assist in habitat management and assessment of managed sites in terms of food resource availability.

Future directions

- Continue the monitoring at Warralong to assess the effectiveness of threat management to bilbies.
- Review progress against the bilby research program and identify future research directions.

Genetic assessment for conservation of rare and threatened fauna

SP 2012-034

K Ottewell, M Byrne, S McArthur, R Sun, L Umbrello, B Huntley

Context

Genetic analysis of threatened species can provide important information to support and guide conservation management. Genetic information can aid resolution of the taxonomic identity of species and sub-species to determine whether they have appropriate conservation listing. At a population level, analysis of the genetic diversity present, and its distribution across extant populations, provides information on the genetic 'health' of threatened species. Concurrent analysis of some of the proximal drivers of genetic change can identify appropriate management responses for declining populations to improve conservation outcomes. Further, emerging genomic technologies enable novel genetic monitoring approaches, expanding the available toolbox for threatened species monitoring.

Aims

- Assess the genetic diversity and genetic structure of target species.
- Use genetic approaches to assist in resolution of taxonomic boundaries of target species.
- Undertake genetic monitoring of translocated and natural populations of target species.
- Use novel genetic technologies to assist and/or inform conservation management of target species.

Progress

- Genetic assessment of Western Australian *Isoodon* bandicoot species has been published in *Diversity*. Genomic analyses to further resolve closely-related taxa is underway, and genomic analysis of island, mainland and reintroduced populations of golden bandicoots to inform future translocations is ongoing.
- Genomic analysis of Western Australian black-flanked wallaby populations is underway to assess population structure and genetic erosion. A manuscript on the Kalbarri National Park translocation of black-flanked wallaby is in preparation.
- Genetic monitoring of ghost bats at West Angelas, the Robe Valley, Brockman and South Flank mining precincts has been completed, and reports provided. Retrospective analysis of ghost bat genetic monitoring data has been completed and capture-recapture models have been trialled to assess population census size. A revised SNP array for ghost bat genetic monitoring is in development to incorporate molecular sexing markers. Genome and transcriptome sequencing is underway to develop a ghost bat reference genome.
- A SNP array for bilby genetic monitoring has been developed and is being trialled.
- An R package has been developed to analyse SNP data for non-invasive genetic monitoring.
- Genomic analysis of wild, translocated and historical populations of Gilbert's potoroo is underway.
- Genetic analysis of Pilbara leaf-nosed bat populations shows high genetic connectivity amongst roosts, and high genetic health of sampled populations. A manuscript is in preparation.
- Collation and DNA extraction of chuditch tissue samples for genomic analysis has commenced.
- Genetic analysis of Kimberley snubfin dolphins has been completed.

Management implications

- Genetic assessment of golden bandicoot populations will inform future translocations and genetic management of current populations.
- Genomic analysis of rock wallaby populations will assess the genetic health of current populations and impacts of past management to inform future action.
- Non-invasive genetic monitoring of ghost bats provides insight into species' ecology, including rates of cave fidelity and dispersal distances as a basis for impact assessment and conservation. Capture-recapture methods applied to ghost bat genetic monitoring data have been successful and provide information for optimising future monitoring.

- High-throughput SNP genotyping methods have enabled more rapid, cost-effective and reproducible screening of non-invasive DNA samples of ghost bats and bilbies.
- Genetic analysis of Gilbert's potoroo will inform a population management strategy to ensure genetic diversity is conserved across the species.
- The high genetic connectivity amongst roosts of Pilbara leaf-nosed bat provides information for management of potential impacts to this species.
- Genetic analysis of chuditch populations will inform future translocations and management of the species.

Future directions

- Genomic analyses on Gilbert's potoroo, chudich, bandicoots and rock wallaby populations will be progressed.
- Trials on the performance of bilby and ghost bat SNP arrays will be completed and manuscripts prepared.
- A manuscript on the genomic analysis of Pilbara leaf-nosed bat will be submitted for publication.

Barrow Island threatened and priority fauna species translocation program

SP 2012-025

L Gibson, A Burbidge, J Dunlop, C Sims, J Angus, S Garretson, K Nilsson

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 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. Targeted 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

- Camera monitoring of rakali (water rats) continued on Barrow Island to better understand their distribution and occupancy as a potential source population for translocation.
- Boodies and golden bandicoots translocated from Barrow Island to a fenced enclosure at Matuwa continued to be monitored, with populations showing signs of recovery following drought conditions.
- Golden bandicoots also continued to be monitored outside the enclosure at Matuwa, with recent detections on camera traps.
- A strategic approach to introduced predator management continued at Matuwa and Cape Range National Park.
- A manuscript describing the Barrow Island fauna translocations has been accepted by *Pacific Conservation Biology*.
- A review of the monitoring program is now complete.

- Genetic assessment of golden bandicoots on Doole Island indicates the population does not require augmentation at present.

Management implications

- Arid zone rangelands fauna reconstruction and conservation techniques developed by this project will have broad State and national application.
- The project outcomes 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, and provided the basis for ongoing monitoring of fauna of the Montebello Islands.

Future directions

- Continue the monitoring of translocated populations.
- Continue monitoring the effectiveness of integrated fox and feral cat baiting at Cape Range.
- Consider installing camera traps for ongoing monitoring of golden bandicoots on Doole Island.
- Review camera trapping data of rakali on Barrow Island.

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

SP 2012-024

C Lohr, K Nilsson, L Gibson

Context

Operation Rangelands Restoration commenced in 2000 with the acquisition of Lorna Glen (Matuwa) and Earaheedy (Kurrara Kurrara) ex-pastoral leases by the WA Government. We are working in collaboration with the traditional owners, Tarlka Matuwa Piarku Aboriginal Corporation, who were granted native title (exclusive possession) over the area in 2014, to restore ecosystem function and biodiversity in the rangelands. Matuwa once supported many mammal species, which have now suffered large declines. This project seeks to reintroduce 11 arid zone mammal species following the successful suppression of feral cats and foxes. Mammal reconstruction will also contribute to the restoration of rangeland ecosystems through re-establishment of ecosystem services such as digging, grazing/browsing of vegetation and seed dispersal.

The first 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 a 1,100 hectare introduced predator-free fenced enclosure. The enclosure is intended to provide species with an opportunity to acclimatise to the desert environment. The ultimate goal is to release animals outside the enclosure and establish a free-ranging, self sustaining population of these species.

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 a rangeland ecosystem.

Progress

- A manuscript discussing the habitat selection by vulnerable golden bandicoots in the arid zone was published in *Ecology and Evolution*.

- A manuscript describing the successful reintroduction of bilbies to Matuwa was published in *Rangeland Ecology and Management*.
- A manuscript discussing how boodies alter soils but not vegetation was published in *Ecology and Evolution*.
- A manuscript discussing the need for research on inter-specific competition in fenced reserves is in press at *Ecological Management and Restoration*.
- A final report was completed describing the translocation of golden bandicoots from the fenced enclosure to unfenced managed land on Matuwa.
- Monitoring of boodies, golden bandicoots and mala inside the enclosure continued. Camera traps have detected golden bandicoots outside the enclosure.
- Introduced predator control, including aerial baiting using Eradicat continued.

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 consider the effects of environmental conditions (droughts), annual cycles of reproduction and behaviour and potential predators and competitors on reintroduction success.
- Detailed monitoring to identify causes of mortality and subsequent identification of predators and their removal in a timely fashion is critical to the success of reintroduction programs. Monitoring has demonstrated that applying 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

- Ongoing monitoring of reintroduced species and introduced predators.
- Complete publications on the ecology of boodies and population genetics of brushtail possums.
- Facilitate training in fauna handling in stakeholder groups.

Conservation of south coast threatened birds

SP 2012-022

A Burbidge, A Clarke, A Pinder

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, 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 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 the creation of management prescriptions that will benefit all threatened south coast animals.
- Investigation of life history characteristics and ecological processes impacting recruitment in the Australasian bittern.
- Survey and monitor Australasian bittern populations and habitat to assist tracking current trends.

Progress

- An analysis of the occurrence of western bristlebirds in relation to fire over several decades in Fitzgerald River National Park has been accepted for publication.
- An evaluation of feral cat control and impacts on western ground parrots was published in *Wildlife Research*.
- A risk assessment and a translocation proposal were developed for western ground parrots. Eight birds were translocated from Cape Arid National Park to a site east of Albany. Movements of these birds are currently being tracked.
- Extensive surveys for Australasian bitterns were conducted, and ARUs were deployed.
- Further experience was gained in deploying traps to catch Australasian bitterns for fitting birds with satellite trackers, but no birds were captured. Trap design will be modified before further capture attempts are conducted.
- Continuous depth and rainfall data at wetlands important to the Australasian bittern were collected for the tenth and final year, providing data that can be used to understand hydrological regimes in wetlands used by this species.

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 analysis of high quality depth and rainfall data will be critical to development of modelling designed to predict the hydrological futures for high priority bittern breeding wetlands. This information will help inform stakeholders and land managers where to target mitigation strategies.

Future directions

- Analyse survey data for ground parrots, scrub-birds, bristlebirds, and bitterns.
- Examine occupancy of ground parrots in relation to fire.
- Continue to monitor key populations of Australasian bittern and their habitat.

Ecology and management of the northern quoll in the Pilbara

SP 2011-005

J Dunlop, M Craig, L Gibson

Context

The northern quoll (*Dasyurus hallucatus*) is listed as an endangered species under the *Biodiversity Conservation Act, 2016*. Funding from mining offset conditions is being used to gain a better understanding of quoll distribution, ecology, demographics and management requirements in the Pilbara. The two major components of the project are 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

- Analysis of monitoring data showed that current monitoring protocols using either live trapping or motion-sensitive cameras are sufficient to detect quolls with 95% confidence.
- Further analysis of monitoring data showed that quoll detections are too sparse to accurately calculate absolute population sizes or densities for most populations.
- Analysis of 1844 genetic samples showed Pilbara mainland populations are genetically homogenous and that females typically disperse 1-2 km, and occasionally up to 4 km, while males disperse 10-15 km, occasionally up to 30 km.
- Analysis of litter paternity revealed a highly promiscuous breeding system and that females on the Pilbara mainland showed no obvious mate selection whereas females on Dolphin Island preferentially mated with smaller males.
- Felixer grooming traps were shown to target feral cats and not northern quolls during a trial of three units.

Management implications

- Monitoring of northern quoll populations can be conducted most cheaply and powerfully using motion-sensitive cameras.
- The cheapest and most effective monitoring design minimises the number of cameras at a site and maximises the number of sites.
- High quality quoll habitat occurs on rocky outcrops and outcrops that are large, have reduced edge-to-area ratios and are surrounded by multiple other outcrops that provide optimal habitat.
- Quolls rarely occur on *Triodia* sandplains, but they disperse through them, so management of sandplain habitat for quolls will help to maintain genetic connectivity and metapopulation dynamics.
- Felixers are safe to use in the presence of quolls and should be considered as an additional tool to manage feral cat populations, as appropriate.

Future directions

- Complete a review and report the progress against the Pilbara Northern Quoll Research Plan from 2016-2020.
- Identify future research directions informed by the review.
- Continue trials to investigate the effectiveness of Felixer feral cat grooming traps in toxic mode.

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 has identified that predators, such as northern quolls (*Dasyurus hallucatus*) 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 trialled 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 'teacher toads' (metamorphs too small to be lethal) to induce an effective conditioned taste aversion (CTA) response from native species threatened by toads.
- Develop operational techniques to roll out taste aversion training across Kimberley landscapes.
- 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

- Monitoring of quolls and other toad-susceptible species continued using cameras on Adolphus Island and images were examined and prepared for analysis. All toad susceptible species are persisting on the island.
- Experimental apparatus to test for CTA in freshwater crocodiles was established at Windjana Gorge. Naive crocodiles displayed CTA and the development of a landscape scale method to train crocodiles to avoid toads is underway.
- A northern quoll mark-recapture survey and an aerial drop of CTA baits were carried out at Mt Hart Station just prior to the arrival of the cane toad front. The response of quolls to CTA training will be compared with control populations using mark-recapture trapping and camera arrays.

Management implications

- Freshwater crocodiles displayed the ability to learn not to eat cane toads, so it is possible to undertake CTA training of populations in seasonally isolated waterbodies such as Windjana Gorge.
- Aerial trials of the CTA baits have resulted in the survival of northern quolls in some areas invaded by toads, indicating potential promise for the technique in preserving populations. Data from studies on Mt Hart in 2021-22 will help clarify its value.

Future directions

- Examination and analysis of camera arrays examining quoll survival in areas with and without aerial drops of CTA baits.
- Publication of CTA trials, the development of CTA baits and observations on the persistence of quolls and susceptible reptiles on an island following toad invasion.
- Landscape scale CTA learning of susceptible goanna and freshwater crocodiles to mitigate the impact of invading cane toads.

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, effective, and cost-efficient 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 baiting strategies to provide long-term and sustained effective control.
- Assess the potential impact of baiting programs on non-target species and devise methods to reduce the potential risk where possible.
- Provide a technique for the reliable estimation of cat abundance.
- Refine the feral cat trapping technique to effectively collect information on population parameters relevant to control strategies, while minimising risk to non-target species. Also, assess the utility of trapping as a follow-up measure post-baiting where eradication of cats is required (e.g., small-scale areas and islands) or to provide additional control effort.

Progress

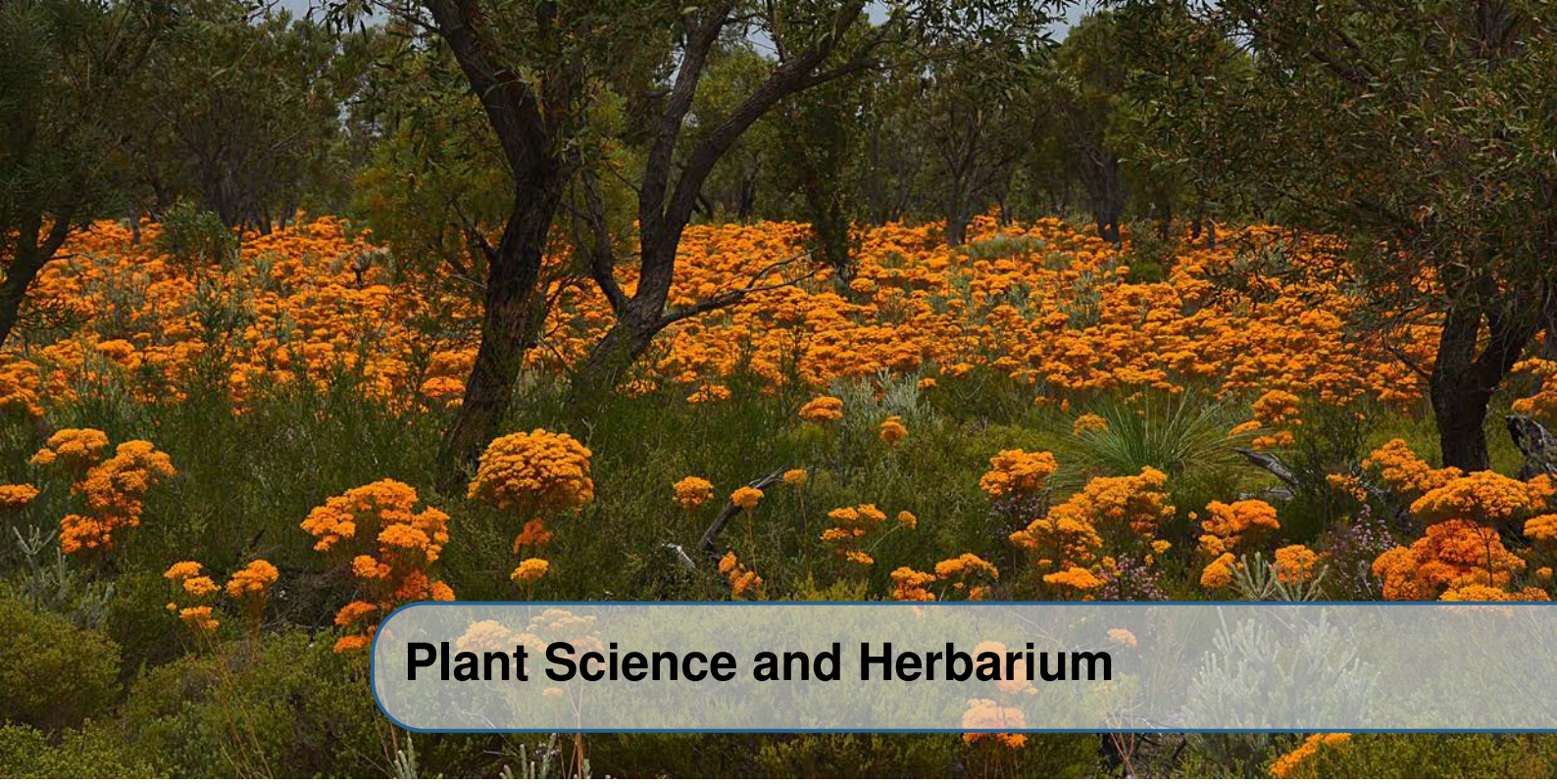
- Trials to improve bait palatability have demonstrated that inclusion of certain amino acids in the bait matrix could enhance bait consumption.
- A review of cat activity/movement patterns during large-scale aerial baiting has suggested that baiting campaigns could benefit by altering current delivery methods to increase bait encounter rate. This has been published in *Australasian Journal of Environmental Management*.
- Initial trials of the *Hisstory*® feral cat bait have been completed and a report has been provided to the Australian Government, National Landcare Programme.
- Trials to assess several cat attractants for monitoring cat abundance have commenced.
- Recent modifications to the trapping technique to minimise risk to non-targets are being field-tested.
- The utility of trapping to provide additional control effort is being evaluated.

Management implications

- 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 allows persistence of the native fauna on these islands and enables effective reintroductions of mammals where appropriate, and restoration of habitat and ecosystem processes.

Future directions

- Conduct further refinement of the bait medium to improve bait consumption and test a long-life lure that may enhance bait longevity.
- Further analyse the baiting operation and refine the methodology (targeted/strategic) where necessary to optimise baiting efficacy.
- Continue investigation of bait consumption by non-target species and where potential hazards are identified, devise methods to minimise risk.



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 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

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 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 to 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

- Phylogenetic analyses of whole chloroplast sequences identified three introductions of *P. foetida* from South and Central America. The data shows a main group that represents the Western Australia, Northern Territory and some of the Queensland locations clustering with samples from Ecuador, and two smaller groups that represent locations in Queensland and New South Wales, one of which clusters with samples from Brazil and the other of which clusters with samples from the Caribbean.
- The analyses also identify the phylogenetic relationships of native, commercial and invasive *Passiflora* in Australia in the context of diversity in the native range of *P. foetida* in South America.
- A paper has been accepted for publication in *Frontiers in Plant Science* on the relationships among species and the origins of the introductions in Australia.
- Genomic analysis of 870 samples from 37 populations from Queensland, 35 populations from the Northern Territory and 14 populations from Western Australia that represent the introduced range in Australia, show low diversity and confirm the expansion of one of the introduced lineages across northern Australia from the location of introduction in Queensland. A manuscript is in preparation.

Management implications

- Information on the potential taxonomic entities and origin of *P. foetida* in the Pilbara will inform the identification of, and guide the search for, putative control agents from the natural range.
- Information on local adaptation within invasive populations provides a basis for understanding the dynamics of invasion and determining the effectiveness of potential control agents.

Future directions

- Complete manuscript on the population genetic analysis of collections from the invaded range in Australia.
- Investigate the ability to recover adaptive loci, considering the low diversity that has been found in populations in Australia.

Is restoration working? An ecological genetic assessment

SP 2016-015

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

- Genetic diversity and the mating system were largely equivalent among restoration and remnant populations of *Hakea nitida*, although divergence was surprisingly high. Patterns of pollen dispersal were random, and pollen immigration was low in the restoration sites. A paper on pollen dispersal, mating system and genetic diversity has been published in *Restoration Ecology*.
- Analysis of *Hakea 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 species richness was similar. A paper has been submitted to *Restoration Ecology*.

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 largely established with local provenance material with the exception of *H. nitida*.
- 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

- This project will be complete when papers on *H. nitida* and *H. laurina* are 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 100 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 *Darwinia* and *Verticordia* (Myrtaceae) have been published.
- A paper on a new genus, *Austrobaeckea,* has been submitted.
- Papers on *Balaustion, Hypocalymma* and *Tetrapora* are in preparation.
- Funding from ABRS has commenced for the transfer of approximately 350 species and subspecies flora treatments onto *eflora of Australia*.

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

- Continue investigation of generic boundaries in subtribe Chamelauciinae based on molecular and morphological evidence, making new combinations and describing new genera where required.
- Submit papers on *Balaustion* and *Hyocalymma.*
- Continue preparation of papers on *Hypocalymma* and *Tetrapora* and new genera.
- Update previously prepared flora treatments.

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 a description of *Darwinia sphaerica* (Myrtaceae), a new species currently known from one granite outcrop, in *Nuytsia*.
- Published a description of *Gomphrena verecunda* (Amaranthaceae), a modest new species from Western Australia's arid zone, in *Nuytsia*.
- Published a description of *Acacia lachnocarpa* (Fabaceae), a new geographically restricted Wattle from the Coolgardie bioregion of Western Australia, in *Nuytsia*.
- Published a description of *Swainsona katjarra* (Amaranthaceae) and a key to Western Australian species of *Swainsona,* in *Swainsona*.
- Published *Wildflowers of the South Coast* in the Bush Books series.

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, Gomphrena* 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, T Macfarlane, S James

Context

The Western Australian Plant Census (a component of WACensus) is the authoritative database of all plants found 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 data sets, including the threatened and priority flora databases maintained by the Species and Communities Program, the Herbarium's specimen database (WAHerb), Max (the department software for information based on taxonomic names), *Florabase* and *NatureMap*.

The Australian Plant Census (APC) is a Council of Heads of Australasian Herbaria project, designed to provide a consensus view of all Australian plant taxa. The APC delivers authoritative information on what species occur in Australia as a whole to obtain accurate national statistics and resolve 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 formally 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 and the Australasian Virtual Herbarium.

Aims

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

Progress

- Six hundred and thirty-one plant names (591 formally published and 40 informal names) were added to the WACensus.
- A total of 1,247 other edits were made to the WACensus.
- WACensus updates were regularly distributed to 264 registered Max users.
- Finalised a critical review of several years backlog of APC name updates resulting from ongoing taxonomic activity in Australia and internationally.
- Contributed to discussions on taxonomy and nomenclature to assist in the publication of a national consensus known as the Australian Plant Census for the National Species List (NSL).

- The State's contribution to maintenance of this national cooperative database continued with the addition of 53 new vascular plant names to the NSL database and the creation of 452 new instances (data on synonomy 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, and other linked databases or websites.
- Users of plant names can 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 names through WACensus.
- WACensus feeds Western Australian information to national biodiversity systems such as the Atlas of Living Australia, Australasian Virtual Herbarium, the Australian Plant Census (National Species List), and the e-flora of Australia. The national list contributes to international names databases such as the Global Biodiversity Information Facility and Encyclopedia of Life.

Future directions

- Development of a new, more efficient online database forum for APC.
- Continue to provide a comprehensive and up to date State and National census across all plant, algae, and fungal groups.

The Western Australian Herbarium specimen database

CF 2011-110

J Percy-Bower, S James, A Curtis, S Sinha, E Wood-Ward, S Coffey, O Nazarova

Context

The Western Australian Herbarium specimen database (WAHerb) allows staff at the Herbarium to manage and maintain the Herbarium's collections and assets. It 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. An upgrade of the collections management system to Specify is underway.

Aims

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

Progress

- The Western Australian Herbarium added 10,544 specimens to collections, including 728 specimens of priority taxa, 107 specimens of threatened taxa and one specimen of a presumed extinct taxon.
- Regularly provided customised specimen data requests (species lists and label data) to departmental officers, researchers and the public.
- More than 69,000 specimen records were edited as part of activities to ensure the collection is scientifically valid, up-to-date and aligned with the department's conservation codes.

- Significant collections added to the Western Australian Herbarium included industry surveys; departmental regional surveys; Herbarium Research Associates; and exchange specimens from Australasian herbaria, including Desert Discovery, Fortescue Marsh Floristic Survey, Kimberley Islands Biodiversity Survey, Pilbara Biological Survey and Yilgarn Calcrete Survey, AM Coates, CJ French, C Tauss, JE Wajon, LSJ Sweedman, MD Barrett & RL Barrett, NH Brittan, S Carlquist, SD Hopper and TEH Aplin. Collections from regional herbaria were also received.
- Data cleaning and migration are underway to transfer records to a new collection management system.

Management implications

- WAHerb enables the efficient management of the State's botanical collections assets.
- WAHerb represents the most comprehensive vouchered specimen database for Western Australian plants available and provides a source of information that land 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, timely editing and validation of specimen records to maintain currency and connectivity between the Herbarium collection, the Western Australian Plant Census and external biodiversity data providers, including the AVH, ALA, and GBIF.

Herbarium collections management

CF 2011-105

S James, C Parker, J Huisman, J Percy-Bower, A Curtis, S Coffey, M Hislop, R Davis, O Nazarova, S Sinha

Context

The Western Australian Herbarium houses the State's botanical collections, the core resource for knowledge of the State's plants, algae, and fungi. The collection is growing constantly and consistently through accessions of new taxa and distribution records from internal and external sources. The collection is maintained to the highest standard utilising international natural history collections and archival best practice, and provides the department and the community with the fundamental resource that provides knowledge of the diversity, temporal and spatial distribution and abundance of the flora throughout Western Australia.

Aims

- Document and audit the diversity of Western Australia's plants, algae, and fungi.
- Maintain, in perpetuity, a comprehensive and representative research collection of specimens of all taxa in groups occurring in, and adjacent to, Western Australia.
- Contribute to, support and service the research, conservation and decision-making activities of the department and stakeholders.
- Contribute to, support and service taxonomic and other research by the local, national and international scientific community.

Progress

- The Western Australian Herbarium added 10,544 specimens to collections, increasing the size of the collection to 821,735 catalogued items, representing more than 18,500 taxa.
- More than 69,000 specimen data records were updated during the year, and through the Australasian Virtual Herbarium and Atlas of Living Australia, almost 40 million herbarium data records were downloaded in 13,900 download events. The Western Australian Herbarium dataset is now also available via the Global Biodiversity Information Facility (GBIF).

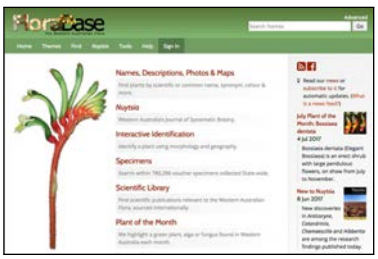
- Specimens and data were cited in more than 140 publications.
- COVID-19 continued to impact the exchange of specimens between herbaria. The Western Australia Herbarium shared specimens with 12 national and 2 international institutions, and shipped almost 350 specimens in 14 transactions for scientific research. A total of 1,354 exchange specimens were sent to collaborating institutions, and 26 requests for 535 tissue samples from herbarium specimens were processed for molecular and other scientific analyses.
- Major activities within the collections included substantial and targeted reduction in unprocessed specimens, incorporation of specimens returned to the Western Australian Herbarium from Manjimup, and receipt and incorporation of orphaned regional herbarium and private collections.
- With the assistance of volunteers, 7,550 specimens were mounted.
- Volunteer participation continues to be a significant and invaluable resource, totaling 16,850 hours, equivalent to approximately 10.7 full time employees. The Herbarium was assisted by about 50 regular volunteers and 41 Research Associates.
- About 1,900 users used the Reference Herbarium for plant identifications and other scientific purposes.
- The Research Collection was accessed by 1,004 visitors for the study and identification of taxa.
- More than 5,600 high resolution images of Herbarium specimens were captured and shared with departmental staff and industry consultants and a further 153 high resolution images of type specimens were captured and shared with the online Global Plants Initiative.
- The Herbarium Identification Program provided identifications to a range of clients, including departmental staff, other government agencies, environmental consultancies, regional herbaria and the public. More than 3,370 specimen identifications in 279 transactions, along with 130 image-based identifications, were undertaken for external clients.
- Educational programs consisted of eight Herbarium tours and monthly induction sessions (approx. 260 participants) for departmental staff, tertiary institutions, environmental consultancies, community groups and the media. As part of National Science Week, and in collaboration with the Wildflower Society of WA, the Herbarium provided a Herbarium Volunteer Day and invited 60 volunteers from regional and Perth herbaria to attend tours of the collections, participate in learning activities and listen to talks provided by herbarium botanists.

Management implications

- Maintenance and curation of the Western Australian Herbarium botanical collections provides an authoritative inventory of the plant biodiversity of Western Australia, which underpins flora conservation and national and international research programs.
- The collections are drawn upon constantly by DBCA staff, consultants and others, to validate specimen records from biological surveys and assess the conservation status of native taxa.
- The curated collections data is a much utilised digital resource for systematic and taxonomic research, collections management, environmental assessment, ecological and other scientific research, restoration and remediation projects, biosecurity management and planning, educational uses and citizen science.

Future directions

- Develop curation workflows and volunteer programs that enable the imaging of physical collections for online delivery and sharing.
- Continue to significantly reduce the currently unprocessed and uncatalogued specimen items in storage.
- Initiate workflow for curated vouchered tissue collection and maintenance plan for future molecular studies.
- Scope gap analysis for collections.



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 State's central database for botanical taxonomic information. Florabase draws from three core databases for names (WACensus), specimens (WAHerb) and images (Imagebank). Actively managing the currency, authority, data quality and linkages between these datasets is an important task, both for the maintenance of Florabase and for contribution 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 and is the sole source of specimen data used by Florabase. Imagebank is the Herbarium's image collection.

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

- Launched Florabase 3 providing redeveloped features and new functionality.
- Improved features in the Herbarium Agent Migrator to allow it to be used in the WAHerb data migration.
- Provided support to migrate the MS Access-based application, WASeed, into Microsoft Remote Desktop Services to enable it to continue to be used by multiple staff following the removal of access to network drives.

Management implications

- Florabase is an essential data library that allows the community and department staff to retrieve the most recent information on the name, features, status and distribution of the 14,047 currently recognised native and naturalised Western Australian vascular plant taxa and 3,145 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.
- 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

- Continue the development of up-to-date, integrated and accessible data catalogues and databases.
- Continue to ensure data is effectively captured, curated and accessible to support conservation management and decision making.

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 resulted in significant changes to the classification of the epacrids at the generic level. The circumscription of the genus *Styphelia* has now been expanded to include all taxa previously in *Astroloma*, *Coleanthera* and *Croninia*, and a large percentage of those in *Leucopogon.* A recent publication formalising these changes has opened the way to 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 are short range endemics of conservation significance. In addition, there is still much taxonomic work remaining to do in *Leucopogon s. str.*

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 that may be geographically restricted.

Progress

- *Styphelia capillaris*, a new species of threatened flora was described in the *Nuytsia* 50th special anniversary edition.
- *Stenanthera localis,* a rare, new species was described in the *Nuytsia* 50th special anniversary edition. It is currently identified as a Priority 1 species, and has recently been nominated for threatened flora status.
- An updated key to the genera of Western Australian epacrids has been published in *Nuytsia*.
- An interim key to, and composition of, the species groups in Western Australian *Styphelia* has been published in *Nuytsia*.
- Two papers are well-advanced, in which numerous species of *Styphelia*, many of conservation significance, will be described.
- A new, apparently uncommon phrase-named taxon, *Styphelia* sp. Kirkalocka, has been added to the census.

Management implications

- The epacrids, of which *Styphelia* (in the newly expanded sense) and *Leucopogon* are 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 about 400 species of herbs and shrubs. Sixty-five taxa are currently recognised in the Eremaean and Northern Botanical Provinces of Western Australia, including 26 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 cannot be adequately identified as they belong to poorly-known, undescribed taxa or species complexes. Their identification is further hindered by the absence of up-to-date taxonomic keys and 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 their conservation status.

Aims

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

Progress

- Two papers revising species groups were published (*Nuytsia*), including clarification of several species and description of four new species.
- Four papers are in advanced draft, with 21 species described, 17 of them new.
- Profile pages for the *eFlora of Australia* have been drafted for approximately 60 species.
- Key to *Tephrosia* in the Eremaean (Pilbara and desert) region of WA drafted.
- A collaborative worldwide molecular phylogenetic study of *Tephrosia* was supplied with samples of Australian species and results are pending.
- Final reporting for ABRS funding of the project was completed.

Management implications

- Further species of *Tephrosia* have been taxonomically clarified with existing names accurately applied and new formal names published. This extends the proportion of species with up-to-date diagnostic information and illustrations to aid identification.
- Conservation status has been re-assessed in light of improved knowledge of taxonomy and distribution for a number of species are included in recent research.
- A draft key to *Tephrosia* in the Pilbara and desert regions of WA will, for the first time, provide an identification tool for conservation and environmental survey workers.

Future directions

- Complete draft papers.
- Complete provision of species profiles for the *eFlora of Australia*.
- Complete and publish the draft key to Eremaean WA.

Taxonomy of selected families including legumes, grasses and lilies

SP 2011-001

T Macfarlane

Context

Successful conservation of flora requires that 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, and 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 taxonomic issues need to be resolved, including apparently new species to be described and unsatisfactory taxonomy that requires clarification.
- Carry out taxonomic revisions using field work, herbarium collections and laboratory work, resulting in published journal articles.

Progress

- *Althenia* – A new species was described in *Phytotaxa* with an updated key.
- *Wurmbea* - The new species, *W. flavanthera,* was described in *Nuytsia*. Field collecting of samples for Genomics for Australian Plants (GAP) Conservation Genetics project was completed.
- Hydatellaceae - A field survey at Hutt River confirmed the presumed extinct status of *Trithuria* locally.
- *Thysanotus* - Taxonomic studies of the twining *T. patersonii* group continued with new populations located of poorly known species, a new non-twining species described in *Nuytsia,* and field surveys of the conservation priority species *T. formosus* conducted.
- *Corynotheca* - A taxonomic revision was published in *Telopea* with 13 species recognised.
- Asparagales - Limited progress was made on phylogeny of *Lomandra*.
- Poaceae - Participation continued in the international molecular phylogenetic study of the grass family (PAFTOL project) based at Kew, UK.
- Anarthriaceae - A review of *Anarthria gracilis* was published in PeerJ, showing that it actually comprises three species. A paper on male reproductive development in this family is being prepared.
- Priority conservation species - Six papers describing new species in *Arthropodium, Bossiaea, Caesia, Deyeuxia, Thysanotus* and *Wurmbea* were published in a special series of *Nuytsia*.

Management implications

- Identification of species known or suspected to have restricted distributions will enable re-assessment of 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.
- Better knowledge of plant relationships adds to the appreciation of the global significance of the Western Australian flora and facilitates its appropriate representation in a wide range of research.

Future directions

- Complete and submit papers describing new species of *Wurmbea*, *Thysanotus, Althenia* and *Lomandra*.
- Conduct field searches for species or populations of relevant families that are insufficiently known.
- Continue to revise plant groups and investigate various putatively new species in order to improve knowledge of the flora, and provide stable plant names and a means of identifying species.
- Publish and present 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 Australia's most abundant and diversified genera. 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. The most significant issue at this point is the lack of an overarching flora treatment for the family Stylidiaceae, which hinders accurate identification by conservation personnel, botanical consultants and other stakeholders. Given the high proportion of taxa that require further surveys 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 this data to inform taxonomic research and conservation management.

Progress

- *Stylidium shepherdianum*, a newly discovered species from the Mallee bioregion, was published in a golden anniversary edition of *Nuytsia*.
- Targeted field work in south-western Australia was conducted to support taxonomic resolution of putative new species and the circumscription of known species, obtain data for species profiles and collect voucher material (herbarium specimens, photographs and dried leaf material for DNA analysis).
- 545 *Stylidium* specimens at the Western Australian Herbarium were annotated to correct or confirm their identity, improving our understanding of the distribution and rarity of the State's triggerplants. Several novel taxa were discovered in the process.
- Taxonomic data continues to be generated and consolidated for the *Flora of Australia* treatment, with several associated manuscripts being prepared in parallel.

Management implications

- Herbarium-based taxonomic research and targeted field work continue to improve our understanding of the distribution, habitat requirements and conservation status of Australia's triggerplant flora.

Future directions

- Continue writing species profiles for the *Flora of Australia* and associated research papers.
- Conduct targeted field work to obtain necessary collections and images to complete research publications.

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 areas of commercial interest to provide baseline information that will enable a more comprehensive assessment of the Western Australian marine biodiversity. These include Shoalwater, Marmion, Ningaloo, Dampier Archipelago, Barrow Island, Montebello Islands, Rowley Shoals, Scott Reef, Maret Islands, etc.

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 guide for north-western Australia, documenting this biodiversity.

Progress

- A summary of the algae and seagrasses of the Kimberley was published in the *Records of the Western Australian Museum*, recording 296 species for the region.
- The new species of red algae, *Leptofauchea lucida* and *Champia patula,* were described in a special edition of *Nuytsia*.
- Original material of the red alga *Galaxaura major*, first described in 1842, has been discovered in a French herbarium and the name resurrected for use in Australia, as *Dichotomaria major*.
- A further new species of red algae, *Hypnea corona*, has been accepted for publication in *Pacific Science*.
- A manuscript resurrecting the Australian species *Plocamium pusillum*, previously thought to be conspecific with the seemingly widespread *Plocamium cartilagineum*, has been submitted to *Cryptogamie, Algologie*.

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.
- Publication of papers describing new and existing genera, species and other categories.
- Undertake further taxonomic studies of Western Australian species of the red algal genus *Champia*.
- Undertake further taxonomic studies of the potentially invasive red algal genus *Hypnea*.
- Undertake taxonomic assessments of turf algae, including descriptions of potentially new species of *Derbesia* and *Vaucheria*.

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, O Nazarova

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, 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

- The descriptions of 542 taxa (family, genus and species level) from *Algae of Australia: Marine Benthic Algae of North-western Australia, 2. Red Algae*, have now been added to *Florabase*.
- Numerous fact sheets describing morphological and reproductive features have been prepared for inclusion in the interactive key, to assist in character recognition.
- 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 202 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.
- 1,293 existing WA Herbarium records of marine flora 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 stakeholders to marine plant species inventories and up-to-date names.

Future directions

- Further refinement and completion of 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 mining leases. There are more than 1,140 putatively new and undescribed taxa on Western Australia's vascular plant census, around half of which are poorly known, geographically restricted and/or under threat. 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 a manuscript or phrase-named plant taxa, particularly threatened and priority flora and those taxa vulnerable to future mining activities.

Progress

- 25 conservation-listed species were published, the majority of which formed part of a golden anniversary edition of *Nuytsia* in which 50 novel Western Australian species were named and described. Social media was widely used to promote this unique initiative and popular articles were published in *Landscope*, *Yarning Times* and the newsletters of the *Australasian Systematic Botany Society* and *Australian Flora Foundation*.
- Targeted field work to progress research on an array of undescribed, conservation-listed taxa was carried out. This included intensive sampling for projects on *Geleznowia*, *Isopogon*, *Synaphea* and *Wurmbea* that are being conducted as part of the Genomics for Australian Plants initiative.

- 10 putatively new and poorly known species from the genera *Calytrix*, *Eremophila*, *Fitzwillia*, *Microcorys*, *Olearia*, *Streptoglossa*, *Styphelia* and *Swainsona* were discovered by team members and added to the State's vascular plant census under phrase names. *Heliotropium mitchellii* was also conservation-listed following advice from Herbarium staff.
- Specimens of phrase-named entities from Western Australia are gradually being assessed to document collection gaps and needs.

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.

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 the 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

- A paper on *Lambertia orbifolia* genetics and mating systems was published in *Restoration Ecology*.
- A plan was developed to establish two multi-species seed orchard sites for threatened Stirling Range plant species impacted by fire and *Phytophthora* dieback. One of the seed orchards at Redmond was established with site infrastructure installed, and planting and initial monitoring completed.
- A plan to establish a seed orchard for *Grevillea calliantha* was prepared. Additional planting at an already established translocation site of this species was undertaken and rabbit proof fencing was installed at a natural location of this species, to assist in the protection of plants from grazing.
- Preparation of a paper commenced describing the analysis of flora translocation data from 22 years of plantings and examining factors that contribute to translocation success.

Management implications

- Translocations lead to the 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 departmental 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

- Finalise and publish meta-analysis of translocation methodologies, outcomes and success in Western Australia.
- Complete and publish paper on *Schoenia filifolia* cross pollination study that investigated the impact of genetic composition of founding plants on translocation success.
- Develop a PVA model for translocated and natural populations of *Acacia cochlocarpa* subsp. *cochlocarpa* using demographic data already collected.
- Continue to monitor plant survival at the Redmond and Porongurups sites.
- Establish monitoring of *Grevillea maxwellii* translocation and natural populations in order to develop PVA model.

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

- Data analysis has been completed 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. A manuscript is near completion.
- Data analysis is being undertaken 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 traits is ongoing in a common garden experiment involving 1,100 seedlings of *B. brownii* from montane and lowland populations, 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 has been completed. A paper describing this work is being prepared. 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 and data analysis has been completed on three translocated and nine natural populations of *Lambertia orbifolia*. Genotyping will enable the assessment of mating system variation and genetic variability, and benchmark mating system performance and genetic diversity in translocated populations. A paper has been published in *Restoration Ecology*.
- Data analysis has been completed on genetic diversity data for natural and translocated populations of *Acacia cochlocarpa* subsp. *cochlocarpa* and *A. cochlocarpa* subsp. *velutinosa*. 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. A paper describing this study is in preparation.
- Completed analysis of genotyping and mating system data for *B. anatona,* to assess mating system performance and genetic diversity in a translocated population compared to natural populations. A manuscript describing this study is near completion.
- A common garden experiment to assess the fitness of *L. orbifolia* subsp. *orbifolia* and *L. orbifolia* subsp. Scott River Plains has been planted.

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*, *A. cochlocarpa* and *S. filifolia*.
- Develop and implement a monitoring plan for the *L. orbifolia* common garden experiment.

The population ecology of critically endangered flora

SP 2000-015

C Yates, C Gosper

Context
South-west Western Australia is a global hotspot of plant diversity. Therefore, 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 the 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
- Monitored the Eastern Stirling Range Montane Heath and Thicket TEC and associated threatened flora to assess impacts and recovery following the May 2018 and December 2019 bushfires.

- Completed a population viability analysis of *Banksia verticillata* investigating the relative roles of canker disease, fire-interval and fire patchiness in the taxon's observed decline. A paper has been published in the *Australian Journal of Botany*.
- Monitored the effect of invasive bulb occurrence and the effect of invasive bulb control methods on the population dynamics of the critically endangered *Ptilotus pyramidatus* on the Swan Coastal Plain.
- Monitored an experiment testing the effect of a novel herbicide to control invasive African lovegrass on native flora, including the endangered *Grevillea curviloba*.
- Completed a regional analysis of the spatial distribution of threatened and priority flora and major threatening processes in the Southwest Australian Floristic Region (SWAFR). A paper has been published in the *Biological Journal of the Linnean Society*.
- Completed a review of published literature to determine the influence of evolutionary, genetic and ecological traits on exposure and susceptibility of the flora to major threatening processes in the SWAFR. A paper has been published in the *Biological Journal of the Linnean Society.*
- Vegetation condition was sampled in ~40 plots across the major geologies of Fitzgerald River National Park, and paired with remotely piloted aircraft photogrammetry, to quantify the extent and severity of putatively climate- and disease-driven decline in *Banksia*.
- Persistence or local extinction over a 20-40 year period was assessed in ~100 populations of long-lived serotinous flora in fragmented landscapes.

Management implications

- Studies of the effects of fire interval and *Phytophthora* dieback on population trends for 26 threatened and priority flora in the Stirling Range National Park provided critical information on impacts of 2018 and 2019 fires and priorities for species recovery through translocation.
- Population viability analysis provided critical information on fire interval and patchiness for management of *B. verticillata* and identified twig and stem cankers as a major threat to *Banksia* diversity on the south coast.
- Demographic studies and experiments investigating the impact of environmental weeds on *P. pyramidatus* and *G. curviloba* will provide critical information for supporting species recovery.
- Spatial analysis of threatened and priority flora and threats identified ancient, infertile uplands and surface geologies of limited extent within 300-500 km of the present-day coast as hotspots for flora conservation and management. Flora on these geologies have higher frequencies of traits that elevate their susceptibility to extremes in fire interval and *Phytophthora* dieback.

Future directions

- Continue demographic studies investigating environmental weed impacts and recovery actions for threatened flora within the Swan Region.
- Complete the analysis of spatial patterns of threatened and priority flora distribution and threat intensity in the SWAFR to define hotspots and priority areas for flora recovery and management.
- Develop a model of vegetation condition in Fitzgerald River National Park so that temporal and spatial trends in *Banksia* decline can be assessed and monitored.
- Analyse data on flora persistence in fragmented landscapes to identify plant trait, landscape context and land management correlates of population persistence.

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

SP 1999-010

A Crawford, S Dudley, A Monaghan, D Symons

Context

Seed conservation is a specific and targeted action to conserve biodiversity and entails banking 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 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 135 seed collections (106 species) were banked at the Western Australia Seed Centre (Threatened Flora Seed Vault); 82 of these collections (55 species) were listed as Critically Endangered, Endangered or Vulnerable (threatened flora), 46 of these collections (44 species) were listed as priority flora.
- Sixteen seed collections from 12 Stirling Range species were collected as part of post-fire recovery projects.
- Sixty seed collections from 52 plant species that will potentially be impacted by Myrtle Rust were collected.
- The seed bank now contains 6,044 collections (1,959 taxa) representing 346 threatened flora, 744 priority flora and 869 restoration species.
- Two hundred and fifty-nine germination tests were conducted.
- Seedlings of 18 threatened flora species were provided for translocation.
- Seedlings of two priority flora species were used in an establishment trial in the Stirling Range National Park.
- One species *(Darwinia squarrosa*) was planted into a seed production area at Woodlupine Primary School.
- Testing of the storage performance of seed from 61 species (83 collections) that had been in storage for a period of at least 10 years was undertaken. Provisional results (46 tests) indicate a majority of these collections (n=43 or 93%) have maintained their viability over a period of 11 to 27 years.

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.
- Re-testing of old collections (> 10 years) is showing that the storage conditions at the Western Australian Seed Centre are maintaining the viability of most tested collections. Viability declines, whilst uncommon, have occurred, highlighting the importance of ongoing monitoring at regular intervals to the management of *ex-situ* seed collections.

Future directions

- Ongoing collection of seed of threatened flora for long-term conservation and use in translocations.
- Secure seed of conservation significant Western Australian native plant species potentially susceptible to myrtle rust prior to disease occurrence.
- Complete a review of the long-term (>10 years) storage performance of seed collections held in the Western Australian Seed Centre.

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

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 the 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 phylogenetic and population genetic relationships among the disjunct populations of *Eucalyptus virginea* and related species, including the potential hybrid status of *E.* x *phylacis*.
- Determine the phylogenetic relationships among Western Australia *Leptospermum* species and examine the genetic boundaries among several species complexes.
- 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 relationship between *Verticordia spicata* subsp. *spicata* and the critically threatened *V. spicata* subsp. *squamosa.*
- Determine the genetic relationship between populations of *Davesia obovata* in the Stirling Ranges and Fitzgerald River National Park.
- Determine the genetic relationships among several subspecies and unnamed entities within *Conospermum caeruleum*.

Progress

- Genomic analysis of *E. virginea* and related species confirmed the identification of the disjunct population of *E. virginea* in Meelup and the status of *E. phylacis* as an F1 hybrid between parents, *E. virginea* and *E. decipiens*. A paper detailing genomic assessment of the relationships among *E. virginea*, *E. relicta*, *E. lane-poolei*, and *E.* x *phylacis* was published in *Biodiversity and Conservation*.
- Phylogenomic analysis of relationships in the *Leptospermum* genus, with a focus on Western Australian taxa, has been submitted to Taxon. The analysis shows separation into four clades with other genera nested within, indicating taxonomic revision is required.
- Field collections, sequencing and genomic analysis for the *L. erubescens* species complex showed clear separation of *L. maxwellii* and a clinal relationship between *L. erubescens* and *L. oligandrum*. A paper is has been submitted to *Taxon*.
- A paper detailing the genomic, morphological and ecological divergence of the cryptic lineages in *E. salubris* has been published in *Ecology and Evolution*. Genomic analysis of the nine species of the gimlet complex is completed and a paper is in preparation.
- Genomic analysis is complete for the putative *Eucalyptus* hybrid entities in the Stirling Ranges. This study confirmed eight suspected hybrid combinations and identified the parental taxa involved. A paper has been published in *Annals of Botany*.
- Genomic analysis and morphological assessment of *V. spicata* has shown that there is a lack of evidence to support the continued recognition of *V. spicata* subsp. *squamosa* as a subspecies distinct from *V. spicata* subsp. *spicata*.
- Field collections, sequencing and preliminary genomic analysis of the *C. caeruleum* species complex has been completed and a report has been written. Genomic data warrant the recognition of at least three distinct species and three independent management units within the south-west species.

Management implications

- Population genetic analysis of relationships among disjunct populations of *E. virginea* provides information for management of the populations, and confirmation of the hybrid status of *E.* x *phylacis* provides information for management priorities.
- 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.* x *katatona* as a hybrid and synonymisation of *S. exastia* and *S. elliptica* mean that neither taxon meets the criteria for conservation listing.
- 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.
- Resolution of the taxonomic status of *V. spicata* subspecies will allow re-assessment of the need for conservation listing of *V. spicata* subsp. *squamosa* and ongoing management of this subspecies.
- Population genetic analysis of *D. obovata* provides information for the management of these highly disjunct populations.
- Genomic analysis of the *C. caeruleum* subspecies will provide a basis for taxonomic revision of this highly morphologically variable group, particularly in regard to potential new taxa that may be threatened and require conservation listing and management.
- Identifying genetic entities in *A. viscosa* and *A. tetandra* will provide a basis for taxonomic resolution of these species complexes.
- Strong genetic differentiation and variable degrees of clonal diversity among populations of *B. mimica* indicate taxonomic revision is required and provides information for population census counts and differing management of populations.
- High genetic differentiation over very short distances in *M. aquilonaris* provides information for assessment of the impact of disturbance on sub-populations of this species.

Future directions

- Complete population genomic analysis of the *Leptospermum* species complex and delineation of the major Western Australian taxa.
- Complete genomic analysis of the gimlet complex and write paper.
- Write paper on the *V. spicata* subspecies and revise taxonomy.
- Conduct additional genomic analyses to further clarify relationships among south-west populations of *C. caeruleum.*

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 provide 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 and monitoring associated ecological responses and effectiveness of mitigation strategies. The program also investigates genetic diversity, evolutionary history and ecological plasticity of plant populations to guide 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.

Evaluating the application of eDNA and metabarcoding as biodiversity and monitoring tools

SP 2020-068

J Hyde, A Wills

Context

Ecological monitoring is a key element of adaptive conservation management projects, but can be resource intensive. In recent years techniques such as camera traps, audio recorders and satellite tracking have improved effectiveness of monitoring programs. Metabarcoding and environmental DNA (eDNA) are emerging technologies that may be used to enhance environmental monitoring. While no single tool can provide all the information necessary for monitoring, eDNA has some advantages over other methods in some situations. For example, significant taxonomic expertise is often required to identify taxa, especially invertebrates, but such expertise is increasingly unavailable. Additionally, some existing methods are not ideal for detecting elusive or poorly known taxa and can be laborious. eDNA may overcome some of these limitations, and this project will examine how eDNA can be effectively used as a monitoring tool, complementing existing methods and projects in DBCA.

Aims

- Apply eDNA and metabarcoding methods to a range of survey and monitoring projects to evaluate whether they can effectively replace or compliment traditional ecological sampling.

Progress

- Soil and leaf litter samples from FORESTCHECK fire chronosequence sites near Dwellingup were collected and processed in the laboratory for invertebrate eDNA.
- Pitfall trap samples collected from the same FORESTCHECK fire chronosequence sites were identified to morphospecies and processed in the laboratory to create a barcode reference library.
- Samples of zooplankton from the Pilbara were collected for processing in the laboratory for metabarcoding. This is part of a study into the impacts of invasive redclaw crayfish on river pool communities.
- Water samples were collected from rivers in the south-west of Western Australia and were used to test protocols for collecting, extracting, and sequencing freshwater eDNA.
- Soil microbiome samples were collected from Yarragil experimental catchments and are currently undergoing bioinformatic analysis.

Management implications

- Results of these projects will help inform how eDNA can be applied in future monitoring projects.
- The development of standard protocols for eDNA collection, extraction and sequencing could contribute to standardisation across the department and potentially other agencies as this approach starts to be implemented.
- The development of reference barcode libraries will improve species discovery, knowledge of species' ranges and ecological requirements and provide greater understanding of ecosystem conservation values.

Future directions

- Complete the reference barcode library from the FORESTCHECK pitfall traps and continue to add species to the library as opportunities arise.
- Synthesise the results of the freshwater eDNA projects to produce guides on how they can be incorporated into existing management.
- Write a paper on the responses of the soil microbiome to ecological thinning.
- Write a paper on the utility of eDNA for understanding the effect of fire on invertebrate diversity.

Lifeplan: A planetary inventory of life

SP 2020-009

A Pinder, S Easton, G Barrett, A Barrett, M Brotherson, R Glowicki, K Quinlan

Context

Lifeplan is a global biodiversity survey project funded by the European Research Council and led by the University of Helsinki. As a fundamental data platform, Lifeplan will generate standardized, global data on a range of species groups, allowing quantification of variation in ecological communities at spatial scales from 0.1 km to 10000 km across hundreds of thousands of species. This project is establishing 100 sites globally, with additional denser sampling in the Nordic countries and in Madagascar. Each of the 100+ global sites will consist of paired urban and natural locations. Perth has been selected as one of the global sites, with plots located in woodlands dominated by *Banksia* and *Casuarina* in Lowlands Nature Reserve and Kings Park. In addition to investigating global patterns in biodiversity, the project aims to scale up the use of efficient biodiversity monitoring tools (machine learning analysis of ecoacoustics and camera trapping data, and metabarcoding of aerial spores, soil fungi and flying insects). The project will be carried out over six years, with sampling alternating between the Lowlands and Kings Park locations.

Aims

- Gain an understanding of the application and effectiveness of novel biodiversity survey methods through participation in a global project.
- Survey and contrast the biodiversity values of a large semi-rural nature reserve and a large urban bushland with similar dominant overstorey vegetation.
- Improve understanding of the broader biodiversity values of a Threatened Ecological Community (banksia woodlands of the Swan Coastal Plain).

Progress

- Sites at Kings Park and Lowlands Nature Reserve were selected in spring 2019.
- The site at Lowlands Nature Reserve was established in February 2021.
- Weekly sampling or data downloads have been undertaken and audio and camera data uploaded to the Lifeplan data repository.
- The first batches of insect samples have been mailed to the University of Guelph in Canada and soil and spore samples mailed to the University of Helsinki for metabarcoding.
- A presentation on progress at the Perth site was made at the inaugural online project meeting and information was provided at a meeting of the Lowlands Stakeholder Group.

Management implications

- Involvement with this global project will provide DBCA and Botanic Gardens and Parks Authority (BGPA) staff with an improved understanding of the capacity for newer technologies for efficient survey and monitoring of biodiversity.
- The monitoring will provide insights into threatening processes such as urbanisation, feral animals and fire. In particular, it will provide BGPA with an understanding of how management of Kings Park has allowed retention of biodiversity inhabiting *Banksia*/*Casuarina* dominated woodlands on the Swan Coastal Plain.
- The project will add to an understanding of temporal patterns in biodiversity values of a Threatened Ecological Community (banksia woodlands of the Swan Coastal Plain), which can be used to design monitoring programs and management actions.

Future directions

- Continue monitoring at Lowlands during 2021 and at Kings Park in 2022.
- Compile reference libraries of faunal images and bird calls from the cameras and audio recorders to train the machine learning analyses.
- Undertake botanical surveys at the Lowlands, and Kings Park sites to add to the information base for these sites and add context to analyses.

Tracking the condition of Ramsar wetlands in Western Australia

SP 2020-007

M Venarsky, B Huntley, G McGrath, A Pinder, M Coote, A Barrett

Context

The management of Ramsar wetlands on Western Australia's conservation estate is the responsibility of DBCA, in partnership with external organisations. The department coordinates documentation on the wetlands' condition and reports to the Commonwealth Government and the Ramsar Secretariat. Like many wetlands globally, Western Australia's Ramsar wetlands are threatened or currently being affected by various factors. These include water resource development, agriculture and urban development, invasive species, mining, plant diseases, salinisation, and climate change. This project aims to undertake monitoring of the State's Ramsar wetlands to improve reporting capabilities and determine efficient monitoring techniques for adaptive management programs.

Aims

- Undertake monitoring of Ramsar wetlands to enable effective management and reporting on their condition.
- Understand spatial and temporal patterns in wetland hydrology, water quality and vegetation structure as primary drivers of wetland biodiversity.

Progress

- Constructed a bibliography for six Ramsar sites that includes digitally available reports and publications.
- Commenced development of protocols to use photography via unmanned aerial vehicles (UAVs) to track changes in wetland vegetation structure.
- Commenced analyses to develop remote sensing methods for measuring depth and inundation extent using depth data set from the former South West Wetland Monitoring Program.
- Determined water quality at five Ramsar sites.
- Conducted waterbird surveys at six Ramsar sites.
- Conducted fish and aquatic invertebrate surveys in the Muir-Byenup system.
- Reinstalled multiple depth gauges throughout the Muir-Byenup system.
- Developed a research project in collaboration with the Peel-Harvey Catchment Council, which will assist with the monitoring of Lake Clifton thrombolites.

Management implications

- Direct measurements of habitat quality and quantity as surrogate indicators of broader wetland health and biodiversity values will improve the ability to report on limits of acceptable change in the Ecological Character Descriptions.
- Monitoring of waterbird populations will provide consistent data on which to base assessments of limits of acceptable change.
- Site specific monitoring and research will provide local managers with information to assist with adaptive management of Ramsar wetlands.

Future directions

- Continue developing bibliography for the remaining Ramsar sites.
- Finalise UAV protocol and begin conducting vegetation monitoring at Ramsar sites.
- Use remote sensing to analyse inundation extents and frequency for Ord River Floodplain and Vasse-Wonnerup systems.
- Conduct fish and invertebrate surveys at Muir Byenup in response to concerns about drying and deteriorating water quality in these wetlands.
- Conduct aquatic invertebrate survey at the Peel-Yalgorup Ramsar site to provide baseline data and understand values of this component of biodiversity.

Understanding the implications of a drying climate on forest ecosystem function to inform and improve climate change adaptation

SP 2019-068

K Ruthrof, D Tarrant, R Van Dongen

Context

Little is known about the effects of climate change on the forest ecosystem. A broader understanding of the range of effects that climate change has on forest ecology and functioning, is required to predict how forest ecosystems will respond to future climates. By increasing our understanding, management intervention techniques may be explored that could reduce the severity of changes to forest ecosystems. The Forest Management Plan 2014-23, identified a requirement for research focus on understanding the implications of a drying climate on ecological function, biodiversity and forest health to inform management and development of climate adaptation strategies.

Aims

- Understand the impacts of climate change and extreme events on structure, composition and functioning of forest ecosystems in south-western Australia.
- Investigate response to ecological thinning in forest ecosystems.
- Investigate the use of the Landis II model to examine the implications of climate change on forest composition and management intervention techniques.

Progress

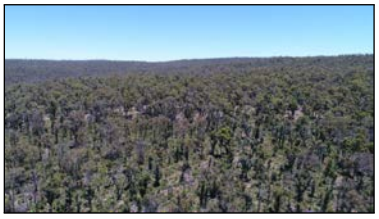
- Analysis of forest sites affected by drought and wildfire showed that these sites are more physiologically stressed during the summer than burnt sites that have low vulnerability to drought.
- A drought-affected forest site was examined in detail using resistivity equipment, which indicated that the site was dominated by shallow soils of ~8m above granite bedrock, compared with deeper soil at a non-drought-affected site (~30m).
- An investigation of two thinned and unthinned catchments in the Northern Jarrah Forest (Yarragil and Cobiac) has shown that thinned catchments and their associated riparian zones, lost less vegetation cover during the 2011 and 2016 heatwave events than unthinned catchments.
- Based on available information, a preliminary review of thinning and harvesting operations indicated that many major forest ecological variables are unlikely to have significant negative responses.
- Case study land management units have been chosen to investigate the use of an ecological forest model: Landis II.

Management implications

- Tracking forest health changes in response to multiple disturbance events such as fire and drought will provide information to understand the vulnerability of forest ecosystems to climate change.
- Examining how soil depth influences stand health can help map drought-vulnerable sites across the forest.
- Examining how thinned and unthinned forest responds to chronic changes in climate (long term decreasing rainfall) and extreme events (heatwaves) can assist with making decisions about forest intervention activities.

Future directions

- Further examine forest stand structure, carbon and compositional changes following wildfire and drought.
- Examine the response of dense regrowth and old growth areas of forest to climatic extremes and chronic changes.
- Investigate drought-affected sites for soil depth and develop an ecohydrological model and vulnerability map for the forest.
- Examine the ecological impacts of forest thinning from below, using new, lighter machinery.



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 north-east of the Forest Management Plan area was noted in *mid-term review of performance of the Forest Management Plan 2014-2023*. The decline is broadly consistent with climate change predictions, although other factors may be contributing. Previous research suggests that *Eucalyptus wandoo* has been undergoing a series of declines associated with drought and increasing temperatures, and a buprestid beetle (*Cisseis fascigera*). *Eucalyptus marginata* and *Corymbia calophylla* have been reported to be vulnerable to acute drought and heatwave events at water-shedding sites with shallow soils, as well as frost events.

More information is needed about the landscape, site and stand characteristics that predispose forests to decline. 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 interventions.

Aims

- Investigate the cause of decline in vegetation density in south-west forests by understanding the interactions of contributing factors.

Progress

- At the landscape scale for the Northern Jarrah Forest, climatic analysis combined with trends in vegetation cover indicate that the decrease in cover can be explained via lower rainfall and higher vapour pressure deficit, particularly in areas with larger (>9%) rainfall decline, and particularly ecosystem types of Western Wandoo Forest and Woodland, Swamps and Jarrah-Sandy Basins.
- In the north eastern portion of the Jarrah Forest, an explanatory model using Landsat indicated that the decrease in vegetation cover can be explained via time since last fire, and those areas of high cover (>33%) with an aspect of <87 (facing east to north) had a large decrease in cover.
- A plot-based field survey indicated that decline sites have higher levels of canopy and midstorey dieback, are more likely to be upland, on slopes, ridges water shedding sites, compared with control sites (those with a relatively stable vegetation cover).

Management implications

- Knowledge gained from this study can be incorporated into forest management policy and planning, and contribute to mapping forest health and reporting for the next forest management plan.

Future directions

- Undertake field work investigating vegetation cover decline east of Collie and further south to understand the stand and site variables associated with decline.
- Continue to investigate the recovery time needed by forest ecosystem types from a range of fire frequencies and fire severities.

Hydrological function of critical ecosystems

SP 2016-005

J Rutherford, G McGrath, 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 journal article covering the use of remote sensing and airborne geophysics in the Walyarta study area was published. Another is in preparation on the hydrology and hydrochemistry of the area.
- Hydrological monitoring at Ashfield Flats has been completed. Journal articles documenting the results are in preparation.

Management implications

- The workflow and techniques developed for the Walyarta study can be utilised elsewhere to identify the dominant aquifers that sustain spring flow. This information will help develop appropriate monitoring programs and allow groundwater management programs to consider the water requirements of springs appropriately.
- The Brixton Street Wetlands are underlain by saline groundwater and are sensitive to changes in climate and development. Results from the study will provide the basis to develop optimal hydroperiods for clay pans along the Darling Scarp.
- Sea level rise and contaminated groundwater were identified as key issues for management at Ashfield Reserve. The results of the hydrological study will form the basis for future stakeholder engagement and community consultation.

Future directions

- Develop simple spring water balance models to assess and quantify the water requirements of springs.
- 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.
- Finalise publications from Ashfield Flats study and participate in stakeholder engagement and community consultations.

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

SP 2015-001

J Rutherford

Context

Changes in the hydrology of Toolibin Lake and the Lake Bryde catchments, due to land clearing, has resulted in these previously ephemeral freshwater 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 modelling 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

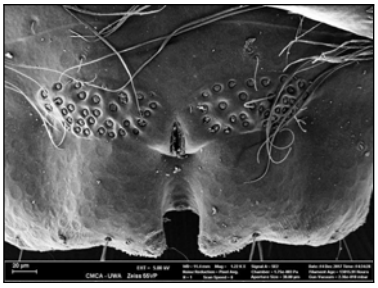
- Hydrological monitoring in Toolibin Lake and its catchment has demonstrated that salt movement in the semi-arid WA Wheatbelt aquifers is generally discrete, very slow and difficult to measure and interpret on an annual basis. Solute flushing is most effectively resolved by decadal borehole surveys (transects) that follow groundwater gradients.
- A numerical model has been constructed for Toolibin Lake and has successfully simulated groundwater levels and decadal changes in regolith salt storage measured by borehole geophysical tools.

Management implications

- The research at Toolibin Lake has resulted in conceptual and numerical models to support management decisions involving groundwater pumping and the siting of lake re-vegetation and engineering structures.

Future directions

- Determine the economic and environmental criteria to optimise the pumping program and assess risks.
- Use criteria to design a workplan with CyMod Systems to assess pumping options and threats.
- Complete journal articles and 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 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 the description of Western Australian aquatic invertebrate biodiversity and allow more consistent identification of specimens by departmental and external researchers.

Progress

- Specimens of ostracods and molluscs and associated data from recent DBCA survey projects were provided to PhD students undertaking taxonomic research, resulting in the discovery of new taxa.
- Specimens of water mites and associated data were provided to an external taxonomist for descriptions of short-range endemic species.

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 as required.

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

SP 2014-024

J Rutherford

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 Western Australia, providing refugia from seasonal and long-term drying for a range of geographically restricted flora and fauna. This includes rare wetland dependent orchids and a total of 21 Priority plant species, short-range endemic aquatic invertebrates, the threatened Australasian bittern and south-west endemic fish.

Some peat wetlands in the Muir-Byenup System Ramsar site wetland suite are threatened by acidification and some have already acidified due to declining groundwater levels. Drying is also making these organic wetlands more prone to catastrophic fires. The peat also can contain 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

- Data collection to assess the hydrology and hydrochemistry of four peat wetlands was completed.
- Organic carbon, potential acid and solute stores for the peat profile were constructed at the bore and wetland scale. Upscaled results for all peat wetlands within the Muir-Unicup Catchment provide a conservative estimate of organic carbon in peat at around one million tonnes.
- Most significant changes in organic carbon and contaminant stores occur in desiccated peat in Tordit-Gurrup Lagoon. The extent of the changes indicates drying is long lived and has occurred over thousands of years, rather than decades.
- An interpretation of geophysical data reveals that most peat wetlands are sited within palaeovalley's enclosed by geological barriers (shallow bedrock). These barriers help peat retain moisture. They are absent around Tordit-Gurrup Lagoon and this is likely to have accelerated the drying of peat.

Management implications

- Peat wetlands that contain high levels of metals and metalloids which can be released when they undergo prolonged drying have the potential to undergo acidification. Some peat wetlands are more resilient to drying due to their ability to maintain moisture. This study shows that this resilience can be better characterised with a knowledge of shallow groundwater gradients and contaminant storage. In a drying climate it is important to identify resilient wetland systems in order to prioritise management actions.

Future directions

- Continue to investigate the nature and extent of hydrological and hydrogeochemical processes of the Muir-Byenup Ramsar site.
- Complete the modelling, interpretation and reporting.

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

- Analysis of genetic structure and association with climatic variables has identified signals of selection for *Taxandria linearifolia.* Gene flow was restricted between populations in the drier, hotter upper catchment compared to those residing in the cooler wetter regions of the catchment, potentially limiting the flow of genes adapted to predicted future climates. The highest number of correlations were between loci and the environmental variable of mean moisture content of the coldest quarter, confirming the hypothesis that adaptation in floodplain species is linked with water availability. The development of adaptation in isolated populations may make it feasible to facilitate the transfer of dry adapted genotypes to other populations thus, facilitating long term persistence under changing climates.

Management implications

- Changing climates require a re-evaluation of appropriate seed sourcing strategies for revegetation and restoration of ecological function in degraded sites. The use of local seed will not provide adequate resilience to maintain ecological function under changing climates. Understanding climate adaptation will provide a scientific basis to undertake best-practice restoration and facilitate the establishment of biodiverse plantings that maximise ecological function for enhanced persistence and resilience.

- Current findings extend our understanding of the factors that influence selection across climate gradients, confirming that gene flow influences signatures of selection. These results also verify the need for management strategies that support genetic connectivity and, when needed, intervention to assist migration of genes to maximize the resilience of populations and species persistence in the face of changing climates.

Future directions

- This project will be complete when a manuscript on genetic structure and signals of selection in *T. linearifolia* is published.

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 management activities, such as timber harvesting, on the terrestrial vertebrates of the jarrah forest is necessary for biodiversity conservation and development of ecologically sustainable forest management. This project began in 1994 and uses a before-after, control-impact study design to intensively investigate biodiversity responses to, and ecological consequences of disturbance by 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 of mammals on three standardised transects was maintained with six repeat surveys per transect per year. The critically endangered ngwayir (western ringtail possum) population in the greater Kingston is currently in decline, their recovery since 2012 has not been sustained. There has been a 74% decline in the last 4 years. The average annual detection rate of ngwayir across sites in Kingston in 2021 is 1.7% of peak levels recorded in 1998.
- The decline observed in ngwayir detections over the last four years coincides with an 80% decline in woylie cage trapping results over the same 4 years from the greater Kingston area.
- These population changes are not related to timber harvesting directly and are occurring more broadly across the landscape.

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

M Lyons, A Markey, M Langley, M Byrne

Context

Flora surveys of targeted areas provide knowledge of floristics and vegetation pattern and structure for a variety of purposes, including provision of baseline biodiversity data, monitoring of management effectiveness, understanding distributions of threatened taxa, defining threatened and priority communities, determining suitability of vegetation for fauna translocation and conservation operations such as fencing and stock control. Recent surveys have included Walyarta Conservation Park, land parcels in the Fitzroy Valley, Lake Carnegie and Fortescue Valley dunes.

Aims

- Undertake targeted surveys to provide specific management advice, monitor long-term change in vegetation at specific sites and specific communities, or fill specific knowledge gaps.

Progress

- A final report on the flora and vegetation of Walyarta Conservation Park, is in progress.
- The field program and species identifications for a survey of selected land parcels in the Fitzroy Valley have been completed, and the final stage of report preparation is underway.
- Plot based data for gypsum plant communities, sampled during a collaboration with Spanish researchers as part of the GYPWORLD project funded by the European Union, has been compiled following the completion of specimen identifications. Contribution to phylogenetic studies in Frankenia is ongoing. A journal article on a novel method for measuring soil hydraulic properties developed during this project was published in *Journal of Hydrology*.
- Plant specimen identifications were completed and plot data have been compiled for the survey of Lake Carnegie wetlands and fringing landscapes. Collections included a new taxon in the genus *Ruppia*.
- A subset of the monitoring plots was rescored and floristic data compiled to inform district adaptive management initiatives.
- Samples of weed species from the Pilbara have been taken from Herbarium specimens and genome skimming datasets have been compiled. Data analysis is underway to provide chloroplast barcode reference libraries for the species.
- Field work and reporting were completed for a survey of the Fortescue Valley Dunes priority ecological community (PEC), south east Marillana Station, as part of a Pilbara Environmental Offsets Fund pilot project to improve vegetation condition by excluding stock.
- Field work and reporting were completed for an investigation into the suitability of proposed translocation sites in the south coast region for the western ground parrot.
- DBCA staff have assisted DPIRD in their *Typhonium* sp. Kununurra survey of the Ord Valley by taking part in field work, collections management, priority species identifications and habitat descriptions and providing advice and liaison between departments and consultants. A new variant of *Hibiscus austrinus* has been resolved from this work. Lodgement of these collections is underway and findings on conservation-significant taxa will be provided.

Management implications

- Walyarta Conservation Park (Mandora Marsh) vegetation survey and mapping will enable identification of vulnerable vegetation communities for monitoring, and is currently providing information for both a monitoring plan to determine the effectiveness of feral herbivore exclusion or removal and for interpreting hydrogeological findings.
- 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.

- The Lake Carnegie flora survey will provide vegetation descriptions for assessment of the conservation status of Lake Carnegie, management planning and provide a baseline for monitoring.
- Floristic data from the gypsum areas sampled will contribute to the assessment of the conservation status of these plant communities, facilitating the assessment of the impacts of gypsum mining proposals.
- Tutanning flora data and species traits data will be useful for determining species distribution, vegetation descriptions and ecological responses and should be useful to regional adaptive management projects.
- The Fortescue Valley Dune PEC is a significant and unique plant community in the context of the Pilbara bioregion. Exclusion of stock by fencing aims to maintain and improve vegetation condition in different areas of the PEC occurrence.
- 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 provide a basis to relax restrictions on field sampling time for plant specimens as fertile vouchers, particularly for ephemeral species, which will no longer be essential to confirm identification.

Future directions

- Complete a paper on Jurien coastal wetland flora.
- Ongoing curation of Tutanning flora data records and vouchering of relevant collections.
- Complete reports on flora of Walyarta, Fitzroy Valley and Lake Carnegie surveys.
- In collaboration with European researchers undertake analysis of GYPWORLD plant community data and commence reporting.

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

SP 2011-020

L Mccaw, 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 that 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 of predominantly 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 this 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

- The effects of thinning on growth and inter-tree competition in regrowth stands of jarrah and karri have been analysed using data from long-term experiments at Inglehope and Sutton forest blocks, respectively. Two papers on jarrah growth response have been published in *Forest Ecology and Management* and two

manuscripts on karri growth response are in review. A fifth manuscript examining marri growth response to thinning is also in review.
- Trees retained following second thinning of 1972 regrowth karri forest at the Warren block experiment were remeasured, enabling quantification of stand basal area and ongoing monitoring of individual tree growth and condition.
- Data quantifying litterfall and biomass accumulation in south-west Australian forests were collated and analysed for a continental scale review paper published in *Ecosphere*.

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 evident 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 publication of tree growth response at Inglehope and Sutton thinning experiments.
- Undertake periodic measurement of long term silvicultural experiments.
- Review findings and utilise data from long-term thinning experiments to inform future management options for maintaining forest health and productivity in a drying climate.

Western Australian wetland fauna surveys

SP 2011-018

A Pinder, K Quinlan, 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 wetland surveys 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 an 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
- Sampled aquatic invertebrate communities in Pilbara river pools to determine impact of the invasive redclaw crayfish.

- Surveyed aquatic invertebrates, waterbirds, wetland associated flora and small ground-dwelling vertebrates of the Lake Carnegie environs, in association with the Tarlka Matuwa Piarku (Aboriginal Corporation) and Goldfields Region.
- Completed sorting aquatic invertebrate samples and progressed identifications as a continuation of wetland survey work in the Goldfields. This will provide context for the Lake Carnegie survey.
- Refined identifications of aquatic invertebrates from wetlands supporting western swamp tortoise to add to data on vegetated claypans of south-western Australia.
- Published a paper on aquatic invertebrate community composition and biomass in potential western swamp tortoise translocation sites in Marine and Freshwater Ecosystems.
- A report on temporal patterns in biodiversity and water quality at Lake Ronnerup, using data collected forthe State Salinity Strategy wetland monitoring project, was provided to the Wheatbelt Region.
- Reported on composition of aquatic invertebrate communities to Peel Harvey Catchment Council.
- Submitted a paper on changes in alpha, beta and gamma diversity of aquatic invertebrates in relation to declining rainfall in the Wheatbelt region.

Management implications

- New knowledge of arid zone wetlands' biodiversity values will assist with assessing the conservation status of species and communities and the environmental impact of mining and pastoralism, including direct removal of wetland habitat, altered ground and surface water hydrology, and degradation of fringing vegetation through grazing.
- The biological survey of Lake Carnegie and associated wetlands will contribute to a management plan and other conservation measures for this proposed addition to the conservation estate.
- Survey work is helping understand the threats posed by redclaw crayfish in the Pilbara and provide impetus for minimising its spread.
- An understanding of invertebrate composition and biomass in south coast wetlands contributes to decision making around translocation of western swamp tortoise in a drying climate.

Future directions

- Survey aquatic biodiversity at priority wetlands as opportunities allow.
- Publish a paper on invertebrate diversity in vegetated claypans of south-west Western Australia.
- Write a paper on biodiversity patterning across Kimberley springs.
- Survey additional wetlands in the northern Wheatbelt for the brine shrimp *Parartemia extracta*.
- Further assess the conservation status of south-western Australian aquatic invertebrates.
- Complete research into impacts of the invasive redclaw crayfish on aquatic communities in the Pilbara.

Identification of seed collection zones for rehabilitation

SP 2006-008

M Byrne, H Nistelberger, S McArthur

Context

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 them 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 of the three species in the nuclear genome with shared cpDNA haplotypes, showing a signal of earlier divergence of C. *haematoxylon* and later divergence of *C. ficifolia* following expansion of *C. calophylla* into the wetter southern areas. Population differentiation was higher in the two restricted patchy species when compared to the widespread, semicontinuous *C. calophylla*. Genetic diversity in *C. haematoxylon* was similar to that in *C. calophylla*, but diversity was lower in the highly localised *C. ficifolia*, likely due to genetic bottlenecks. A paper has been submitted to *Australian Journal of Botany.*
- Genetics analysis of microsatellite and cpDNA data 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 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. A paper has been published in *Ecology and Evolution.*

Management implications

- Knowledge of genetic structure and local adaptation will enable the identification of appropriate seed collection zones for rehabilitation of forest areas, in order to maintain the genetic integrity of the forest. 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, 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

- This project will be complete with 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, 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 was 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 manuscript reporting findings from the 10-year monitoring period has been submitted for publication and is in review.
- Reports on monitoring undertaken in the Jarrah Forest South ecosystem and the Jarrah Forest North West ecosystem fire chronosequence have been prepared.
- Soil and leaf litter samples from the fire chronosequence have been analysed to examine the potential for using eDNA to monitor invertebrate biodiversity.
- A manuscript examining understorey flowering activity in relation to environmental conditions and the Noongar seasonal calendar has undergone review and is now in revision.
- A manuscript examining ground surface macroinvertebrate responses to silviculture and wildfire is in submission to *Australian Forestry*.

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.
- 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 examining the impacts of a changing climate over the longer term.

Future directions

- Publish further findings from the 10-year monitoring period and the more recently sampled jarrah forest ecosystems.
- Continue to investigate alternative biodiversity monitoring techniques with a focus on eDNA.

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

SP 2000-003

J Kinal, L Mccaw, G McGrath

Context

This long-term experiment was established in 1999 to address part of Ministerial Condition 12-3 attached to the *Forest Management Plan 1994-2003* to monitor and report on the status and effectiveness of silvicultural measures in the intermediate rainfall zone (900-1100 mm/yr) of the jarrah forest to protect water quality.

Aims

- Investigate the hydrological 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.
- Data loggers in Yarragil 4L, 4X and 6C catchments to monitor rainfall, streamflow, stream salinity, and stream turbidity were reinstalled following the burn at 4L and summer maintenance at 4X and 6C.
- Ten groundwater bores at Yarragil 4L and 4X were instrumented with data loggers to record hourly water levels and a weather station was procured to be installed at 4L in 2021.

- The first phase of silviculture to increase the intensity and duration of the hydrological response following the re-thinning of Yarragil 4L was completed. This involved felling non-commercial trees not marked for retention and poisoning the stumps.
- At Yarragil 4L a burn was conducted and re-sprouts sprayed with herbicide to manage regrowth and reduce fuel load post harvesting.
- A paper examining the relative contribution of groundwater to streamflow generation in jarrah forest streams was published in *Hydrological Processes*.

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.
- 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.
- Examine shifts in water use by plants resulting from thinning using isotope analysis.
- Synthesise historical fine scale changes in stream hydrological responses and biogeochemistry.

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

SP 1998-007

M Byrne, R Binks, M Millar, D Bradbury, N Delnevo, 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 mine sites in the Pilbara.

Progress

- Analysis of the tree species, *Corymbia hamersleyana* and *Acacia pruinocarpa*, showed extensive gene flow across all populations in the Pilbara indicating high pollen and seed dispersal, possibly by water movements during cyclones. A paper was published in *Genes*.
- Comparative analysis of two small acacia shrubs with patchy distributions, *Acacia hilliana* and *A. spondylophylla,* show genetic differentiation among populations indicating some restrictions to gene flow in contrast to the widespread gene flow in the tree species. A manuscript has been submitted to the *Journal of Biogeography*.
- Analysis of the small shrub *Mirbelia viminalis* shows genetic diversity similar to other widespread Pilbara species and genetic differentiation among populations indicating some restrictions to gene flow as found for other Pilbara species of low stature. A manuscript is in preparation for *Australian Journal of Botany*.

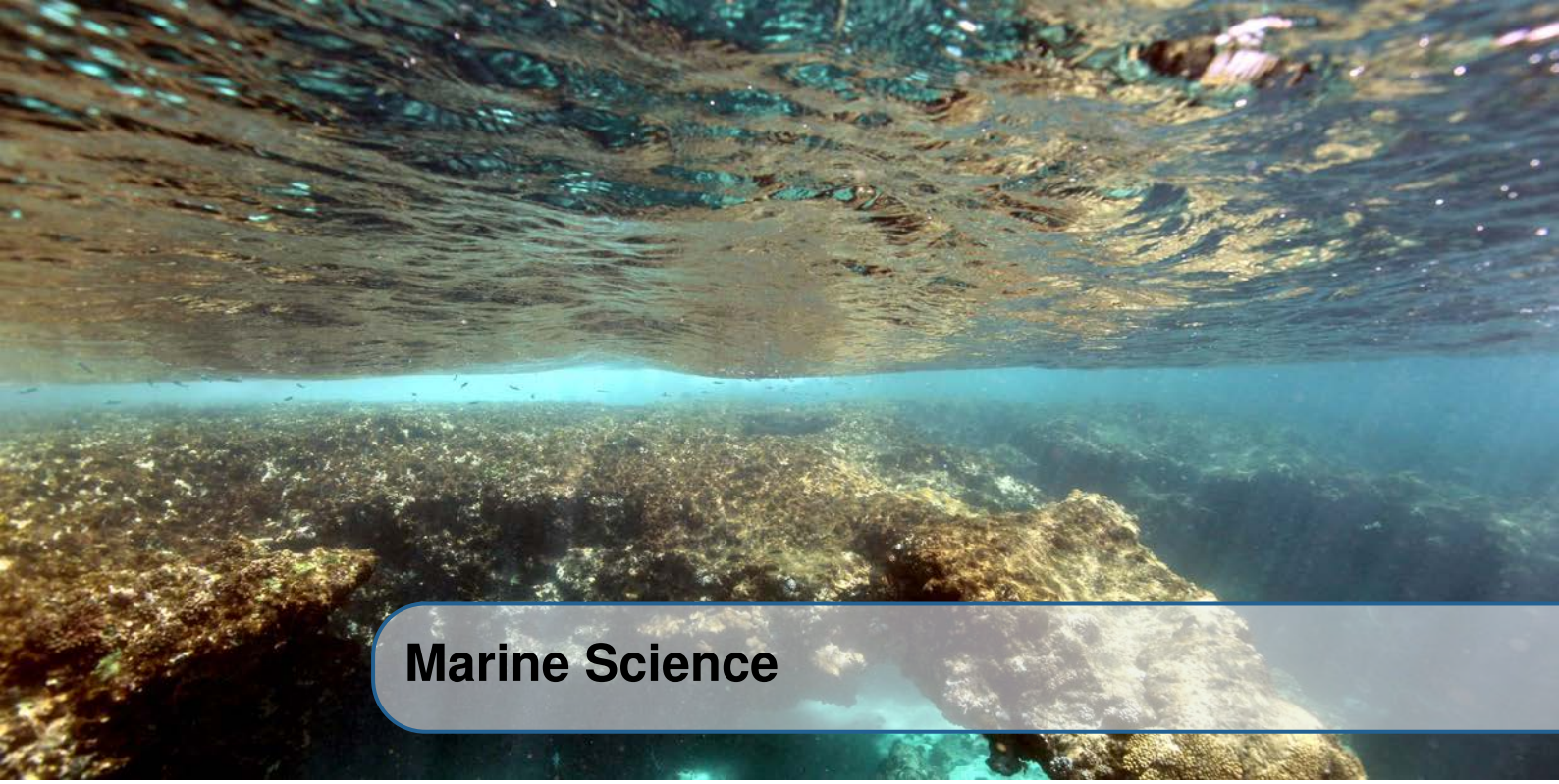
- Analysis of two widespread shrubs, *Petalostylis labicheoides* and *Indigofera monophylla,* showed higher genetic diversity in *I. monophylla* than in *P. labicheoides*, and slightly higher diversity was located in the Hamersley Ranges for both species. A divergent lineage of *P. labicheoides* was detected in the northeast Pilbara, and some structure in *I. monophylla* indicated higher levels of range-wide differentiation in these shrubs compared to widespread trees. A manuscript is in preparation.
- Analysis of genetic diversity in *S. glutinosa* subsp. g*lutinosa* found a high level of identical genotypes in populations, and further analysis of seedlings revealed them to have identical genotypes as the mother plant. This indicates that the species has a high level of apomixis in its mating system, although some sexual reproduction was evident. There was no pattern of geographic structure in the species and evidence of long distance seed dispersal likely driven by water movement following cyclonic activity.
- Naturalised populations of *Acacia saligna* in Tigray, Ethiopia, have been sampled and genotyped with nuclear microsatellite markers. Genetic diversity is moderate and genetic divergence among populations is limited. The majority of Tigrayan individuals were assigned to the '*lindleyi*' and more specifically the north-western '*lindleyi*' genetic entity of the *A. saligna* species complex. A paper on diversity, divergence and origin of Tigrayan *A. saligna* has been published in *Tree Genetics and Genomes*.

Management implications

- Understanding patterns of genetic diversity provides information for seed collection strategies in restoration and revegetation. Analysis of a range of species in the Pilbara provides information to support effective mine site restoration.
- While one tree species, *E. leucophloia*, showed a pattern of the ranges being refugia, other species have not. The low level of differentiation in other tree species and large shrubs, such as *C. hamersleyana* and *A. pruinocarpa*, *I. monophylla*, 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. This is similar for *P. labicheoides,* after excluding the divergent lineage.
- High genetic differentiation within species such as *A. hilliana*, *A. spondylophylla and M. viminalis* that have more restricted and patchy distributions indicate more limited seed collection zones are appropriate.
- Introductions of *A. saligna* present in Tigray provide a sound basis for seed production, biomass for particle wood production, fuelwood and poles, whilst minimising invasiveness more prevalent in other subspecies of the species complex. There is an opportunity to increase genetic diversity present in the informal subsp. '*lindleyi*' in Tigray.

Future directions

- Finalise papers reporting the genetic results for Pilbara species *Indigofora monophylla*, *Petalostylis labicheoides*, *Mirbelia viminalis* and *Senna glutinosa* subsp. *glutinosa*.
- Write a synthesis paper to summarise the broad genetic patterns in the eight Pilbara species, focusing on seed collection zones for mining restoration.



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 linked to departmental priorities and programs.

Primary productivity and energy transfer between marine ecosystems.

SP 2020-002

R Evans, S Wilson, M Moustaka

Context

Primary productivity provides energy that fuels food webs and is recognised as an important driver of local diversity and secondary production. Hence conservation planning often aims to identify where primary production is high; what systems, including their spatial arrangement, are most productive and how efficiently productivity from these producers is transferred to other systems or consumers. While marine productivity is largely attributable to oceanic phytoplankton, productivity from benthic macrophytes becomes increasingly important in coastal food webs. However, the link between benthic productivity by vascular plants and algae and secondary production remains equivocal. Moreover, local variations in hydrology are likely to influence the supply of nutrients, temperature and light (caused by turbidity), all of which are fundamental determinants of primary productivity. This project will investigate rates of primary productivity and energy transfer in the shallow, turbid waters of the Dampier Archipelago.

Aims

- Develop an updated coarse benthic habitat map for the Dampier Archipelago and fine resolution benthic habitat maps for up to 16 sites.
- Develop fine scale oceanographic modelling of the Dampier Archipelago to provide water flow/retention data for interpreting spatial differences in productivity.
- Measure water quality parameters (TSS, salinity, nutrients, Chl-A) and assess how they vary spatially and temporally.
- Measure primary productivity in different marine habitats (mangroves, seagrass, seaweed and coral reef) and assess how rates vary among locations and between seasons in the Dampier Archipelago area.
- Measure abundance, diversity and growth rates of fish and benthic communities and assess how this relates to spatial variation in primary productivity.
- Measure stable isotopes of primary producers and secondary consumers, and use isotopic signatures to assess the extent of transfer from different primary producers to secondary consumer tissues and between different habitats.

Progress

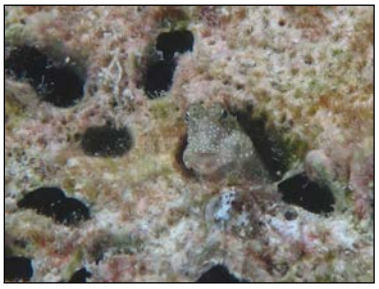
- Four field trips were conducted to Dampier Archipelago.
- Shallow bays of the Dampier Archipelago have been filmed and analysed to ground-truth benthic habitat maps. Preliminary maps have been produced and are currently being refined.
- Preliminary samples of primary producers from the Dampier Archipelago have been processed and submitted for stable isotope analysis.
- Consumers (fish and invertebrates) have been surveyed and collected for stable isotope analysis.
- Oceanographic instruments have been deployed to obtain data for development of fine scale hydrodynamic modelling.
- Sampling to evaluate water quality has begun and the first samples sent for analysis at the Australian Institute of Marine Science.
- Coral productivity baseline study using Structure from Motion photogrammetry has been completed.
- Public presentation to the Environmental Professionals Network in Karratha outlining the project.

Management implications

- The project will identify locations of high productivity that may be used in spatial planning within the Dampier Archipelago and improve scientific advice relating to development projects in the area.
- The results will also be transferable to planning in other locations with similar environmental conditions, by assessing which environmental factors correlate with high productivity.

Future directions

- Continue field work for development of productivity models, hydrodynamic models, and analysis of fish, coral and invertebrate communities.
- Prepare and submit primary producer, invertebrate and fish samples for stable isotope analysis.
- Develop preliminary hydrodynamic model for the Dampier Archipelago.



Do marine reserves adequately represent high diversity cryptobenthic fish assemblages in a changing climate?

SP 2019-031

S Wilson, J Goetze

Context

Small-bodied fish (<5cm) typically account for ~40% of all described fish species on coral reefs and therefore are expected to represent a substantial proportion of fish diversity in the State marine reserves. Short life spans of these small fish also suggest they are important conduits of energy transfer in marine food webs and will respond more rapidly to environmental change and stressors than larger-bodied counterparts. This is especially pertinent along the WA coastline, where marine heatwaves have dramatically impacted habitat, and fishing may have reduced the abundance of small fish predators. Standard visual methods of surveying fish are not suitable for monitoring these small cryptobenthic fish (CRF). This project will investigate whether environmental DNA (eDNA) from water and sediment samples is a viable alternative to collecting poison (e.g., clove oil) and visual approaches for assessing CRF assemblages. By collecting data from different habitats and management zones within marine parks, the project will also assess how effectively different techniques detect a change in CRF due to spatial variation in environment or management.

Aims

- Develop appropriate methods for measuring and monitoring CRF assemblages
- Compare CRF assemblages collected inside and outside of no-take sanctuary zones
- Compare CRF assemblages across a gradient of reef (habitat) types from high coral cover and complexity to reefs dominated by macroalgae with low complexity.

Progress

- Fish assemblages have been surveyed inside and outside of two sanctuary zones within Ningaloo Marine Park, using clove oil and visual census. In addition, water and sediment samples were taken at each survey site for eDNA analysis.
- Fish collected with clove oil have now been positively identified at the Western Australian Museum, tissue samples have been taken for DNA sequencing and DNA has been extracted from water/sediment samples.

Management implications

- Comparison of different sampling techniques will identify appropriate methods for monitoring CRF and develop indicators that will rapidly inform managers of shifts in the condition of fish assemblages due to changes in habitat and fishing.
- These monitoring tools will assess if management zones within the State's marine reserves adequately protect CRF in different marine habitats.

Future directions

- Statistical analyses of eDNA data, comparison of samples collected with clove oil and assessment of spatial differences in CRF assemblages from different management zones.
- Survey of CRF assemblages from different habitat types

Understanding the key ecosystem services provided by the seagrass meadows of Western Australia

SP 2018-136

S Strydom, S Wilson, B French, K Murray, T Holmes, B Huntley

Context

Seagrasses are foundation species that support important ecosystem services and processes worldwide. Seagrass meadows are declining globally and anthropogenic pressures such as terrestrial run-off, anchor damage and dredging threaten the ecological, economic and social services that seagrass meadows provide. Some of the world's largest and most diverse seagrass meadows occur in Western Australia and support many

commercially, recreationally and culturally important fauna. As the condition of seagrass meadows respond readily to pressures, they are used as indicators for the overall effectiveness of management across marine reserves managed by the department. Across-region comparisons and thorough temporal assessments of seagrass condition will provide a broader appreciation of seagrass health among the State's network of marine reserves. Furthermore, a greater understanding of how climate change related pressures (i.e. increased seawater temperature and extreme events) impact seagrass meadows and the ecosystem services they provide is needed. This is particularly the case in vulnerable regions like Shark Bay, where the full extent of seagrass loss since the 2010/11 marine heatwave in Western Australia's largest World Heritage Area was, until recently, not well understood.

Aims

- Describe seagrass distribution and condition over time across the sub-tropical/temperate WA marine reserves.
- Establish appropriate methods for surveying and monitoring faunal communities in seagrass meadows.
- Assess faunal communities in different types of seagrass meadows across the seascape to inform how key ecosystem services are affected by pressures that impact seagrass condition.

Progress

- A global database on seagrass growth and reproduction was compiled to assess which genera and regions are data depauperate.
- Indicators of seagrass condition have been collated across 60 sites in six WA marine reserves to assess the influence of environmental factors on long-term trends in seagrass condition.
- Data was collected for 20 sites in Shark Bay to assess the potential short-term impact of flooding, heat stress and cyclone activity on seagrass meadows, following strong 2021 La Niña conditions.
- A paper published in *Ecological Indicators* found that a combination of trawling and video techniques was best for assessing diversity of fish communities in seagrass.
- A paper published in *Fisheries Research* identified appropriate trawl net mesh size for avoiding or surveying syngnathids that are fish of conservation concern.
- Fish assemblage and associated seagrass patch metrics data was collected in Monkey Mia to explore relationships between fragmentation and fish abundance, diversity and size class.
- Updated maps suggest some seagrass recovery in the outer seagrass banks of Monkey Mia since 2016.

Management implications

- By identifying and mapping seagrass areas vulnerable to climate stressors, this work will help identify meadows resilient to environmental disturbance that should be protected from other stressors e.g. dredging.
- An improved understanding of the effects of heat stress on seagrass has been used to develop metrics that can predict the impacts of heat in the future and at other locations.
- Methods for sampling fish communities within seagrass, including species of conservation concern, have been identified, facilitating more effective monitoring and research of fish within this habitat.

Future directions

- Update the Shark Bay seagrass habitat map for 2020 and quantify change in seagrass extent since 2016.
- Analyse data to assess environmental influence on seagrass condition in WA marine reserves.
- Further investigate short-term impacts of multiple stressors (heat and low-light stress) on seagrass meadows in Shark Bay.
- Assess how fragmentation of seagrass meadows has affected fish assemblages and associated ecosystem services in Shark Bay.
- Examine long-term trends in fish assemblages associated with seagrass meadows in Geographe Bay.

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 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 for key biodiversity asset conditions and major pressures affecting them at key sites in the area of the proposed Dampier Archipelago marine reserves.

Progress

- The draft ecological monitoring report for the Dampier Archipelago has been compiled and is currently in review.
- A co-authored manuscript on coral recruitment patterns and drivers was published in *Marine Environmental Research*.

Management implications

- An established monitoring program will inform managers of trends in asset condition and associated pressures and facilitate long-term adaptive management for the proposed reserves and promote environmental understanding with a range of stakeholders and the community.
- The Dampier Archipelago ecological monitoring report will provide baseline data for the department, joint management partners, the public, peers and other key stakeholders to facilitate effective management and conservation of Western Australia's marine values.

Future directions

- Finalise the ecological monitoring report for the Dampier Archipelago.

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

SP 2014-021

K Waples, H Raudino

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 (including 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 these are 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, leading to greater certainty in assessing and managing impacts related 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

- A paper on minimum image resolution needed to differentiate between small coastal dolphin species from aerial survey has been re-submitted to a special issue of *Mammalian Biology a*nd is under final review.
- A manuscript is in preparation using density surface modelling for the Pilbara to better understand abundance estimation of coastal dolphins at a regional scale in the Pilbara.
- A seven day field trip was undertaken to the Montebello Islands Marine Park to conduct dolphin surveys and collect biopsy samples and photo-id data to better understand the dolphin populations that inhabit offshore islands, their site fidelity, habitat use and connectivity to mainland populations. A total of 10 bottlenose dolphin and two humpback dolphin genetic samples were collected and a total of 50 dolphin sightings recorded (16 humpback, 31 bottlenose and three mixed species groups).
- The Marine Fauna Sightings app has replaced the DolphinWatch app and we continue to promote the use of this app to marine users across the Pilbara.

Management implications

- A baseline understanding of dolphin habitat use in the Pilbara region, will inform the assessment of environmental impacts relating to future coastal developments and will assist in determining the conservation status of coastal dolphin species in Pilbara waters.
- The availability of baseline data and long-term monitoring protocols for coastal dolphin species in State waters will inform approaches to conservation and management.

Future directions

- Produce an abundance estimate of coastal dolphins in the Pilbara from aerial survey data and finalise the manuscript for submission.
- Undertake genetic analyses of the tissue samples collected from two species of dolphin at the Montebello Islands Marine Park.

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 adequately 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 individuals tend to be shy, evasive and difficult to study. Although they range southwards to the Pilbara region of Western Australia, there has been little local based research on this species and much of this remains unpublished. This project will compile existing data on snubfin dolphins across the Kimberley to better understand 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.

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 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

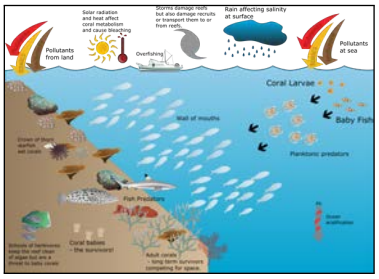
- A manuscript on broadscale distribution of snubfin dolphins across the Kimberley region using a range of data sources, including surveys with Indigenous partners, was published in a special issue of *Frontiers in Marine Science*.
- A *Landscope* article was published on the snubfin census in Yawuru Nagulagun/Roebuck Bay Marine Park.
- A vessel-based dolphin survey was undertaken in the Prince Regent River with Dambimangari joint managers. Traditional owner elders were also taken on Country during the survey. A survey report has been provided to the regional staff and joint managers. The survey confirmed that a population of approximately 20 snubfin dolphins inhabits the Prince Regent River area at any given time, and this likely includes some resident animals. Recommendations have been made about the continuation of this monitoring program, including the timeframe and protocol for surveys.

Management implications

- Collation of scientific and traditional knowledge of a poorly understood marine mammal of high conservation value means managers now have baseline knowledge of the abundance of snubfin dolphins in the 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 assess the conservation status of snubfin dolphins more accurately.
- The research has established partnerships with Indigenous sea ranger groups to develop survey methodologies, data storage and reporting structures 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. They will be used to address the key performance indicators related to maintaining abundance and diversity of these dolphin species in the Yawuru Nagulagun/Roebuck Bay Marine Park.

Future directions

- Undertake a second snubfin dolphin census in Yawuru Nagulagun/Roebuck Bay Marine Park.
- Complete the genetic analysis of tissue samples collected from snubfin dolphins in Prince Regent River to contribute to understanding the genetic population structure and connectivity across the Kimberley.



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, K Murray

Context

The focus of work for the Wheatstone Development Offset Project B will be to add to 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 and associated taxa in the tropical north-west of Australia. Broadscale 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 more distal 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 modelled 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

- A manuscript identifying dispersal barriers for a colonising seagrass using seascape genetic analysis was published in the journal *Science of the Total Environment.*
- A manuscript on recurrent coral bleaching in NW Australia and associated declines in coral cover was published in the journal *Marine and Freshwater Research.*

Management implications

- As the seagrass *Halodule universis* has limited dispersal ability (10s of kilometres), any recovery of meadows following disturbance will be dependent on existing seedbeds and nearby meadows.

Future directions

- Complete and submit manuscripts on coral and seagrass connectivity.

The influence of macroalgal fields on coral reef fish

SP 2013-006

S Wilson, T Holmes, J Goetze, K Murray

Context

Macroalgae are a prominent component of tropical benthic communities along the north-west coast of Australia. Within Ningaloo Marine Park, large fields of macroalgae are a distinct feature of the lagoon, covering approximately 2,000 hectares. These macroalgal fields are important habitats 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

- Spatial and temporal analyses were progressed to identify locations, conditions and habitats that consistently have high abundance of juvenile fish at Ningaloo over the past 10 years.
- A meta-analysis of how important macroalgal associated fish are to small-scale tropical reef fisheries is being prepared for publication. Early results indicate that ~25% of the catch is dependent on macroalgal habitat, though recreational catch in the Pilbara and Ningaloo is highly dependent (>50%) on fish that associate closely with macroalgal habitats.

Management implications

- Tropical macroalgal habitats are important nurseries for fish of ecological and fisheries importance in Ningaloo Marine Park. Canopy forming macroalgal fields are therefore, habitats of high conservation value that should be considered for protection when planning marine reserves.
- Identifying locations and environmental conditions that consistently have high abundance and diversity of juvenile fish will help to pinpoint essential nurseries for fish, which as adults play key ecological roles, maintain biodiversity of fish assemblages and/or contribute to local fisheries.

Future directions

- Complete meta-analysis which examines the contribution of fish from macroalgal habitats to small-scale tropical fisheries.
- Investigate the spatial and temporal dynamics of canopy forming macroalgae at Ningaloo and how this is influenced by environmental disturbance.
- 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, T 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 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 www.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

- A paper published in *Remote Sensing* reported on work that found that aerial surveys detect 77% of Flatback Turtles, showing that one-third were located within 5km of industrial sites and are exposed to the pressures associated with these industries.
- Research on eDNA, published in *Marine and Freshwater Research*, showed that water samples can detect the presence of turtles, providing baseline information on habitat use.
- Extensive surveys of Green Turtles found that Biologically Important Areas are protected, but these underestimate foraging areas used by these turtles. This information was published in *Diversity and Distributions*.
- The green turtle data set included 96 nesting females from WA and identified new foraging areas across WA, NT and Qld.
- The hawksbill data set included 40 nesting turtles from WA and two from Timor Leste and showed that all WA nesting turtles remained within WA waters when they returned to their resident feeding areas.
- The flatback data set, one of the largest in the world for any turtle species, included 309 turtles from a combination of nesting and foraging turtles. A manuscript on nesting and foraging is in preparation.
- Movements of tracked turtles were displayed in real time on a website (www.seaturtle.org).

Management implications

- Data on turtle movements assists the conservation of turtles and implementation of recovery actions by informing boundaries of Biologically Important Areas (BIA). Previously, BIAs for this life stage were only estimated for WA.
- Three surveys provide some of the first quantifiable evidence to identify BIA's for the migratory corridors and resident feeding areas of these species that informs conservation planning.

- The tracking studies of flatback turtles in Roebuck Bay has provided insight into habitat use and diet of turtles that can be used for marine park management, including port planning and vessel use.
- Updated information on BIA and migratory pathways informs management on sensitive areas to human pressures. Information is useful for the Recovery Plan for Marine Turtles in Australia.

Future directions

- Prepare papers on detailed investigations of migration patterns and inter-nesting habitat use.

Marine monitoring program

SP 2012-008

T Holmes, C Ross, W Robbins, S Strydom, B French, L Peel, M Moustaka, K Murray, S Wilson, E Lester, J Goetze

Context

A State-wide system of marine protected areas has been 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 long-term, monitoring, evaluation and reporting program that is designed to increase the efficiency and effectiveness of marine reserve and threatened marine fauna conservation and management across Western Australia.

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 by DBCA or collated from direct collaborators for fish, coral, seagrass, macroalgae, mangroves, macro-invertebrates, little penguins, shorebirds, intertidal invertebrates, dolphins and water quality during field work conducted across 15 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 advice and data interpretation for the Montebello/Barrow Islands, Ngari Capes and Lalang-garram marine parks.
- Seven scientific papers incorporating departmental monitoring data or examining developments in monitoring methodologies/indicators were published in *Global Change Biology, Methods in Ecology and Evolution, Marine Policy, Ecological Indicators, Journal of Ecology, Marine Environmental Research* and *Environmental DNA*.
- Significant scientific advice was provided as a part of the ongoing planning process for a marine park in the Buccaneer Archipelago, community engagement associated with the south coast Planning for our Parks process, the alignment of external research/management agency priorities (AIMS, DPIRD, RIA, Minderoo Foundation, Resilient Reefs), state-wide coral bleaching network, and externally contracted

reports relating to intertidal invertebrate communities in EMBMP and YNRBMP, and Loggerhead turtles on Dirk Hartog Island.
- Significant development in automation of download, analysis and cleaning processes for fish and seawater temperature data.

Management implications
- The long-term marine monitoring program provides data that informs 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 refine approaches to managing ecological values based on rigorous scientific evidence collected as part of a strategic state-wide framework.

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.
- Finalise and publish static ecological monitoring reports.
- Continue the implementing and periodic review, ecological value monitoring across the marine reserve system, including planning and prioritising of monitoring activities in the new Buccaneer Archipelago marine reserves.
- Re-prioritisation of monitoring programs in the Kimberley marine reserves in collaboration with regional staff and joint managers.
- Continue to provide 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 scientific knowledge for the marine parks and reserves reporting process.

North West Shelf Flatback Turtle Conservation Program

CF 2011-118

S Whiting, S Fossette-Halot, T Tucker

Context
The Northwest Shelf Flatback Turtle Conservation Program (NWSFTCP) is one of four additional environmental 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. This project coordinates the planning and implementation of works required for the NWSFTCP and coordinates 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 NWSFTCP Strategic Plan.

Progress
- Monitoring of nesting turtles continued at Delambre and Thevenard Islands, Eco Beach and Cape Domett, with only a minor interruption at Delambre Island caused by cyclone evacuation.

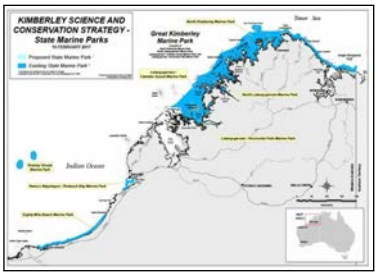
- Studies of resident foraging turtles continued at Roebuck Bay, Broome with transmitters attached.
- Data was analysed from all tracked flatback turtles and a manuscript prepared.
- Foxes were removed for the third year at a major Pilbara flatback turtle rookery at Mundabullangana Station.
- Indigenous engagement activities continued at several sites including employment at Delambre Island, community visits at Thevenard Island and Bells Beach, assistance with the Indigenous Saltwater Working Group in the Kimberley and a continuing partnership with Wirrpanda Foundation.

Management implications

- The monitoring of nesting turtles provides time-series data to assess the North West Shelf genetic stock of turtles and inform conservation and management decisions.
- Continued research of resident flatback turtles at Roebuck Bay has provided valuable insight into habitat use and diet which joint managers use (DBCA and Yawuru Aboriginal Corporation) to assess how other activities in the bay such as pearling, shipping and recreational boating overlap with flatback turtles.
- This program continues to cull foxes at Mundabullanagana Station, which contributes to protection of turtles by directly mitigating mortality of eggs and hatchlings.
- A broad-scale aerial survey of nesting beaches across the Pilbara has identified all nesting habitat and defined relative nesting abundance across these areas. This information will be used to estimate the relative proportion of nesting that is potentially impacted by industrial developments and specifically, will assist the NWSFTCP in assessing the potential impact from the Gorgon Gas Project on North West Shelf flatback turtle genetic stock.
- Long term natural resource management benefits from community engagement through local partnerships. The inclusion of Indigenous groups (such as Yawuru Aboriginal Corporation and Ngarluma Aboriginal Corporation) as partners has enhanced the long-term benefits of the program by providing: a cultural perspective and relevance to the work; positive communication of the program throughout the communities; stability in governance and advice pathways; and additional conduits for information transfer to Joint Management bodies.

Future directions

- Develop a new strategic plan for 2022 -2029.
- Further analyse tracking data to provide insight into migration paths and inter-nesting habitat.
- Continue to monitor key flatback nesting beaches including Delambre and Thevenard Islands, Port Hedland, Eco Beach and Cape Domett.
- Continue student projects on feral animals and climate change.
- Build and maintain Indigenous partnerships, engagement and employment through local opportunities and training.



WAMSI 2: Kimberley Marine Research Program

CF 2011-117

K Waples

Context

The Kimberley Marine Research Program (KMRP) represents a program of marine research to support the management of the Great Kimberley Marine Park (which includes State marine parks at Camden Sound, Horizontal Falls, North Kimberley, Roebuck Bay and Eighty Mile Beach) and the coastal waters outside of these marine parks. The KMRP was developed and 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 outlines the priority research and information needed 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 was undertaken between 2012 and 2017 and involved up to 80 scientists from eight research or management institutions in Western Australia working collaboratively on 25 research projects. Indigenous participation and engagement were key components to the success of the research program. All projects involved engagement with Aboriginal people and development of partnerships with the relevant traditional owners to include their participation and ensure the research outcomes benefit local communities. A key outcome for the KMRP is delivering knowledge to the key end users who benefit most, including the joint managers of marine and coastal waters of the Kimberley.

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 scientific findings, so that the program produces a clear understanding of Kimberley marine ecosystems and the interactions between them that are useful to management.
- Ensure that the KMRP is undertaken in a culturally appropriate way in partnership with local Aboriginal people and delivered to help their longer-term aspirations.
- Ensure that knowledge transfer and uptake occurs between scientists, joint managers and decision makers.

Progress

- Based on the learning and implementation of the KMRP, communication of the KMRP achievements and outcomes continued through a range of activities including ongoing dialogue with regional and BCS end-users and the development of communication products and activities with Indigenous communities that have been working with scientists for healthy country outcomes.
- A review of the Kimberley Indigenous Saltwater Science Project was initiated in collaboration with the Indigenous Saltwater Advisory Group (ISWAG) to determine whether the protocol and process for researchers to engage with traditional owners were working effectively. This has involved interviews with scientists, DBCA and joint managers and findings and recommendations have been presented to ISWAG to consider.
- Priority knowledge gaps that remain for the Kimberley and synergies and priorities for scientists and joint managers were identified. A manuscript detailing this process has been submitted.

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

- Continue extension activities to deliver priority products/tools requested by key stakeholders that will assist them in using KMRP outcomes for marine and coastal management with a focus on supporting joint managers.

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

SP 2009-013

S Strydom

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 fish in the estuary is important for management of the marine park.

Aims

- Determine spatial patterns and temporal variation in the WNIMP benthic invertebrate community.
- Assist in developing long-term monitoring methods of benthic invertebrates in WNIMP and more broadly across temperate estuarine marine protected areas.
- Determine whether there are spatial and temporal differences 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 2021. Third year undergraduate students studying Coastal and Marine Management with Professor Paul Lavery collected data on bivalve communities and investigated methods for assessing stingray abundance across the estuary.
- Invertebrate samples have been processed to generate data for analysis.

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. 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 2022.
- Analyse several data sets and prepare reports and manuscripts for publication.

Fire Science

Program Leader: Ben Miller The Fire Science Program seeks to inform fire management and biodiversity conservation on lands managed by the department, including 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.

Development of a systematic approach to monitoring and reporting on the outcomes of prescribed burns and bushfires

SP 2018-134

V Densmore, K Zdunic

Context

Fire severity describes the amount of biomass removed, reduced or substantially altered (e.g. charred) by either unplanned bushfire or planned burning. Severity relates to fire intensity but extends the consideration beyond fire behaviour to incorporate ecological effects and structural changes. Thus, fire severity represents a valuable approach to gauge how planned burning or unplanned fire has impacted future fire hazards and the persistence of habitat for flora and fauna. A systematic tool to assess fire severity supports the objective evaluation of the outcomes of decision making, the methods used to apply planned burns, and assists in meeting statutory reporting obligations including fire management performance indicators and potential impacts on listed flora and fauna.

Aims

- Develop a framework for a systematic approach to assessing and reporting the outcomes of prescribed burns and bushfires based on remote sensing and field surveys.
- Develop and test a variety of reporting tools and metrics related to environmental outcomes.

Progress

- Four models were developed to categorise severity of prescribed burns and bushfires into five classes for four IBRA sub-regions using several spectral indices derived from multi-temporal mosaics of pre and post-fire satellite imagery that were compared to field assessment. Within-class accuracies ranged from 82 to 98 percent, and overall accuracies from 51 to 65%.
- Fuel hazard was assessed using an expanded version of the Vesta Field Guide on ~1025 transects distributed across eight IBRA sub-regions and fuel ages from 2 - 9 years.
- The field assessment tools have been developed into Android and iOS applications to facilitate efficient data collection and promote data integrity without multiple data entry steps.
- Work has progressed to transition the fire severity models into an operational product.
- Severity maps have been produced to investigate the role of severity in affecting quokka populations in Perth Hills District.

Management implications

- Improved ability to quantify spatial patterns of fire activity and vegetation effects will support cost-effective and meaningful reporting on the extent to which prescribed burning has achieved specified objectives and success criteria for biodiversity management, bushfire risk management and other land management values e.g. forest regeneration.
- Improved reporting will enable further research and knowledge development and contribute to refinement of the prescribed fire planning process including objectives that are measurable, achievable and relevant to particular land management values.
- Applying the same approach to quantify spatial patterns of fire activity and vegetation effects following bushfires will allow analysis of fire history drivers across vegetation types and regions and an informed comparison of the effectiveness of the overall fire management program.

Future directions

- Automate the process to produce burn achievement and burn severity maps to incorporate within the Spatial Support System.
- Overlay severity maps with aerial ignition patterns and species populations to support fire management and conservation decisions.
- Assess severity patterns over time using spatial analyses of current and past fire events.

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 nationally 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 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

- Banksia woodlands fuel dynamics manuscript is close to completion.
- Weed management continued at Kings Park, Bold Park, Jandakot and Yangebup (Beeliar) sites. The Jandokot and Kings Park sites were resurveyed.
- Post burn survey of experimental plots examining resprouter seedling survival of fire at two, three and four years after establishment were completed with assistance from Kings Park bushland staff.
- Analysis of patterns of composition, richness and cover commenced with templates and workflows developed from Kings Park data for analysis of a larger dataset.
- Preparation for first short rotation (6-year) burn completed for Kings Park, with assistance from Kings Park bushland staff, FMSB, Swan Region and DFES. Burn planned for April-May 2021 was not possible due to prescription conditions not being met and is postponed to 2022, and creating a 7 year rotation.
- Results presented at local community urban restoration conference and published in a Landscope Article.
- The design of this experiment is being developed as a template for a national post-fire weed management program.

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 a 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.
- Analysis of vegetation response data to be undertaken as a burn x weed treatment.
- Submission of banksia woodlands fuel dynamics analysis manuscript.
- Second experimental burn phase with short rotation burn treatments and increased pre- and post-fire monitoring and analysis commencing 2022.

Understanding the changing fire environment of south-west Western Australia

SP 2014-001

L Mccaw, V Densmore

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, 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, thus 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

- Two papers were published in *Climate Dynamics.* One explored the influence of climate variability modes on fire weather conditions and lightning-ignited bushfires in the Warren Region, and the second used tree-rings to reconstruct autumn-winter rainfall over inland SW Australia from 1350 - 2017 CE.
- A case study examining the role of fire-atmospheric coupling on fire behaviour at the December 2019 Yanchep fire was undertaken collaboratively with the Bureau of Meteorology and Department of Fire and Emergency Services.
- Phased testing was provided for the fuel state editor and fire danger viewer to implement the new Australian Fire Danger Rating System (AFDRS).
- A diagnostic product developed by the Bureau of Meteorology to predict conditions conducive to formation of pyrocumulonimbus plumes above bushfires was evaluated using case studies from Western Australia.
- A webinar was presented on fuel moisture and drying climate as part of a national series hosted by the Bushfire and Natural Hazards CRC.

Management implications

- Understanding the factors that influence the location and timing of bushfire ignitions is vital for developing effective management strategies to minimise the risks posed by unplanned fires and guide the level of resourcing required for bushfire suppression in different management areas. Lightning is an common 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. A 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

- This project is now complete.

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

SP 2012-029

V Densmore, S Samson

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 essential for developing and implementing ecologically appropriate fire regimes and 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 rates.
- Monitor potential interactions between climate change and fire regimes and their impacts on floristic composition and fire behaviour in jarrah forests.

Progress

- Burn prescriptions were updated in both Donnelly and Blackwood Districts to enable fire treatments to continue.
- Burn severity relative to fire treatment was analysed.

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

- Undertake floristic survey following prescribed burn treatments at McCorkhill and Perup plots.
- Undertake digitisation of historic hardcopy data and curate a complete dataset to investigate opportunities for re-measuring components.

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 percent capture rate, or decline of mean shrub projected ground cover to less than 2 percent.
- 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

- Latest monitoring is revealing negative impacts of cane toad invasion on quolls.
- However improved fire and feral cattle management at several Kimberley Parks has improved mammal species diversity and abundance.
- Modelling analysis was completed using mammal data from 94 monitoring sites with multiple surveys. Manuscript submitted.
- Analyses show that threatened mammals are doing best in areas with low feral cat activity. Vegetation attributes and disturbance (fire and cattle) also strongly influence mammal richness and abundance. Threatened mammals are positively associated with increasing site ruggedness/rockiness, increasing amounts of shrub cover and vegetation unburnt for >4 years.
- The Kimberley regional monitoring program is expanding into new areas and the department's Kimberley Region has now taken the monitoring on as core business. Monitoring results are now routinely used in annual planning of fire and cattle management.

Management implications

- Analysis of the monitoring data shows that increasing patchy early dry season prescribed burning benefits most threatened species, including the brush-tailed rabbit rat, northern quolls (in rocky habitats), the endemic Kimberley rock rat and the red cheeked dunnart, providing support for this management approach.
- Most terrestrial rodents (*e.g. Rattus tunneyi* and *Pseudomys nanas*) are fire averse, and respond negatively to fires whether they are early prescribed burns or late season wildfires. This suggests that net reductions in annual burnt area will benefit these rodents.
- There is now strong evidence that prescribed patchy early dry season burning has changed fire regimes in the north and central Kimberley for the better by reducing wildfires.
- There is now strong evidence that cattle have a negative influence on threatened mammals such as the brush-tailed rabbit rat. This supports continuation of the department's feral cattle culling program for the benefit of threatened mammals and the other cattle threatened groups.

Future directions

- Continue monitoring to evaluate management effectiveness for threatened mammals and other groups across the Kimberley region.
- Undertake occupancy modelling to determine the response of threatened species to fire regimes and other threatening processes.

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 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 scientific experts, 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 hindrance to ecological fire management in the region. The GWW supports eucalypt woodlands at very low mean annual rainfall (250-350 mm). Many of the woodland eucalypt species are killed by fire (obligate-seeders), and eucalypt recruitment stimulated by fire but individuals are 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, development of ecosystem structure and changes in carbon dynamics.
- Produce a spatially explicit representation of long-unburnt woodlands through linkage of plot data on vegetation structure with remotely-sensed imagery.

Progress

- Vegetation structure measurements of tree allometry were collected at 150 sites, with remote piloted aircraft and airborne LiDAR data captured from a subset of these, for linking plot-based vegetation structure with satellite imagery to support development of spatial models of woodland age-classes.
- Plant trait data from the *Eucalyptus salubris* chronosequence was provided to a national collaboration cataloguing plant traits (AusTraits), with a publication describing this data set under review.
- Plant vital attribute data from the *E. salubris* chronosequence formed part of a south-western Australian-wide analysis estimating juvenile period in plants from site productivity predictors. Climate and gross primary productivity were strong predictors of juvenile period, allowing the development of spatial models of juvenile period under both recent environmental conditions and those projected to occur in the future.
- Plant fire response data and fire history data from Western Australia contributed to a national analysis of impacts of the 2019-20 megafires on plant diversity, published in *Diversity and Distributions.*
- Plant occurrence data from the multi-century post-fire *E. salubris* chronosequence was used to test a new dimension in fire-response traits in plants - the colonisation ability of fire-intolerant flora, published in *Fire.*

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 a putative vulnerability to decreases in intervals between fires; and large changes in vegetation composition and structure with time since fire and with variation in prior fire interval. This information contributes to management of fire in these woodlands.
- Post-fire succession in vegetation 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.

Future directions

- Finalise journal publications concerning revised estimates of time since the fire of long-unburnt gimlet woodlands and changes in carbon stocks with time since fire.
- Develop spatially explicit models of woodland age-class based on satellite imagery.

Burning for biodiversity: Walpole fine-grain mosaic burning trial

SP 2004-004

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 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 operational techniques to use frequent and planned introduction of fire into the landscape (patch-burning) to create a fine-scale mosaic of vegetation patches at different stages of post-fire development.

Progress

- A paper describing effects of mosaics and responses to time since fire in bird assemblages has been published in *Fire Ecology*.
- A manuscript describing the effects of mosaics and vegetation on epigaeic invertebrate richness and trophic structure has been drafted.
- A paper describing the theory of fire-induced mosaics, how to describe and characterise mosaics, and operational challenges in creating fire mosaics, has been submitted.
- A draft manuscript describing the effects of mosaics on vegetation has been prepared.

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 decisions on this strategy.

Future directions

- Complete publication on epigaeic invertebrate richness, and prepare an overview paper covering the biodiversity outcomes of mosaic burning.

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 focuses on 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, and 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 provides information to support plant species conservation and ecosystem restoration. Research is focussed on the physiology and ecology of seed dormancy, germination, and longevity, the interactions of seeds and seedlings with the soil environment and the development of seed technologies to enhance seedling establishment in threatened species translocation and broad-scale restoration settings. 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.

Aims

- Support and enhance the curation of *ex-situ* collections of germplasm through resolving seed storage behaviour and longevity, 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

- Completed field trials at mine sites in the Pilbara and south-west to stress test newly designed direct seeding machinery and evaluate the technology readiness levels.
- A US Patent was granted for *Seed Ablation* – a seed processing technique to remove appendages from native seeds to improve handling properties for seeding machinery.
- A two year study was completed examining mechanisms of fire seasonality effects on seedling recruitment of nine species of banksia woodland species.
- Completed a study investigating how microsite conditions influence germination of twelve annual plant species in the York gum woodlands.
- Contributed to a number of chapters on seed banking, dormancy and germination, and seed enhancement, in revisions of the *Florabank Guidelines* (2nd Ed.), and the *Germplasm Guidelines* (3rd Ed.), to be launched by the Australian Network for Plant Conservation.

Management implications

- Restoration practitioners and industry continue to trial and adopt the seed ablation techniques and the newly developed seeding machinery. This adoption contributes to increased diversity in restoration through improved seed distribution and the inclusion of species not previously available due to machinery capabilities. Provision of data on the timing of seedling establishment of banksia woodland contributes to informing the regeneration capacity and composition of these plant communities following a fire in different seasons. This data assists land managers in making informed decisions on the timing of prescribed fires.

Future directions

- Investigate seed respirometry and multi-spectral imaging and novel data analyses techniques to characterise seed population responses to time in storage and to predict the onset of viability decline of banked seeds.
- Initiate experiments on alternative storage protocols to improve the storage stability of short-lived seeds.
- Continue to develop novel mechanised seeding equipment and seed enhancement technologies, including bringing automation to the application of ground-based seed delivery systems.

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 influencing growth and survival of plants in restoration.
- Determine factors influencing resilience, sustainability and landscape integration.

Progress

- To determine root system access to soil water, measured plant ecophysiological traits as proxies for soil water access in banksia woodland species. Leaf water potential, stomatal conductance, C and N isotopes, chlorophyll fluorescence, and NDVI (leaf clip) were assessed on 19 species across rehabilitation and reference systems at different distances from the groundwater.
- A critical analysis of vegetation cover estimates, sourced from various monitoring approaches, including ground-based measurements and drone-based greenness indicators, was undertaken. Canopy cover values of a banksia woodland rehabilitation chronosequence and reference sites were determined for 17 plots to inform ecosystem trajectory outcomes in response to management practices and decipher discrepancies in canopy cover methods.
- Basic seed biology (seed fill and viability) of over 60 banksia woodland species was documented.
- Seed collections of native grass pasture species from the Kimberley region were undertaken as part of a collaborative DPIRD-led program. Seed biology assessments were commenced, including seed viability, dormancy identification and germination behaviour.

Management implications

- Application of ecophysiological tools linked with remote sensing will inform scalable vegetation monitoring techniques and establish targets and criteria for restoration activities.
- Deciphering discrepancies in vegetation canopy cover estimates will inform monitoring approaches for banksia woodland reference and rehabilitation systems.
- Improved knowledge of seed biology and seed use efficiency will improve the success of plant establishment in the restoration of both mining and rangeland systems.

Future directions

- Collate the plant traits of banksia woodland species and map against biodiversity outcomes, environmental parameters, and rehabilitation treatments.
- Undertake a mining sector analysis to determine knowledge gaps in returning resilient ecosystems to post-mining landscapes.
- Determine seed biology, ecology, and pasture values of northern native grass species to inform potential management of the Kimberley rangeland systems.

Conservation genetics

SP 2018-068

S Krauss, E Sinclair, J Anthony

Context

The conservation, restoration and horticultural development of Western Australia's unique biodiversity is informed by understanding of patterns of genetic diversity at multiple hierarchical levels (individuals, populations, species, communities), as well as the key ecological and evolutionary drivers of this genetic diversity, such as adaptation, mating and dispersal. Research into conservation genetics seeks to understand the impacts on genetic diversity and the key drivers of this diversity from environmental stressors such as habitat fragmentation, climate change, and introduced species, and identify solutions based on genetic data and theory.

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 the soil microbiome through ecological restoration.

Progress

- Analysis of provenance trials with 3,200 seedlings of *Eucalyptus todtiana* from four sites across the Swan Coastal Plain continue to show little effect of provenance for seedling growth and mortality.
- 16,000 seeds from 40 populations of *Eucalyptus todtiana* and *Banksia attenuata* were collected, processed and planted into each of four translocation trial sites as seed or seedlings.
- Analysis of exclusion trials shows when birds are excluded and insects are the sole visitor to flowers of *Banksia menziesii*, numbers and genetic diversity of seed were significantly reduced.
- Ecological genetic assessment of multiple restored plant populations show resilience for pollinator services, reproduction and genetic diversity.
- An *ex-situ* controlled stress tank experiment showed that *Posidonia australis* showed a higher resilience under heat and light stress than *Amphibolus antarctica*.
- Trajectory analysis of soil microbial communities through restoration chronosequences in jarrah forest and banksia woodland predict median times of recovery to pre-disturbance state of 40-100 years.

Management implications

- Provenance trials continue to suggest that diverse local provenance seed provides resilience to current and future climates for restored plant communities of banksia woodlands.
- Refined understanding of the critical importance of birds for pollination indicates that control of feral honeybees may reduce negative pollination impacts on some native flora.
- Although impacted by extreme climate events, seagrass meadows show a resilience to climate change that suggests local diverse sourcing of propagules provides for effective restoration.
- Enhanced knowledge of soil biota trajectories through post-disturbance restoration shows that soil management can be improved to enhance the return to pre-disturbance communities, and highlights the utility of the approach in assessing progress towards restoration targets.

Future directions

- Undertake analysis of pollinator exclusion in banksia woodland sites.
- Undertake *in-situ* reciprocal transplant trials in Shark Bay, transcriptome population genomic analysis, and controlled *ex-situ* stress manipulative experiments.
- Undertake provenance trials, glasshouse trials, and seed germination trials of key species for ecological restoration of banksia woodlands.
- Assess restoration success of *Lambertia multiflora* through genotyping of seedlings.
- Assess post-mining restoration chronosequences for bacterial and fungal community composition and diversity.

Orchid conservation and recovery

SP 2018-060

B Davis, J Stevens

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 42 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 and maintaining an orchid mycorrhizal library. This collection provides a basis for orchid translocations, 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 threatened and priority listed species to investigate the potential for supplementation of wild populations. Maintain and build *ex-situ* seed and fungal banks of the orchid flora of Western Australia for conservation and research purposes.

Progress

- First phase translocation (210 plants) and augmentation (140 plants) plantings of *Caladenia busselliana* were conducted and monitored for re-emergence to investigate the effect of age of seedlings and season of planting on translocation success.
- A further 450 *C. busselliana*, 918 *Caladenia viridescens* and 900 *Caladenia lodgeana* seedlings were propagated and are currently in transition from laboratory to glasshouse.
- Newly collected fungal isolates and seed sources were tracked for *C. busselliana* germination performance and survival.
- Pollinator surveys continued for *C. busselliana* and *C. lodgeana* to help inform future translocations.
- Surveys across the extent of *C. lodgeana* and *C. busselliana* provided updated numbers on population size and new plants.
- Further propagation of *Thelymitra variegata*, and trials on other *Thelymitra* species were initiated.
- Collections of 44 species (totalling 53 seed and 45 fungal accessions to the *ex-situ* collection) focused on the Swan region.

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.
- Growing *ex-situ* collections of other threatened orchids *(C. viridescens* and *C. lodgeana*) of the Capes region and greater south-west Western Australia, provides conservation support for species with dwindling or singular populations that are at threat from stochastic events.
- Indications of the identity of pollinators, pollination syndrome, abundance of pollinators and distribution across habitat types inform conservation management of habitat remnants, selection of potential translocation sites and whether reproductive management of the orchid species may be necessary.
- Updated population numbers and the discovery of new plants of *C. busselliana* and *C. lodgeana* provide vital demographic and location data to better manage populations of these threatened orchids.
- Development of a germination protocol for *T. variegata* provides conservation support to this and other threatened *Thelymitra* species. This advancement brings the possibility of translocations as a conservation tool for the genus *Thelymitra*.

Future directions

- Continue with subsequent phases of the *C. busselliana* translocation and species recovery.

- Make targeted seed and fungal collections to supplement *ex-situ* orchid collections and support conservation efforts.
- Optimise propagation protocols across orchid genera to increase supplementation success from laboratory to *in-situ* site.
- Develop protocols for cross-pollination, seed collection and fungal collection in small orchid populations.
- 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 streams is essential to progress and enhance the ex-situ conservation and germplasm storage options for threatened plant species, where other forms of germplasm storage are not possible. 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 vascular plant taxa and seeds and mycorrhizal fungi of many native orchid species, including a number of rare taxa.

Aims

- Develop micropropagation for plants requiring translocation and for living collections.
- Develop cryopreservation protocols for ex-situ long-term storage of germplasm of selected species.

Progress

- Novel cryopreservation protocols were investigated for a range of species, including *Grevillea scapigera, G. dryandroides subsp. dryandroides* and *Syzygium* species.
- *Banksia ionthocarpa subsp. chrysophoenix* showed poor culture growth regardless of culture conditions.
- The *Banksia montana* culture lines were maintained as a living collection in the tissue culture laboratory.

Management implications

- *In-vitro* propagation provides *ex-situ* germplasm material for threatened species where cutting propagation or seed is unavailable. This approach provides biosecure storage in culture collections or cool storage for selected genetic material of endangered plants. This material can be accessed to provide plants for future translocations if required.
- Cryopreservation provides very long term 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 research to understand the effects of cryopreservation on the metabolism of plant germplasm material.
- Develop transcriptomic methods to assess stress response in plant material during cryopreservation.
- Develop cryopreservation for rainforest species.
- Develop in-vitro propagation for new species of threatened Australian plants.

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 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 these are threatened by foxes and feral cats. Habitat critical to the species survival has been threatened by extensive wildfires in recent years. In July 2014, seven western ground parrots were transferred from departmental aviary facilities near Albany to Perth Zoo in a successful attempt to 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.
- 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

- One bird (a male) was added to the breeding colony in May 2020 after it showed signs of difficulty flying upon release at an approved translocation site on the south coast. The bird has settled into captivity well.
- No deaths amongst captive parrots were recorded.

- No eggs were laid during 2020.
- Upgrades to the aviaries were made to improve biosecurity, care facilities, bird interaction and mate choice for breeding females.

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

Progress

- A further postage trial captured a variety of temperature, humidity, and shock measurements.

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 (and other parts of Australia) 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 the sentencing of convicted offenders.

Future directions

- Completion of publications.

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

CF 2018-119

P Mawson, E 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 sensory and cognitive functions 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 cue presentation to determine if Asian elephants will respond to an unfamiliar human voice.

Progress

- The bull elephant involved in the study has progressed to successfully vocalising on the target scent in the presence of two distractor scents. An additional distractor scent will be added to the trials in the near future.
- The cow elephant involved in the study is completing trials using a single scent (target scent only).
- Both elephants show motivation and calm, attentive behaviour during trials.

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

- Complete the field trials and analyse the results.

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

CF 2018-118

C Holland, P Mawson, E Polla

Context

Animals survival depends on how good and timely solutions to the experienced problems are. Sometimes problems are widely spaced in time so a problem solving strategy that is not retained in their memory does not provide a substantial cognitive economy to the individual. Among terrestrial mammals, elephants, along with humans and great apes, have 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 its own recently performed behaviours in working memory.
- Determine the ability of such representations to affect future behaviours.

Progress

- Data collection has been completed.
- Data analysis has commenced.

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

- Complete data analysis and if appropriate, publish the study in a suitable journal.

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

SP 2018-115

P Mawson, E Polla

Context

Maintaining or improving animal welfare is a key consideration in operations at Perth Zoo, and behavioural observations of collection animals ensures 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 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

- During the Zoo's closure due to COVID-19, staff were trained to collect basic behaviour and location data for animals throughout the African savannah and Asian rainforest (painted dogs, baboons, rhinos, lions, hyenas, radiated tortoises, Madagascan tree boa, meerkats, giraffes, zebras, porcupines, Galapagos tortoises, orangutans, white-cheeked gibbons, elephants, red-eared sliders, sun bears, red pandas, binturongs, otters, Komodo dragon and tigers). Docents collected data using established methodology so that data could be compared when visitors were present and absent.
- Behaviour of the Zoo's one remaining tiger was monitored following the death of the Zoo's other elderly tiger.

- Bridled terns housed in the penguin exhibit were observed to gather data that could help determine the cause of poor foot health in this species.
- Methodology for recording nesting behaviour in black-necked storks was developed in advance of the next breeding season.
- Galapagos tortoises were observed during periods of unobstructed human interaction and when interactions with humans occurred with a visual barrier between the two tortoises in an attempt to determine whether the 'finching' response (raised body posture in response to tactile stimulus) exhibited by the dominant male is influencing the frequency of other behaviours, such as biting and chasing.
- Observations have begun for meerkats to compare the behaviour of an easily identifiable male to the behaviour of a male with skin irritation, possible habitual scratching and biting behaviour.
- Observations have also begun on capuchins with a focus on male Chaz to inform future social grouping decisions.

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 animal behaviour in areas of possible concern where the reduction in visitor presence associated with COVID-19 and the return of visitors may have an impact on animal welfare.
- Provide empirical data to support accreditation process for a broader range of species.

Geocrinia frog breed and rear for release program

SP 2018-102

P Mawson, C Lambert

Context

There are two species of *Geocrinia* frogs, white-bellied frogs (*Geocrinia alba)* and orange-bellied frogs (*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 to maintain or increase the current extent and viability of populations of these species.

Progress

- A captive breeding colony of *G. alba* and *G. vitellina* was maintained. Egg clutches of both species were collected from the wild and metamorphs were raised to 11 months of age, at which point they were released to the wild.
- 103 *G. alba* and 754 *G. vitellina* juveniles were each released into sites in conservation estate east of Margaret River.

- Evaluation of desiccation and thermal tolerance involving eggs and embryos of both *Geocrinia* species was finalised and published in *Conservation Physiology*.

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 allows informed decisions about which field sites are chosen for the release of juvenile frogs to augment existing, or create new populations and which sites to avoid and abandon.

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 listed 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

- No western swamp tortoise juveniles were released in 2020 due to the poor winter-spring rainfall in south-western Australia and the shortened hydro-period that produced.
- A total of 108 eggs were produced in the captive breeding colony, 70 of which hatched.
- eDNA water samples were collected from western swamp tortoise ponds prior to them being used, and progressively as larger numbers of hatchlings were added to the ponds.
- Historical mortalities of western swamp tortoises held in the captive breeding facility are being evaluated to determine any common factors related to those deaths.
- A research project examining the influence of temperature and vibration on western swamp tortoise nests is being conducted to determine whether there is communication between sibling embryos in the egg stimulates synchronous hatching in the wild and in artificial incubation.

Management implications

- Developing eDNA technologies may facilitate a better and more reliable surveys of real or potential western swamp tortoise habitat.
- Identifying common factors associated with mortality in the captive colony will allow informed decisions around husbandry in the future.

- Understanding the cues to hatching will inform decisions on the management of both wild and captive populations.

Future directions

- Continue to produce juvenile animals for release to sites.
- Research the breeding ecology of western swamp tortoises using wild and captive populations.

Dibbler breed for release program

SP 2018-099

P Mawson, C Lambert, T Friend

Context

Dibblers (*Parantechinus apicalis*) are listed as endangered and were formerly widely distributed along the west and southern coasts of Australia; however, they 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

- Seventeen juvenile dibblers and fourteen adult dibbers surplus to breeding requirements were released onto Dirk Hartog Island National Park. This was the second release of this species onto the island.
- An additional three males and three females were collected from the wild on Boullanger Island near Jurien Bay as part of the foundation breeding stock and added to the captive breeding colony.
- These new animals were settled into captivity and paired for breeding. Forty-two pouch young were produced from those pairings and are developing normally.

Management implications

- The release of dibblers onto Dirk Hartog Island National Park is the first phase of a program to establish a new wild population.

Future directions

- Maintain the size of the dibbler breeding colony to 10 pairs.
- Provide additional dibblers for release onto Dirk Hartog Island National Park.
- Continue to work on husbandry strategies 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, T Friend

Context

Numbats (*Myrmecobius fasciatus*) are listed 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 Dryandra, Mount Gibson Sanctuary in Western Australia, and 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 10 yearling numbats for release into the Dryandra Woodland to augment the population.
- One adult numbat surplus to the requirements of the breeding program was also released into Dryandra Woodland.
- Two males and three females were brought into the program from the Upper Warren Region to expand the genetic integrity of the breeding program.
- Produced 10 pouch young, with nine young developing normally.
- Captive numbats were used in a controlled experiment to assess the capacity of the Felixer Grooming Trap to reliably identify numbats as non-target species.

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.

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 153 (105 as pullus and 48 rehabilitated) Carnaby's cockatoos, along with 5 Baudin's cockatoos (all rehabilitated) and 46 forest red-tailed black cockatoos (all rehabilitated).
- 108 Carnaby's cockatoos and three forest red-tailed black cockatoos were either retrapped/recovered, had their bands/ colour bands photographed in the field and their band number read or inferred. four of those band recoveries involved birds that were dead (3 Carnaby's cockatoos and one forest red-tailed black cockatoo).
- A research paper describing habitat use and flock size in Baudin's cockatoos was published in *Wildlife Research*.
- Analyses of banding data for Carnaby's cockatoo to determine a more accurate annual survival estimate was continued, along with annual survival estimates for rehabilitated Carnaby's and forest red-tailed black cockatoos.
- Work continued on a manuscript describing the costs of rehabilitating black cockatoos, relative to other types of conservation action.

Management implications

- This project has seen the successful release of 709 leg-banded rehabilitated cockatoos from three species (369 Carnaby's cockatoo, 48 Baudin's cockatoo and 292 forest red-tailed black cockatoo). The total number of cockatoos banded (all species and all ages) is now 1,911 from 18 years of work. The rehabilitation techniques and release protocols currently in use provide very high survival rates, contributing to the conservation of the species.

Future directions

- Complete assessment of the costs-benefits associated with the rehabilitation of black cockatoos and prepare a manuscript for publication.
- Determine costs associated with the deployment of artificial nest hollows in comparison to the repair of degraded natural nest hollows.
- Investigate historical and current survival estimates for Carnaby's cockatoo, 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.

Apply acoustic technologies to investigate fish communities and movement

SP 2020-029

S Hoeksema, J Baker, J Watsham, K Trayler

Context

How fish utilise the Swan Canning Estuary, including distances moved on a daily or seasonal basis and movements in response to changes in environmental condition, remains a key knowledge gap despite a number of detailed studies on fish biology and ecology over the past three decades. This information is particularly important in relation to recreationally targeted fish species that have high value in the Perth community.

Acoustic technology can be utilised to provide valuable information on fish movements relative to water quality parameters, such as salinity and dissolved oxygen, and to major interventions within the river system, such as the Swan Canning Oxygenation Program and the Kent Street Weir fishway. Acoustic technology can also be employed to understand how fish utilise habitats of differing complexity, particularly those that are not suited to traditional sampling methods.

Aims

- Utilise acoustic technology to assess fish communities and movement relative to water quality, habitat complexity and in-river interventions.

Progress

- An acoustic receiver array was established in the Swan Canning estuary in 2016 and used to capture data on the movement of 120 tagged black bream. All data has now been retrieved and movements of tagged

bream are being analysed.
- Movement data has demonstrated that the Kent Street Weir fishway was successfully navigated by two tagged bream. One of these fish made repeated passages through the fishway.
- Side scan and acoustic sonar were used to map habitat complexity of the Middle and Upper Swan Estuary and indicated that fish usage of those zones varied between different levels of habitat complexity.
- Surveys of oxygenated and non oxygenated areas of the Upper Swan Estuary using a biosonic echosounder and split-beam transducer indicated a clear movement of fish in response to oxygen availability and avoidance of low oxygen areas.

Management implications
- Acoustic receiver technology has shown that the Kent Street Weir fishway (commissioned in June 2018) is enabling fish movement past the weir.
- The use of sidescan and imaging sonar to identify and map areas of differing habitat complexity through the Middle and Upper Swan Estuary suggested that these habitats may provide differing roles in supporting fish communities and help inform habitat restoration works in the future.
- Acoustic technology may prove useful to supplement existing fish community monitoring, particularly in habitats not suited to traditional netting methods.
- Acoustic technology proved useful in demonstrating how fish responded to the availability of oxygen in the Upper Swan Estuary and the value of artificial oxygenation as a management approach to improving habitat condition.

Future directions
- Continue to assess movement data collected to date by the Swan Canning Acoustic Array and relate to water quality data and modeling data.
- Investigate the use of new telemetred acoustic receiver technology, coupled with water quality sensors, to supplement the existing array.
- Undertake targeted tracking investigations with an initial focus on determining the movements of bull sharks within the river system.

Investigate habitat connectivity in relation to environmental flows and barriers

SP 2020-028

S Thompson, K Trayler

Context

The Swan Canning system is a salt-wedge estuary with many freshwater tributaries that have high biodiversity values. Historically, many of these tributaries have been impounded for water supply purposes and with a growing urban population, there are increased demands for water. Finding the balance between the public water supply system and environmental requirements for water is increasingly challenging in a drying climate. It is important to understand the water requirements of freshwater dependent systems in terms of volume, timing, duration, and intensity of flow to adequately protect them. In addition, once these are determined and set, it is appropriate to monitor that the provisions are met, values maintained and expected outcomes are achieved. The latter includes consideration of how in-stream barriers can be managed to maximise value of the flow provisions.

Aims
- Identify freshwater dependent biomes of ecological significance within the Swan Canning system, threatening processes, water requirements and potential for supplemental flows.
- Determine if there are detrimental impacts to ecosystems downstream of public water supply dams or water abstraction points.

- Determine connectivity of critical habitat and assess impacts of impediments to freshwater flows and movement of riverine biota.
- Determine potential interventions and recommend options for management of in-river structures that might obstruct movement of riverine biota.
- Investigate novel approaches to identification and management of freshwater dependent biomes within the Swan Canning system.

Progress

- Water provisions have been regularly monitored to ensure the prescribed water allocation to the lower Helena River is applied appropriately for maximum ecological benefit.
- A database comprising more than 200 potential barriers to fish passage between the Kent Street Weir and Canning Dam has been established and validated through ground-truthing to determine the degree of obstruction to fish movement. Methods to categorise the severity of impact to fish passage were progressed with the view to building a GIS framework that will support planning and prioritisation of barrier interventions.
- Sampling to improve understanding of distribution of native and feral fish species in the Canning River using traditional sampling and eDNA methods was commenced.

Management implications

- Investigations have determined that summer water releases must be maintained to support healthy fish and invertebrate populations in the lower Helena River. As such, works planned on the Lower Helena Reservoir over summer and autumn 2022 will need to be carefully managed to ensure water availability to lower river pools during the hottest months.
- The removal of identified in-river barriers will improve native fish movement through the Canning River but will require consultation will adjacent landowners and local authorities.
- Identification of some barriers that should be retained will reduce the movement of invasive species and protect upstream native fish populations.

Future directions

- Undertake eDNA and biota surveys on the Canning River.
- Progress the barriers database into a GIS based framework that supports decision making and provides a tool for management.

Swan Canning Water Quality Monitoring

SP 2020-027

S Hoeksema, J Baker, S Robinson, P Howie, J Watsham, J Cosgrove, S Thompson, P Novak, K Trayler

Context

Water quality in the Swan Canning Estuary and its catchment has been routinely monitored over the past 25 years, producing one of the largest continuous data sets for any estuarine system in Australia. Data produced through the monitoring program provides essential information to assess system response to management actions, changes in estuary condition over time and report against estuary water quality targets, catchment nutrient reduction targets and phytoplankton trigger levels. Data has also been used to progress the development of estuarine and catchment models that contribute to decision support.

Aims

- Undertake regular monitoring of water quality and biological parameters in the Swan Canning Estuary and its catchment to provide weekly updates and annual reports on the condition of the river system that

inform management actions.
- Undertake weekly monitoring of physical water quality parameters and collection of phytoplankton samples and fortnightly collection of nutrient samples at routine estuarine monitoring sites, and fortnightly monitoring of physical water quality parameters and collection of nutrient samples at routine monitoring sites in the catchment.

Progress
- Weekly water quality profiles were taken at 42 sites and weekly phytoplankton and fortnightly nutrient samples were collected at 21 sites throughout the estuary.
- Improved efficiency in reporting to management was achieved through electronic entry of field data and rationalised approaches to catchment monitoring.
- Water quality reports and phytoplankton information were updated weekly on the Eyes on the Swan Canning Riverpark web page.
- Annual data reports have been drafted and are currently under review. A web-based interactive map is being developed to replace annual data reports and present monitoring data to the public in a more timely manner.
- A five-year report on the waterway is in development. This will combine both water quality and biotic data sets. Data has been used to evaluate KPIs for estuary and catchment water quality and oxygenation.

Management implications
- Data collected through the monitoring program is being used to inform hydrological and nutrient modelling of the Swan Canning catchment and estuary system. The modelling will underpin a revised Swan Canning Water Quality Improvement Plan;
- Water quality datasets were used to understand factors underpinning algal blooms and fish kills in the Swan Canning Estuary in 2019-21.
- Metrics generated as part of the five-year report on the waterway have been used to report against water quality and biota targets provided for by the Swan Canning River Protection Strategy.

Future directions
- Review monitoring approaches to look for efficiencies in phytoplankton sampling and through the use of real-time monitoring technologies.
- Finalise the data reports on estuarine and catchment condition.
- Continue to develop the web-based interactive map to present water quality data.
- Finalise the production of a five-year trend analysis of estuarine and catchment water quality.

Investigations of contaminants in the Swan Canning

SP 2020-026

P Novak, S Hoeksema, K Trayler

Context

The Swan Canning Estuary is home to diverse faunal assemblages, productive seagrass and macroalgal communities and is a focus for many water-based activities, including recreational fishing. The estuary is situated wholly in the Perth metropolitan region and drains a large agricultural catchment. It faces many anthropogenic stressors including flow reduction, excessive nutrient input, and contaminant loading associated with a range of contemporary and historical land uses. Ensuring environmental and social values are maintained requires an understanding of threats. In particular, it is vital to understand the extent, distribution and potential impact of both novel and legacy contaminants, evaluate risk to the ecosystem and human health and improve approaches to management.

Aims

- Determine the distribution, extent and type of contaminants in the surface water and sediment of the Swan Canning Estuary and its catchment.
- Determine the uptake of contaminants in key estuary biota.
- Understand potential risks to human health through consumption of estuarine species.
- Explore potential control mechanisms for contaminants.

Progress

- A report was completed determining the distribution extent and likely sources of Perfluoroalkyl and Polyfluoroalkyl substances (PFAS) contamination in the Swan Canning Estuary and catchment, focusing on surface water and two ecological and recreationally important aquatic species, blue swimmer crabs and black bream.
- A report determining the concentration and composition of contaminants in western school prawn in the Swan Canning Estuary to provide human consumption guidance and baseline data for this species, has been reviewed by external stakeholders, and is being finalised.
- A report investigating the change in sediment contamination status in the Swan Canning Estuary has been prepared and reviewed by external stakeholders.
- Sampling to determine the effectiveness of the Ellen Brook constructed wetland to remove and store PFAS from surface water, has been completed.
- Field surveys to determine the distribution, extent and abundance of plastics in the Swan Canning Estuary have substantially progressed.

Management implications

- Information on the distribution and concentration of contaminants in the estuary is used to identify the potential for environmental risk to the estuary.
- Analysis of PFAS in surface water in the estuary indicates low risk. Three surface water catchments where PFAS concentrations were elevated have been identified, and management activities to mitigate PFAS run-off have been initiated.
- Evaluation of PFAS levels in black bream, and blue swimmer crabs, and the contamination in western school prawns, provided evidence for decisions on health risk to recreational fishers from consumption of these species.
- Sediment contamination in 2015 was largely consistent with that in 2007 and provides a useful baseline for determining contaminant change over time and in response to management action. Information on sediment contaminant levels informs development planning approvals and highlights zones where risks associated with contaminant disturbance are greatest.

Future directions

- A report on the effectiveness of the Ellen Brook constructed wetland to remove PFAS from surface water will be completed.
- Finalise report investigating sediment contamination status of the Swan Canning.

Incident investigations, response and advice

CF 2018-095

K Trayler, J Cosgrove, S Hoeksema, S Thompson, P Novak

Context

Rivers and Estuaries Science plays an essential 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 response actions.

Aims

- Monitor toxic algal blooms as they arise and report to an incident response team.
- Investigate fish kills as they arise and inform the incident response team.
- Investigate dolphin deaths as they arise, collate information and influence management and operations where required.
- Investigate and provide advice to management on contaminant spills.
- Provide information and advice to support river management and planning.

Progress

- Incident response teams were initiated in response to the Wooroloo fires, flooding, fish kills, toxic algal blooms and pollution events.
- February rainfall in the Avon catchment caused flood flows in the Swan River and triggered moderate-scale fish kills between Belmont and Bassendean. Low oxygen was identified as the cause of that event.
- The ichthyotoxic dinoflagellate *Karlodinium* spp. bloomed sporadically in the Swan Canning Estuary - December 2020 and April 2021. No fish kills occurred but precautionary toxin sampling was initiated.
- An extensive bloom of the nuisance dinoflagellate *Prorocentrum* spp. (mid-April) caused discolouration and oxygen extremes. Response samples were collected to characterise the bloom extent and evaluate the risk to biota. No fish kills were associated.
- A *Landscope* article was published that described the 2019-2020 *Alexandrium* blooms and their toxicity with the intent to support community understanding of the risk associated with this harmful algae.
- *Alexandrium* bloomed in late November - December 2020, but declined quickly.

Management implications

- Monitoring of algal blooms and toxins has informed public warnings and provided data on new species and bloom trends.
- Knowledge of the *Alexandrium* bloom provided evidence base for communication with stakeholders and advice to fishers.
- Investigation of fish kill events provides information to support incident response and provides information on impacts to valued recreation assets.

Future directions

- Response guidelines for harmful algal blooms are revisited annually.
- Refine triggers for algal bloom response, protocols for biota testing and determine trigger levels for biota toxin response and consider inclusion and settings for additional species of concern.
- Investigate data collated pre and post the extensive Wooroloo fire to understand the impact of nutrient-laden ash to the Swan River.

Seagrass monitoring and evaluation

SP 2018-039

J Cosgrove, K Trayler, P Howie, J Baker, J Watsham, K Murray, S Strydom

Context

Seagrasses are a highly valued component of estuary ecosystems as they improve water quality by reducing sediment resuspension and removing nutrients, and provide habitat and a food source for waterbirds. Seagrasses respond to changes in their physical and chemical environment and are recognised as being a bioindicator of ecosystem health, with loss of seagrass representing degraded conditions. Ensuring that seagrass communities remain viable and resilient is an essential component of effective estuary management. DBCA continues to

monitor seagrass throughout the Swan Canning Estuary to inform management decisions on new development proposals and to track the condition of estuarine health.

Aims

- Describe the natural variability of seagrass cover, species composition and other seagrass meadow characteristics to assess changes in response to key climatic conditions.
- Understand the sensitivity of seagrass metrics in response to anthropogenic stressors such as water quality, sediment stress, drift macroalgae load and invasive species.
- Periodically update seagrass habitat maps.

Progress

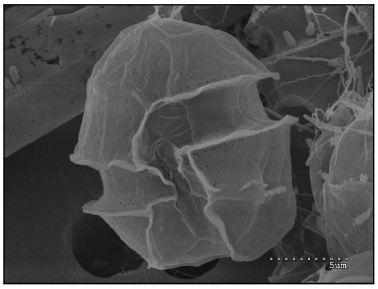
- 2020-21 was the seventh summer sampling season completed and the first year applying a modified design in response to a review of approaches.
- Sampling site area was expanded to better account for local-scale variability in seagrass condition. The Dalkeith site was discontinued due to high levels of watercraft impact.
- At Rocky Bay, seagrass presence and percent cover were 60% and 43% of the historical average, respectively. While some of this decline could reflect methodological change, it should also be noted that this site was the most heavily impacted by the February 2017 flood event.
- Percent cover increased at Pelican Point and Alfred Cove but changes are thought to reflect more expansive monthly quadrat sampling in the new sampling design and inclusion of slightly deeper areas at these sites.
- Results are being incorporated into a 5-year report on the waterway.

Management implications

- The new sampling design is considered to be more representative. However, care will need to be taken making comparisons to previously collected data.
- Seagrass performance is a management key performance indicator for the Swan Canning River Protection strategy and the Swan Estuary Marine Park. Monitoring of site-specific responses to environmental perturbation, showed that the Rocky Bay location is susceptible to high flow events, and the shallow Milyu and Alfred Cove sites are susceptible to heat impacts.

Future directions

- Finalise reporting on seagrass in the 5-year report on the waterway.
- Explore contemporary approaches to sediment sampling for indicators of stress.



Algal blooms: investigations and control

SP 2018-035

K Trayler, J Cosgrove, S Thompson, S Hoeksema

Context

Parts of the Swan and Canning Rivers are affected by algal blooms, with the species effecting blooms varying temporally and spatially. While most algal blooms are harmless, on occasion, toxic blooms occur that can be harmful to the rivers, wildlife and humans. The impact of these blooms on environmental and social values will depend on the type and severity of the bloom. Understanding the dynamics of algal blooms is important in determining their impact and approaches to their control. Regular monitoring of the Swan and Canning Rivers enables retrospective analyses of bloom events and adaptive approaches to in-river bloom management. Many approaches are promoted for managing algal blooms. Finding useful and applicable methods for managing blooms in the Swan and Canning Rivers requires a combination of desktop analyses, laboratory and field based trials. It is also important to consider the potential impact of control products on waterway values.

Aims

- To investigate harmful algal blooms and understand factors influencing their presence and toxicity.
- To test the products suitable for controlling algae in laboratory and field settings.
- To understand the risks associated with blooms and bloom control products.
- Refine tools that contribute to understanding algal blooms.

Progress

- Genetic analyses identified *Karlodinium armiger* as well as *Karlodinium veneficum* were present during a bloom event in 2021.
- Work is progressing to interpret patterns in the spatial and temporal extent of *Alexandrium* relative to water quality parameters using multivariate analyses. Harmful algae was detected at much lower densities in 2020-21 (maximum 225 cells/mL) compared with 2019-20 (maximum: 15,453 cells/mL).

Management implications

- This project has confirmed the first identification of *Karlodinium armiger* in Australia, previously known from the northwest Mediterranean. *Karlodinium armiger* is a harmful algae known to produce karmitoxins that may present an additional health risk to aquatic fauna. Algal monitoring will need to distinguish the different *Karlodinium* species and build an understanding of the relationship between observed densities of *K. armiger* and impacts on fish and shellfish.
- While lower levels of Alexandrium were detected in 2020-21 compared with 2019-20, there is a risk that this harmful algae will return at high levels in future spring and summer periods. Therefore management plans need to be in place to respond to its recurrence and potential seafood toxicity.

Future directions

- Quantify karmitoxin production by *Karlodinium armiger* and the risk it presents to fish in the Swan Canning.
- Gather further information on *Alexandrium* where possible, including mapping sediment cyst load, PST depuration rates and PST toxicity trials (impact on zooplankton and planktivores).
- Finalise multivariate analyses of patterns in *Alexandrium* spatial and temporal extent.

Investigating fish communities as an indicator of estuarine condition

SP 2018-033

K Trayler

Context

Fish communities exhibit predictable responses to ecosystem degradation and 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 worldwide to quantify the ecological health of rivers, lakes, estuaries and many other environments. This project applies a Fish Community Index (FCI) 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

- Undertake evaluation of the fish communities in the Swan Canning Riverpark for the purposes of applying the fish community index of estuarine condition and reporting.

Progress

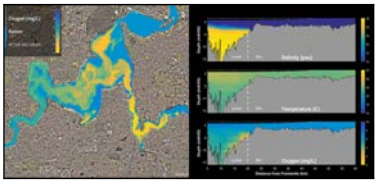
- Fish communities were sampled at 48 sites through February and April. Fish at each site were collected using either seine or gill nets, identified, counted and returned to the water alive.
- Species abundances in each sample were used to derive values for core metrics including the numbers, diversity, 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 indices and were used to calculate overall index score for each zone.
- A report and summary paper documenting the 2020 results were completed. The report translates index scores to quantify ecological health and results are reported as a conceptually simple letter grade.
- In 2020, the shallow nearshore areas and offshore waters were assessed as fair to good, overall. These results are consistent with the relatively stable trend in condition since 2011.
- Since 2016, the offshore waters of the Canning Estuary have scored poorly compared to other zones, receiving a D grade in 50 percent of monitored seasons.

Management implications

- The FCI considers the fish community as a whole and provides a means to assess how fish communities in shallow nearshore and deeper offshore waters respond to an array of stressors affecting the ecosystem.
- Monitoring of fish communities provides a basis for evaluation of the health of the Swan Canning Riverpark.
- DBCA is working with UWA and Murdoch University to apply the Swan Canning Estuary model in hindcasting water quality across the four zones over the past decade. This will help to discern factors influencing index scores in the Canning Estuary.

Future directions

- A report documenting the results of the 2021 sampling will be completed.
- Analyse data sets arising from the Swan Canning Estuary response model to evaluate patterns in fish communities between 2012 and 2020.



Model frameworks for estuarine reporting

SP 2018-027

K Trayler, J Cosgrove, S Hoeksema

Context

In the period spanning 2011-2016, the department and project partners at The University of Western Australia (UWA) and Department of Water and Environmental Regulation have resourced 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. 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 project explores the capacity of a predictive model framework to rationalise water quality monitoring data, display information in a near real-time format and enhance understanding of the waterway.

Aims

- Evaluate optimal water quality data requirements for predictive modelling of estuarine conditions.
- Develop a display showing near real-time data.
- Validate model forecasts and hindcasts.
- Apply model to enhance understanding of estuarine dynamics.

Progress

- The SCERM model was updated by UWA in 2020 and a revised model known as SCERM44 has been applied to supporting water quality improvement planning for the Swan Canning.

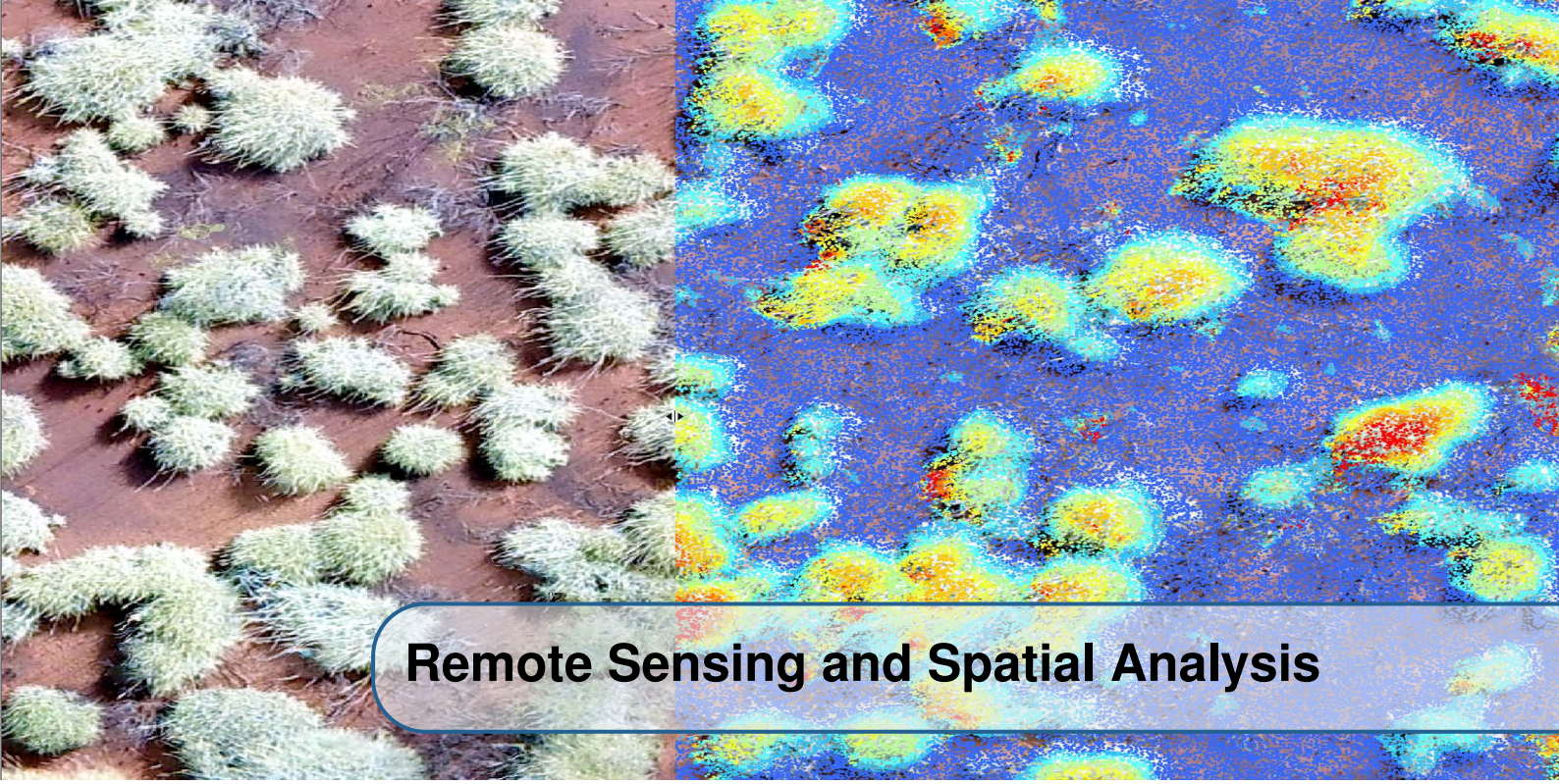
- The SCERM44 model shows greater accuracy in validation of water quality predictions as it applies inputs from 44 drainage inputs vs 8 in the earlier model - SCERMv3.
- Water quality outputs from the revised model have been requested to support comparison to biological datasets including fish communities, western school prawn distribution, invertebrates in the upper Swan, dolphin and fish movement.
- UWA has worked with DBCA to couple the SCERM44 estuary model with a catchment model to predict the impact of climate and land use change on nutrient loads and hydrological flows to 2050.

Management implications

- The Swan Canning Water Quality Improvement Plan (SCWQIP) is a critical document for management of the waterway, providing information that supports approaches to nutrient management on the landscape and underpinning planning. The plan will be updated based on the output of waterway and catchment modelling.

Future directions

- Utilise hindcast model outputs to correlate water quality and biological information and inform spatial and temporal patterns.
- Refine the model for water quality planning, focusing on catchments of most concern.



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 understanding natural processes and informing 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 data into a form where they directly assist 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.

Novel methods combining ground-based monitoring and remotely sensed observations to inform management and measurement of ecosystem condition in the rangelands

SP 2021-011

G Page, K Zdunic

Context

The mulga rangelands of the Midwest have experienced long-term degradation from the cumulative impact of 150 years of pastoral activity. Changing precipitation regimes and increasing temperatures threaten to further modify the trajectory of ecological condition in these ecosystems, with the impact of vegetation mortality and invasive species both likely to become more pronounced in future decades. However, while the extent of degradation is widely acknowledged, it is not known whether these ecosystems have the ecological capacity to naturally recover when agricultural grazing pressures are removed or how resilient they might be to future climatic extremes.

Aims

- Deliver new insights into the functioning of rangeland ecosystems in WA, and tools to undertake future monitoring and evaluation of these ecosystems.

- Develop a method to relate remote-sensing based measurement of ecosystem condition to on-ground monitoring datasets.
- Integrate new remote sensing technologies into assessments of rangeland condition and change detection.
- Determine the recovery potential of degraded rangeland ecosystems in Western Australia.

Progress

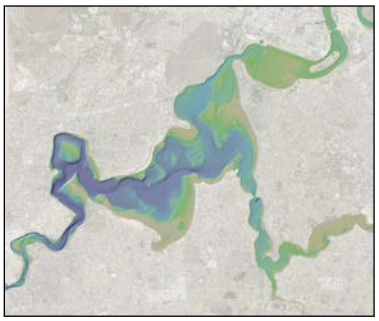
- Obtained the Western Australian rangeland monitoring system (WARMS) data for Boolardy and all DBCA managed properties.
- Visited Boolardy, Muralgarra and ex. Thundelarra to survey sites.
- Produced and currently refining annual dry-season woody perennial cover estimates using the Landsat archive (1988 – present).

Management implications

- Identifying the recovery potential of particular areas of the landscape should allow land managers to design targeted interventions in areas either most at risk of further degradation, or in places with the greatest potential to recover.
- Developing new remote-sensing based monitoring methods will allow more spatially comprehensive assessments of changes in vegetation condition than are currently practicable.

Future directions

- Collect on-ground validation data for vegetation cover mapping and collate infrastructure mapping.
- Finalise the cover mapping methodology and prepare a manuscript for publication.



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 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 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 create metadata for final spatial data sets developed by departmental activities and science collaborations, and migrate this data into Corporate GIS applications and the Spatial Data Library.

Progress

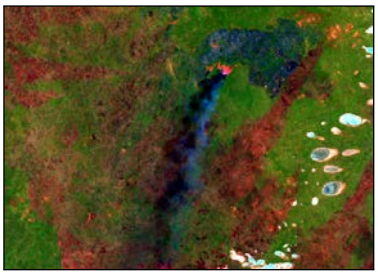
- Development of processes to make spatial data discoverable and accessible as DBCA moves data storage to a cloud environment.
- Copies of LiDAR data sets purchased by other state agencies were obtained and included for corporate use.
- Bathymetry data loggers were installed on three Kimberley vessels that will contribute data to a crowd sourcing bathymetry program run by Geoscience Australia's AusSeabed program.
- Frequently requested datasets, including mangrove and seagrass extents, have had metadata updates created and finalised timeseries products generated.
- Development and training in access and application of scripts to enable access and processing of satellite imagery maintained on the national computing infrastructure.

Management implications

- Terrestrial and marine spatial data of corporate value can be accessed internally using cloud-based platforms, and data that is of value to external stakeholders can be identified, documented and made available on portals such as DataWA.
- Updated state-owned LiDAR and other data reduces duplication and increases our capability in spatial modelling of soils, vegetation and habitats.
- Bathymetry data from regional patrols can now contribute to AusSeabed which will assist department staff in navigation, management and monitoring operations in Kimberley Marine Parks waters.
- 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.
- Access to the national computing infrastructure leverages super computing resources for departmental requirements.

Future directions

- Identify terrestrial and marine spatial data sets to be migrated to the corporate data menu.
- Continue to update satellite imagery, LiDAR and digital elevation model catalogues.
- Continue to develop scripts and functions to utilise satellite imagery on national computer infrastructure.
- Collaborate with Geoscience Australia's AusSeabed program to improving coastal bathymetry in the Kimberley.



Remote sensing and spatial analysis for fire management

CF 2018-074

J Chapman, P Rampant, K Zdunic, R Van Dongen

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 and includes optical and thermal imagery from airborne platforms. Research areas include historical mapping that utilises 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 of major bushfires. These activities 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, fire risk and fire severity 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 providing advice about 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.
- Progress prescribed burn reporting with fire severity model development.
- Provide remotely sensed spatial and temporal data streams to assist with bushfire investigations and reporting.

Progress

- Fire scar information relating to seasonality was provided to the 10 Deserts Project to identify potential research areas in the Western Desert region.
- Fire scar information for the Pilbara and Goldfields regions, Kanyirninpa Jukurrpa and Desert Support Services was supplied monthly and annually to inform and report on prescribed burning activities in the Western Desert and Pilbara regions.
- Support was provided for the operational use of thermal cameras to detect hotspots for burn security.
- Support was provided to regional/district fire managers for interpreting satellite derived burn severity products.
- Model development linking field measures of fire severity to satellite imagery was progressed.
- Development of processing scripts in R to effectively process fire history data.
- Provided data to Fire Management Services Branch to inform fire recovery, fire chronology and new satellite technology/availability.
- Collection of remote piloted aircraft imagery field data and commenced processing for spinifex satellite fuel cover model.
- Updated the fire history over the Great Victoria Desert to 2020 and undertook statistical analysis of the fire regimes in management areas.

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.
- Effectively processing the DBCA fire history data provides quantitative and current statistics on fire frequency, number of repeat fires and fire interval.
- Consistent production and attribution of monthly fire scar mapping have 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.
- Delivery of thermal imagery hotspots to on-ground staff improves the security of burns.
- Satellite derived spinifex fuel cover maps enable regional fire activities to be more targeted, efficient and safe in their fuel reduction activities.

Future directions

- Further development of spinifex fuel cover from satellite imagery with greater field data inputs across the State.
- Continue testing and finalise fire severity model.
- 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 spatial analysis of fire patterns and fuel loads.

Spatial analysis and modelling

SP 2018-073

J Kinloch, K Zdunic, G Loewenthal, 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 is also undertaken by 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.
- Develop and utilise 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

- 2020 vegetation complex statistics and terrestrial lands reports were produced and a forecast report completed on lands proposed for conservation under Plan for Our Parks.
- Finalised spatial inputs into mammal species distribution models (SDM) and provided advice on the development of a species distribution model for the floodplain goanna (*Varanus panoptes).*
- Completed multi-criteria analysis of the ecological value of wetlands applied to the Moora west region.
- Completed a spatial evaluation of conservation values on freehold land to support the identification of land for purchase with offset funds.
- Undertook a broad assessment of threatened flora, fauna and ecological communities and a number of threatening processes for conservation management units in three DBCA regions.
- Assessment of historical fire extent, using NOAA satellite derived burnt area data to reconstruct a 100-year fire magnitude history in two catchments in the tropical savannas.
- Further development of spatial metrics describing threatening processes, particularly fragmentation, that impact on threatened and priority flora, that was included in a paper published in *Biological Journal of the Linnean Society*.
- Spatial modelling to support planning of feral herbivore removal programs was undertaken.
- Undertook spatial analysis aiding identification of properties that have the potential to be abstracting water from the Canning River, Southern River and major tributaries.

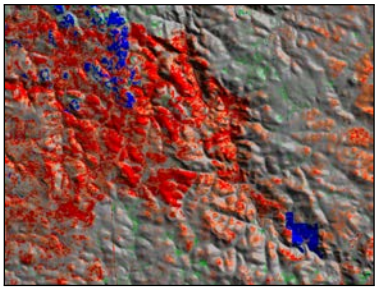
Management implications

- The department uses vegetation and protected areas statistics to assess development applications and, for the lands managed for conservation, report against aspects of the CAR (comprehensive, adequate, representative) principles.
- Species distribution models provide information on the likelihood of habitat for a species being present and are thus are critical for determining species conservation and management priorities and actions.
- Spatial evaluation of the conservation values of freehold lands contributes to shortlisting of freehold properties for on-ground assessment to inform DBCA land acquisition decisions.

- Information on the conservation values and threats present in each conservation management unit, contributes to the identification of funding and management priorities during the development of DBCA's Regional Conservation Plans.
- A 100-year reconstruction of fire will provide an understanding of the long-term fire regime in northern savannas including the impact of climate change.
- Spatial metrics of threat aid the evaluation of the vulnerability of threatened and priority flora to threatening processes.

Future directions

- Further develop landscape scale spatial metrics that assess conservation values and threats for the Conservation Plans being developed for each DBCA region.
- For the Cane Toad Coalition, develop a species distribution model for the floodplain goanna (*Varanus panoptes)* to enable potential source populations of the species to be identified for taste aversion training.
- Contribute to journal publications on the spatial distribution of threats to flora in the Wheatbelt and other areas of the south-west of Western Australia.
- Undertake spatial analysis of fire regimes in conservation areas of the Kimberley to assess the effectiveness of current prescribed burning practices.
- Apply developed multi criteria evaluation of the ecological value of wetlands to south-west Western Australia.
- Identify potential barriers to water flows to the Swan Canning River by examining where primary drainage lines intersect with linear infrastructure, abstraction points and gauging stations.



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; 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 the department can use for reporting on the State of the Environment, managing the conservation estate and assess the threats to biodiversity.

Aims

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

Progress

- 30 year mangrove time-series products have been processed using analysis ready Landsat and Sentinel 2 satellite imagery for Lalang-garram Marine Park reporting.
- Statistics and maps were provided to aid selection of monitoring sites in banksia and wandoo woodland.
- Millstream Chichester National Park riparian vegetation monitoring was continued.

- Developed a method for detecting exposed intertidal seagrass extent from remotely piloted aircraft ground truthing in collaboration with Yawuru Traditional Owners using 2020 Sentinel 2 satellite imagery.
- Shark Bay seagrass data sets and associated habitat mapping and R scripts for creating sea surface temperature metrics, were packaged up with metadata and made publicly available.
- Wetland inundation and hydroperiod analysis for various wetlands throughout the state was undertaken utilising satellite imagery.
- South west wetland monitoring program data reanalysis is underway, including application of a novel method for handling gaps in Landsat 7 data.
- Real-time kinematic remote piloted aircraft image processing workflow for Ramsar and other wetland fringing vegetation is under development.
- Benger swamps remote piloted aircraft data capture and analysis commenced for bittern habitat.
- Undertook survey and remote piloted aircraft data capture of known populations of critically endangered *Grevillea acropogon* in the Warren District.
- Undertook remote piloted imagery capture of known locations vegetation decline in the Fitzgerald River National Park and satellite imagery analysis.

Management implications

- An exposed intertidal seagrass extent product will facilitate annual reporting on intertidal seagrass for the first time in the Kimberley.
- Wetland inundation and hydroperiod analysis provides information to understand the status and conservation significance of wetlands especially those remotely located.
- Evaluation of wetland characteristics informing locations of suitable habitat for threatened species. Consistent production and attribution of monthly fire scar mapping have 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.
- Real-time kinematic remote piloted aircraft image processing workflows will enable repeatable analysis and the development of a framework for vegetation monitoring.
- Vegetation monitoring across various environments including mangroves, riparian zones, rangelands and forests, provides quantitative information for assessing vegetation changes and informs management actions.

Future directions

- Provide inputs to Forest Management Plan reporting, including whole of forest condition and threatened ecological community statistics.
- Continue research into forest condition with a focus on the effect of silviculture treatments on resilience.
- Develop and implement a vegetation monitoring and reporting program for Lake Bryde.
- Continue to explore and develop cloud processing options with Geoscience Australia.
- Develop and refine the use of remotely piloted aircraft imagery for vegetation monitoring and mapping.
- Apply mangrove monitoring methodology through remote piloted aircraft ground truthing and satellite imagery upscaling in Roebuck Bay/Yawuru and 80 Mile Beach Marine Parks, and test the accuracy of the products developed for Lalang-garram Marine Park.
- Apply exposed intertidal seagrass methods to Sentinel 2 imagery from 2017 to 2021 at Roebuck Bay/ Yawuru for annual reporting.
- Develop wetland habitat modelling application for bitterns in Benger Swamp.

Dirk Hartog Island vegetation monitoring

SP 2018-009

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

- Locations ranging from heavy to slight buffel grass coverage were photographed in 2015, these sites were recaptured in May 2021. Analysis of this data is ongoing.
- Vegetation cover change across the island was analysed with 39 percent experiencing a significant increase since destocking.
- Monitoring of the area of sand dune on the island has shown a dramatic decrease by approximately 833 hectares in the period 2009 to 2020.
- A paper regarding the use of remote piloted aircraft data to monitor changes at the nine mammal exclusion plots is nearing completion.

Management implications

- Results from the program demonstrate the benefit of the eradication program and provide 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 vegetation monitoring using Landsat imagery and carry out field validation of vegetation change.
- Update sand dune area movement monitoring.
- Report on changes to buffel grass extent over the period 2015 to 2021.

Species and Communities

Program Leader: Ruth Harvey 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 and 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: conservation of threatened fauna, flora and ecological communities conservation; fauna and flora management; wetlands conservation and off-reserve conservation. It administers the departmental Animal Ethics Committee and provides support to the Threatened Species Scientific Committee and the Threatened Ecological Communities Scientific Committee.

Wetland conservation

CF 2018-067

M Coote, F Felton, A Jones

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 and assists in delivery of the Ramsar goal of the 'wise use of all wetlands' in the State. Maintaining wetland inventory across the State allows the department to provide accurate technical and scientific advice on values and impacts to 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

- A new wetland mapping data set has been developed in collaboration with the Department of Water and Environmental Regulation. The data set has undergone extensive internal review across collaborating agencies and external review from research institutions and non-government scientists.
- Workshops were held to complete assessments of the vulnerability of the Muir-Byenup System and the Peel-Yalgorup Ramsar sites to climate change in collaboration with stakeholder groups.
- Climate change response strategies are being considered in the development of adaptation plans for the Muir-Byenup System and Peel-Yalgorup Ramsar sites.
- Review of the ecological character description and limits of acceptable change was progressed for the Peel-Yalgorup Ramsar site.
- Revisions of the Ramsar Information Sheets have been drafted or finalised for eight of the twelve Ramsar sites in WA.
- Seven requests to modify the *Geomorphic Wetlands Swan Coastal Plain* data set were processed.
- Technical advice was provided to departmental staff, other state and commonwealth agencies, land owners and their consultants for 48 land use planning issues.
- The *Healthy Wetland Habitats* program continued to assist 7 landholders to manage wetlands with conservation value on their properties, with 25 landowners now completed their voluntary management agreements.

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 climate change adaptation plans for the Muir-Byenup System and the Peel-Yalgorup Ramsar sites will facilitate a response strategy to major impacts of climate change.
- Management and land use planning advice will assist in the greater protection and management of wetlands.
- Ongoing involvement of private land managers in the *Healthy Wetland Habitats* program increases awareness of wetlands values, threatening process and best practice management of wetlands.
- Updated wetland mapping is a basis for informed decisions on conservation and management.

Future directions

- Review and maintain wetland mapping for Western Australia in order to identify high ecological value wetlands conservation and inform impact assessment decisions.
- Revision of documentation for the 12 sites listed under the International Ramsar Convention on Wetlands
- Analysis of results from biological surveys of Lake Carnegie will be finalised.
- Technical advice on wetland values will continue to be provided using current wetland mapping information for impact assessment of clearing, mining and other development applications.

Ecological communities conservation and recovery

CF 2018-066

V English, R Luu, J Pryde, P Robertson

Context

The ecological communities team collates and manages biodiversity information, and provides a range of science-based support and advice 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 evidence-based 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 is available within and outside of the department.
- Provide technical advice for 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 provisions of the *Biodiversity Conservation Act 2016* (BC Act) that relate to TECs.

Progress

- As of 30 June 2021, 65 extant ecological communities were listed under the Western Australian Environmentally Sensitive Areas list in policy (20 critically endangered, 17 endangered and 28 vulnerable), and four listed as collapsed. Another 391 ecological communities were on the PEC list.
- Three meetings of the Threatened Ecological Community Scientific Committee (TECSC) were held and Ministerial Guideline 4 (TEC listing procedures and criteria) was revised and approved by the Minister.
- Expert advice was provided to develop and rank targeted actions for the recovery of TECs and PECs across seven department regions to inform the revision of regional conservation plans.
- Evaluation of threat rank for 39 ecological communities was revised and updated, in preparation for consideration for listing under the BC Act.
- Nominations were developed for three collapsed ecological communities.
- New occurrence information was added and edits to existing spatial information on the TEC and PEC database was completed for 261 TEC and PEC occurrences distributed across the State.
- On-ground survey was undertaken for 79 occurrences of TECs and PECs throughout the State to support conservation decision making.
- Twenty-three TEC fact sheets including description, indigenous interests and threatening processes were prepared and placed on the department's website.
- Fire response and fire risk information for TECs and PECs based on 14 risk factors and best practice fire management was also compiled for 65 TECs. Basic fire response information was compiled for 391 PECs.
- Support and specialist input were provided and meetings attended for the Threatened Flora and Ecological Communities Recovery Teams in the Swan and Warren Regions, the Albany, Esperance, Central Wheatbelt and Geraldton Districts.
- Environmental impact assessment advice was provided in relation to 85 clearing permit applications, land use planning, mining and development proposals to improve conservation outcomes for 35 TECs and 11 PECs across the state.
- Current TEC and PEC locational data was provided in response to 451 requests from a range of stakeholders to help ensure up to date information was available for proposal documents. Specialist TEC or PEC advice was also provided with many of these requests.
- Five assessments for applications to modify a TEC in anticipation of listing under the BC Act were completed.

- Two reports were completed for 1600 hectares of land in the Swan and Midwest Regions including five TECs on nine areas of private land for potential areas for consideration for inclusion in the reserve system.
- Instruction and training were provided to 20 University of Western Australia Master of Biological Science students and resulted in evaluation and improved mapping of seven areas of banksia woodland TEC.
- Detailed technical information and advice were provided about TECs and PECs to support proposed boundaries for 29 new reserves proposed under Western Australia Governments Plan for our Parks proposals.

Management implications

- Maintenance of up to date data on the TEC and PEC database assists in resolving the threat status of ecological communities.
- Enhanced data sets for TECs and PECs facilitate improved environmental impact assessments, land use planning, and conservation management.
- Listing of TECs under the *Biodiversity Conservation Act 2016* provides them with increased legislative protection.
- Inclusion of ecological communities on the Priority ecological community list identifies them as requiring investigation to clarify status and threats.
- Recovery plans and management advice support the department and other land managers in maintaining the conservation values of TECs and PECs.
- TEC and PEC data and advice support determinations of priority areas for reservation.

Future directions

- Continue to improve TEC and PEC data.
- Continue to provide data and advice for the protection, conservation and management of TECs and PECs.
- Continue to review and provide advice about the proposed TSC database so that it becomes fit for purpose.
- Continue to support the TECSC. Prepare nominations for the TECSC for high priority ecological communities.
- Update TEC fact sheets as required including description, indigenous interests and threatening processes and place on the department's website.
- Continue to develop standard procedures and thresholds for 'modification' of TECs, and process applications to modify TECs under the BC Act.

Off-reserve conservation

CF 2018-061

M Hunter, C Kemp, G Stack

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 (LFW) program is a voluntary, non-binding scheme that provides advice for registered land managers to assist in managing their land to support biodiversity conservation values. The program is being delivered through a partnership with Natural Resource Management (NRM) Western Australia regional organisations. 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

- Administer the Nature Conservation Covenant program for both conditional and voluntary covenant programs.
- Increase community awareness of biodiversity conservation and promote the department's biodiversity conservation activities through Land for Wildlife.
- Integrate science knowledge into technical biodiversity management advice.
- Improve conservation management on lands not managed primarily for nature conservation.

Progress

- Sixty eight landowners applied for registration with Land for Wildlife during 2020/21. A total of 1,972 properties are currently registered, supporting 1,046,069 hectares of bushland managed for conservation.
- Twenty three property assessments were undertaken for LFW by NRM partners, and eight by the departmental coordinator during the year. Twenty-five properties were added to the program as members and six were deemed unsuitable.
- There were 3 voluntary and 18 conditional enquiries received from landholders regarding conservation covenants, which led to 3 new covenants currently being negotiated.
- Advice was provided to landowners, local government and departmental planning staff on land use planning matters relating to covenants.
- There were 48 changes of ownership of covenanted land and contact was made with new landholders to welcome them into the *Conservation Covenant Program*.
- Collaboration continues with the National Trust of Western Australia (NTWA) and the Department of Primary Industries and Regional Development (DPIRD) covenant programs.

Management implications

- Off-reserve conservation plays an important role in the conservation of the State's biodiversity. Many threatened species and ecological communities occur on land not managed by the department. 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 State.
- Covenants provide protection in perpetuity for biodiversity values on private land.
- Covenants contribute to Australia's National Reserve System through IUCN Management Category IV.

Future directions

- Finalise compliance policy for administration of Biodiversity Conservation Covenants under the *Biodiversity Conservation Act 2016.*
- Continue to administer conditional and voluntary covenants.
- Incorporate remote sensing to monitor covenants.
- Collaborate in stewardship of NTWA and DPIRD administered covenants.
- Continue to administer the Land for Wildlife program.

Flora conservation and recovery

CF 2018-057

M Smith, C Bourke, T Llorens, J Donaldson, K Griffiths, R Rees, S Foster

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 (TPFL) database 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.
- Administer a data provision service to ensure threatened and priority flora data is available within and outside of the department.
- Update records for threatened and priority flora as additional information becomes available.
- Contribute to the assessment of environmental impacts on flora conservation values for development and vegetation clearing proposals in accordance with relevant policy and legislation.
- Review applications for Ministerial authorisations to take threatened flora against acceptable levels of risk to the conservation of threatened flora and issue authorisations in a timely manner.
- Guide strategic and coordinated recovery programs for threatened flora.
- Undertake assessments of conservation status and prepare nominations for the TSSC, as required.
- Develop, inform and influence policy and strategic direction relating to native flora.

Progress

- 209 threatened flora authorisations were issued. Of these, 62 were issued for herbarium specimen collections for identification purposes, 13 for scientific/research purposes and 134 for land management and operational purposes.
- 1433 new records were added to the TPFL database, of which 248 were records of new populations.
- A total of 538 data search requests for threatened and priority flora were processed (34 DBCA, 106 other government departments, 377 consultants/mining sector, and 21 other organisations).
- Conservation status assessments resulted in 29 additions to the priority flora list, change in category of 10 taxa, and delisting of 7 taxa after survey and taxonomic review clarified their conservation status.
- 4 nominations for threatened flora were received in 2020/2021 and are currently under review for addition to the threatened flora list.
- A project was commenced to conduct status reviews for 125 threatened flora species that are currently listed under the *Biodiversity Conservation Act 2016* (BC Act) using superseded criteria. So far, reviews against the current IUCN Red List v3.1 criteria have been prepared for 47 species and 2 species with reviews have had nominations prepared for the TSSC, due to taxonomic changes.
- Conservation status was reviewed for taxa described in 5 draft *Nuytsia* manuscripts.
- Two translocation proposals were approved, 1 internal (for 22 species) and 1 external.
- Impact assessment advice was provided in relation to 56 clearing permit applications, 30 mining or other development projects and 12 land use planning proposals with the potential to affect threatened and priority flora.
- Advice provided on flora licenses for priority flora, bio-prospecting licenses and on issues relating to the management of the Western Australian flora industry.
- Processes and procedures for issuing threatened flora authorisations for bushfire mitigation activities reviewed and revised as required for both internal and external stakeholders.
- Provided support to the Albany District and South West, Swan and Goldfields regions threatened flora recovery team meetings.
- Participated on the national working group for implementing the MoU on a Common Assessment Method and single operational list of threatened species. Two flora species were endorsed by the Federal Minister for formal listing under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).
- Liaison continued with the Commonwealth Department of Agriculture, Water and the Environment (DAWE) regarding the systematic review of species listings under the EPBC Act and the requirement for recovery plans. Advice was provided for 53 flora species.
- Nineteen draft conservation advice documents, prepared by DAWE were reviewed and updated.
- Provided input, advice and edits on 15 threatened flora species' profiles for the National Action Plan for Australia's Most Imperilled Plants.

- Provided comments and factual corrections to the draft 2020 IUCN conservation outlook assessment for the Purnululu National Park World Heritage Site.

Management implications

- Enhanced data sets, and data management systems, and more accurate and comprehensive lists of threatened and priority flora, facilitate improved assessment and conservation.
- Addition of new TPFL records assist in resolving the status of flora and provides more reliable 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 in conserving threatened and priority flora.
- Management programs, threatened flora recovery plans, threatened species profiles and conservation advice documents guide conservation outcomes.
- Provision of expert technical input to 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 flora in an efficient manner.
- Continue to assess the conservation status of native flora and prepare nominations for listing and recovery plans where necessary.
- Prepare high quality technical flora advice to internal and external stakeholders as required.
- Transition to the new Threatened Species and Communities database and ensure high quality data is maintained and shared.
- Continue issuing Ministerial authorisations and ensure processes and guidelines are in place as required.

Fauna conservation and recovery

CF 2018-040

J Renwick, M Davies, K Bain, A Mutton, T Johnston, A Robey, B Richards

Context

The fauna conservation team provides a range of science based support for fauna conservation and recovery. The team coordinates recovery programs and provides advice and input to recovery programs for threatened fauna, coordinates recovery programs, including developing recovery plans, supporting recovery teams, administering strategic translocation planning and other conservation activities. The team oversees the capture, collation, and interpretation of threatened and priority fauna records. Maintaining 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. The Threatened Species Scientific Committee (TSSC) administers the department's Animal Ethics Committee (AEC) to manage requirements for ethical consideration of animals in departmental research and management 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 presence and distribution of threatened and priority fauna.
- Provide a data provision service to ensure threatened and priority fauna data is 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 where appropriate, prepare nominations for the consideration of the TSSC.
- Inform policy and strategic direction relating to fauna.
- Assess applications for Ministerial authorisations to take or disturb threatened fauna under section 40 of the *Biodiversity Conservation Act 2016*, (BC Act) to ensure authorised activities do not cause unacceptable risks to the conservation of threatened species biodiversity.
- 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

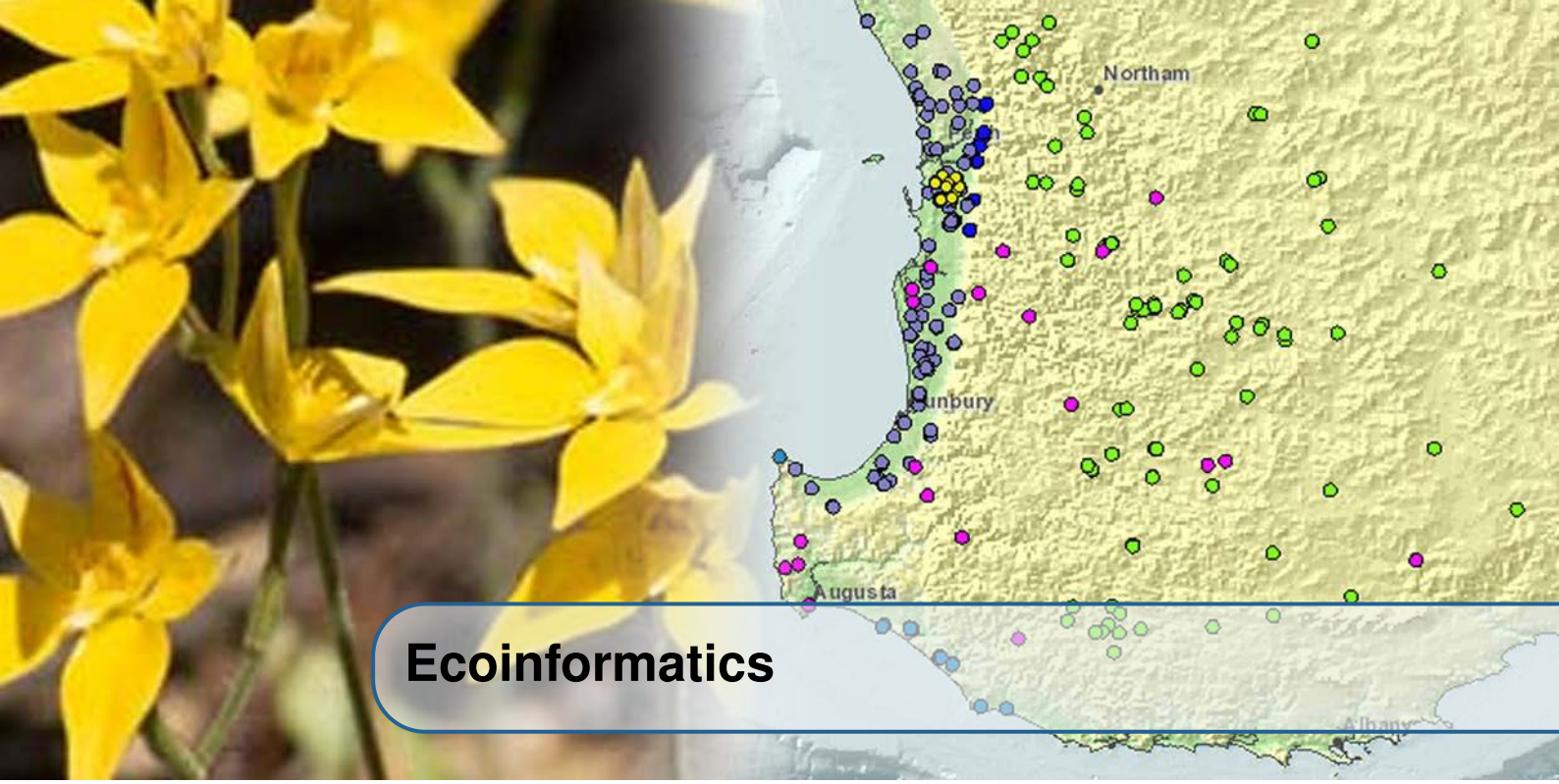
- As at 31 July 2021, under the BC Act, a total of 249 fauna species were listed as threatened species (57 as critically endangered, 58 as endangered and 134 as vulnerable), 23 as extinct species, and 88 as specially protected species (seven conservation dependent, seven other specially protected and 74 migratory species). There were 219 species on the department's priority fauna list.
- A total of 339 new records of sightings, captures or evidence of threatened and priority fauna occurrences were added to the Threatened and Priority Fauna database.
- Two hundred and twenty one Ministerial authorisations to take or disturb threatened fauna under section 40 of the BC Act were assessed and granted. Continue to progress development of processes and systems to support Ministerial authorisation approvals.
- Advice and support were provided to internal and external stakeholders on recovery actions for threatened species and land management activities to support conservation, including advice on national recovery plans.
- Advice and support were provided to 17 state fauna recovery teams to ensure continued conservation and appropriate management for threatened species. Advice was provided to national recovery teams for mala, malleefowl and bilby.
- Support and advice was provided to internal and external stakeholders on wildlife health, and continued to contribute to the State and national wildlife health committees. Four disease investigation projects were undertaken for black and white bird deaths, quenda mange, yellow fungal disease in shingleback lizards and canine ehrlichiosis.
- Supported Wildlife Protection Branch by providing expert technical advice on applications for fauna licences under the *Biodiversity Conservation Regulations 2018*.
- Provided advice and reviewed proposals for intra- and interstate translocation and captive-bred releases of threatened fauna species including dibblers, numbats, western swamp tortoises, greater stick-nest rats, western ground parrots, woylies, boodies and Shark Bay mouse.
- The AEC met seven times, conducted a total of 302 assessments, approved 11 new projects and approved the renewal of 38 projects. There were 128 active projects that covered fauna monitoring, general fauna research, translocations, fauna surveys, education, feral animal control research and marine research.

Management implications

- Enhanced data sets, and data management systems, and more accurate and comprehensive lists of threatened and priority fauna, facilitate improved assessment and conservation.
- Updates to the threatened fauna database assists in supporting nominations and reviews of 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 and 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.
- Threatened fauna recovery plans and teams guide conservation outcomes.
- Provision of input into environmental impact assessment and land use planning processes maximises the potential for positive conservation outcomes.

Future directions

- Continue to deliver strategic direction on and coordination of the conservation, management, protection and recovery of fauna in an efficient and effective manner.
- Implement the new threatened species and communities database and ensure high quality data is maintained and shared.
- Prepare fauna advice within requested time frames.
- Continue to ensure that the correct processes and advice are in place for the department to meet its requirements under the *Animal Welfare Act 2002*.
- Continue to implement the BC Act, through issuing of Ministerial Authorisations and processes and guidelines are in place as required.



Ecoinformatics

Program Leader: Julian Tonti-Filippini The Ecoinformatics Unit manages the digital biodiversity assets of Biodiversity and Conservation Science. It maintains the online portal *NatureMap* that publishes maps, lists and data sets of Western Australian species. The unit collaborates on projects involving complex information management and analysis, such as identifying broad-scale patterns of plant biodiversity. 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

J Tonti-Filippini, 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, 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 they are 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

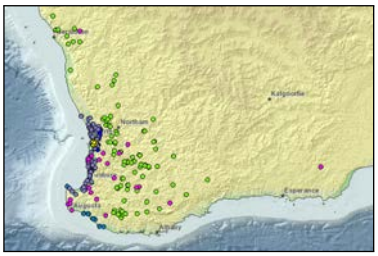
- Data held in BioSys was maintained.
- Documentation for BioSys was updated.

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 of 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.

Future directions

- Requirement for a data repository will be reviewed when the Biodiversity Information Office data system is available.



Online GIS biodiversity mapping (*NatureMap*)

CF 2011-106

J Tonti-Filippini

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

- NatureMap functionality was maintained providing users with access to biodiversity data.

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

- Functionality provided by *NatureMap* will be incorporated into the Biodiversity Information Office data system.

External Partnerships

Partners	Project Title	External Funding	Departmental Involvement
	Karri forest fuel dynamics		V Densmore, A Wills, S Samson
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, L Gibson
Atlas Iron, Main Roads Western Australia	Ecology and management of the Pilbara olive python	$125,000	D Pearson, L Gibson, M Cowan
Atlas Iron, Rio Tinto, BHP, Kanyirninpa Jukurrpa, BatCall WA	Ecology and management of the Pilbara leaf-nosed bat	$320,000	L Gibson, K Ottewell, L Umbrello
AusSeaBed Geoscience Australia	Facilitating collaborations between AusSeabed and Kimberley Region marine operations by crowd sourcing bathymetry to improve national bathymetry data	Nil	K Murray, W Robbins, K Zdunic
Australian Biological Resources Study, Queensland Herbarium, Northern Territory Herbarium, University of the Western Cape (South Africa)	Towards an eFlora treatment of *Tephrosia* (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	T Tucker, S Whiting
Australian Research Council, Australian National University, University of Adelaide, Australian Museum, Western Australian Museum	Island genomes: enhancing management of Australia's threatened mammals	$460,000	K Ottewell, M Byrne

Partners	Project Title	External Funding	Departmental Involvement
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
Australian Research Council, Charles Darwin University, Save the Gouldian Fund, Ballanggarra 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, Flinders University, CSIRO, The University of Western Australia	Optimising seed sourcing for effective ecological restoration	$460,000	S Krauss, D Merritt
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 *Banksia* 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 Western Sydney, Murdoch University	Do hotter and drier regions harbour adaptive variation for climate change	$281,505	M Byrne, R Mazanec
BHP Iron Ore Pty Ltd	Spatial and temporal analysis of ghost bat populations in the Pilbara using non-invasive sampling methodologies: Towards a robust genetic monitoring protocol	$190,000	K Ottewell, R Sun, D Prada, S McArthur
BHP, CyMod Systems, Australian Nuclear Science and Technology Organisation	Hydrogeochemistry of Walyarta Springs	$120,000	J Rutherford
BHP, Department of Primary Industries and Regional Development, Department of Water and Environmental Regulation, Fortescue Metals Group, Precision Biomonitoring, Rio Tinto, Stantec	Redclaw crayfish impact assessment and eDNA detection tool	475000	A Pinder
Beyond fire frequency: understanding seasonal timing of fire for ecosystem management	Beyond fire frequency: understanding seasonal timing of fire for ecosystem management	$453,000	B Miller, C Yates, K Ruthrof
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
BioPlatforms Australia: Threatened Species Initiative	Threatened Species Initiative	N/A	K Ottewell
Biologic Environmental Survey Pty Ltd	Developing and refining microclimate spatial layers for the Pilbara IBRA region to identify refugia for terrestrial mammals	Nil	K Ottewell, J Kinloch, B Huntley
BirdLife Western Australia	Conservation of the threatened Australasian bittern in southwestern Australia	Nil	A Burbidge, A Pinder, S Comer, A Clarke, A Barrett, C Taylor, K Williams
Bushfire and Natural Hazards CRC	Bushfire and Natural Hazards CRC	Nil	L Mccaw
CSIRO Future Science Fellowships in Environomics	Lifespan estimation in marine turtles using genomic promoter CpG density	$310,000	T Tucker, S Whiting
CSIRO, Australian SuperSite Network, Terrestrial Ecosystem Research Network, National Research Infrastructure for Australia	Great Western Woodlands SuperSite	Nil	C Gosper
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

Partners	Project Title	External Funding	Departmental Involvement
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 (*Pezoporus occidentalis*) using GIS and ecological modelling	$38,000	A Burbidge
CSIRO, The University of Western Australia	Marine turtle stable isotopes	Nil	T Tucker, S Whiting
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
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 - 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	C Sims, J Angus, S Garretson, L Gibson
Cooperative Research Centre for Honey Bee Products, University of Adelaide, Dijilarup Manuka Pty Ltd, Spring Gully Foods	Understanding the genetic diversity of native *Leptospermum* 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
Curtin University, The University of Western Australia, University of Queensland, Victoria University of Wellington	Development of a geo-ecological reef carbonate system model to understand responses of reefs and reef-fronted shorelines to climate change	Nil	C Ross, R Evans
Curtin University, Trend Laboratory	Detection and identification of dugong through seawater eDNA	$40,000	W Robbins

Partners	Project Title	External Funding	Departmental Involvement
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
Dambimangari Wanjina-Wunggurr Aboriginal Corporation, Bardi and Jawi Niimidiman Aboriginal Corporation	Benthic biodiversity surveys of intertidal *wooddooroo* (coral reefs) in the Lalang-garram, North Kimberley and proposed Buccaneer marine parks	$214,500	W Robbins, T Holmes
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, T Erickson
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	$160,000	G McGrath, J Rutherford, 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 Environment Regulation	Geographe Bay Seagrass Satellite Mapping	$60,000	S Bell, K Murray
Department of Water and Environmental Regulation, Water Corporation	Millstream riparian vegetation monitoring	$2,000	B Huntley
Department of Water and Environmental Regulation	Improving wetland mapping data sets for Western Australia	$208,800	M Coote, F Felton, K Zdunic, G Loewenthal, A Turnbull
Department of Water and Environmental Regulation	Swan Canning Estuary microplastics and plastics survey	$75,000	P Novak, K Trayler
Department of the Environment and Energy	Western Australian black spot biological survey campaign	$170,000	A Pinder, M Lyons, M Cowan
Duke University, Swedish University of Agricultural Sciences, University of Helsinki	Lifeplan: A Planetary Inventory of Life	30000	A Pinder, S Easton, A Barrett, K Quinlan, G Barrett, R Glowicki, M Brotherson
Ecological Horizons, Fortescue Metals Group, Roy Hill	Testing the efficiency and efficacy of Felixer feral cat grooming traps	$85,000	J Dunlop
European Centre for Medium Range Weather Forecasting, Reading, UK	Using machine learning to predict fire ignition occurrences from lightning forecasts	Nil	L Mccaw
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 Dziminski, F Carpenter

Partners	Project Title	External Funding	Departmental Involvement
Fremantle Ports	Fremantle Marine Quality Monitoring Program	$30,659	S Hoeksema, K Trayler
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
Global Coral Reef Monitoring Network	The Global Coral Reef Monitoring Network (GCRMN) Status of Coral Reefs of the World report	Nil	T Holmes, S Wilson, C Ross, J Goetze, W Robbins, L Peel, R Evans, M Moustaka
Great Victoria Desert Biodiversity Trust	Vegetation cover and fire attributes baseline for the Great Victoria Desert Landscape Conservation Initiative	$34,000	R Van Dongen, P Rampant, K Zdunic
Hanson Construction Materials	Restoring *Banksia* Woodland communities after mining	$25,000 pa	J Stevens, W Lewandrowski
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
Landgate	Western Australian State Government Data Catalogue	$12,000	F Mayer
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 (*Macrotis lagotis*) on the Dampier Peninsula, Kimberley	$600,000	M Dziminski, R McPhail, F Carpenter
Millennium Seed Bank, Australian Seed Bank Partnership, Department of the Environment and Energy	Seed collection, storage and biology	$12,000	A Crawford
Mineral Resources Ltd, The University of Western Australia	Integrated conservation and translocation of the threatened banded ironstone species *Tetratheca erubescens* (Elaeocarpaceae)	$997,000	J Stevens, B Miller, S Krauss, D Merritt, W Lewandrowski, C Elliott
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, S Hoeksema
Murdoch University	Swimming and diving performances of inter-nesting flatback turtles	$50,000	S Fossette-Halot, S Whiting, T 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

Partners	Project Title	External Funding	Departmental Involvement
Murdoch University	Genetic studies of Pilbara EPBC Act listed threatened vertebrate fauna	$235,000	D Pearson, 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	M Dziminski, R McPhail, F Carpenter
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 (*Passiflora foetida*)	$913,000	M Byrne, T Hopley
Office of Environment and Heritage (NSW)	Evaluating BioSys within the Office of Environment and Heritage (NSW) data environment	$150,000	J Tonti-Filippini
Rio Tinto, BHP	Seed collection zones for the Pilbara	$450,000	M Byrne, R Binks
Rio Tinto	Introduced predator control and baiting program - Yarraloola	$3,000,000	L Gibson, R Palmer, H Anderson
Rio Tinto	Identification botanist position at the Western Australian Herbarium	$120,000	J Huisman, S Dillon
Roy Hill, Atlas Iron, CSIRO, Pilbara Corridors, Rangelands NRM Western Australia, Pilbara Mesquite Management Committee	Strategic weed assessment of the Pilbara Bioregion	$350,000	M Byrne, R Binks
Royal Botanic Gardens - Kew, University of Portsmouth (UK)	The *Stylidium* phylogeny and pollination project	Nil	J Wege
SCORE-REEF	Spatio-temporal variability of coral reefs at the global scale: causalities, idiosyncrasies and implications for ecological indicators	Nil	S Wilson, T Holmes, J Goetze, C Ross
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
The University of Western Australia, National Marine Fisheries Service (USA), Northern Territory Museum, Western Australian Museum, Queensland Department of Environment and Science, Pendoley Environmental, Australia Government Department of Agriculture, Water and Environment	Skeletochronology and stable isotope analyses of flatback turtles	$400,000	T Tucker, S Whiting
The University of Western Australia	Sediment Geochemistry of Ashfield Flats Reserve	$14,850	G McGrath

Partners	Project Title	External Funding	Departmental Involvement
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	Influence of physiology on coral-based paleothermometry under varying temperature and light regimes	Nil	C Ross
University of Adelaide, Upsalla 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
University of British Columbia	Meta-analysis of macroalgae and turf algae on coral reefs in the Indian and Pacific Oceans	Nil	T Holmes, C Ross
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	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
University of Western Australia	Long-term monitoring of intertidal communities at limestone and granite reefs in Ngari Capes Marine Park	$5,000	B French
Victoria University of Wellington	Drivers of crustose coralline algae on coral reefs: direct and indirect effects of marine heatwaves	Nil	C Ross
Western Australian Museum	*NatureMap*: data sharing and joint custodianship	Nil	J Tonti-Filippini

Student Projects

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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	151
B Funnekotter, R Bunn	L Whelehan (PhD)	Prof R Mancera (Curtin University)	Characterisation of mitochondrial function in the cryopreservation of threatened flora	2019 – 2022	151
B Funnekotter, R Bunn	L Hardstaff (PhD)	Prof R Mancera (Curtin University)	Conservation of Australian rainforest plant species utilising cryopreservation	2018 – 2021	152
B Funnekotter, R Bunn	M Lukic (PhD)	Prof R Mancera (Curtin University)	Role of redox homeostasis in recovery from cryopreservation in *Arabidopsis thaliana*	2020 – 2023	152
R Bunn, B Funnekotter	L Hou (MSc)	Prof R Mancera (Curtin University)	Development of cryopreservation for the recalcitrant seeded Australian plants *Syzygium australe* and *S. paniculatum*	2020 – 2020	153
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	153
M Byrne	B Nordstrom (PhD)	A/Prof N Mitchell (The University of Western Australia), S Jarman (The University of Western Australia)	Assisted colonisation of the western swamp tortoise (*Pseudemydura umbrina*): the role of energy requirements in translocation decisions	2020 – 2024	153
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	154

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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)	*Reedia spathacea* F. Muell.: a study of phylogeography, population structure and co-occurrence	2016 – 2020	155
M Byrne	N Delnevo (PhD)	Dr E van Etten (Edith Cowan University), Prof W Stock (Edith Cowan University)	*Conospermum undulatum*: insights into genetics and ecology of an endangered species	2017 – 2020	155
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 – 2020	156
M Byrne, C Yates	L Monks (PhD)	Dr R Standish (The University of Western Australia)	Factors affecting the success of threatened flora translocations	2016 – 2020	156
J Cosgrove, K Trayler	M Jung (PhD)	Dr M Fraser (The University of Western Australia), Dr B Martin (The University of Western Australia)	Tracking seagrass condition: development and application of novel molecular biomarkers	2020 – 2023	157
S Cowen, C Sims	Dr F Knox (PhD)	Dr R Vaughan-Higgins (Murdoch University), A/Prof K Warren (Murdoch University)	Dirk Hartog Island fauna reintroductions disease risk analysis	2019 – 2022	157
S Cowen	R Quah (MSc)	Dr D White (University of Western Australia)	Conservation genetics and population modelling to secure wild populations of the Shark Bay mouse (*Pseudomys fieldi*)	2020 – 2021	157
S Cowen	R Stover (MSc)	Dr A Hopkins (Edith Cowan University), Dr R Davis (Edith Cowan University), Dr H Mills (The University of Western Australia)	Comparative analysis of diet in island populations of banded and rufous hare-wallabies in Shark Bay	2021 – 2022	158
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 – 2020	158
S Fossette-Halot	J Hounslow (PhD)	Dr A Gleiss (Murdoch University)	Ecology of flatback turtles (*Natator depressus*) at a coastal foraging ground, Western Australia	2019 – 2023	159
S Fossette-Halot, S Whiting	C Avenant (PhD)	A/Prof G Hyndes (Edith Cowan University)	Understanding predator-prey interactions between ghost crabs and marine turtles for better management of an endangered species	2019 – 2023	159
S Fossette-Halot	M Gammon (PhD)	A/Prof N Mitchell (The University of Western Australia), G McGrath	Predicting the vulnerability of flatback turtle rookeries to a changing climate	2018 – 2022	159
J Goetze	E 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	160

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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	160
J Hyde, S Thompson	E Stevens (MSc)	Dr L Beesley (The University of Western Australia), Dr D Gleeson (The University of Western Australia)	Environmental DNA as a tool to monitor fish movement in the Canning River	2021 – 2021	161
J Hyde, M Venarsky	B Scott (PhD)	Prof J Mitchell (Flinders University)	Environmental DNA detection in sediment from RAMSAR wetlands to indicate presence of species, past and present	2021 – 2024	161
J Hyde	E Dowley (MSc)	Dr D Gleeson (The University of Western Australia)	Mapping the distribution of *Hydromys chrysogaster* in the Southwest of Western Australia	2021 – 2022	161
S Krauss, J Stevens	B Mirfakhraei (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	162
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	162
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	163
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	163
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 – 2020	164
P Mawson	F Coiacetto (PhD)	A/Prof K Warren (Murdoch University)	Hindlimb paralysis syndrome in Carnaby's cockatoos	2015 – 2019	164
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	164
R Mazanec	S 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	165

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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 wildfire on the interactions among regenerating vegetation, fungi and small foraging marsupials in south-west Australia	2017 – 2020	165
G McGrath	K Staples (PhD)	Dr P Neville (Edith Cowan University / Department of Health)	Modelling mosquito development at Ashfield Flats	2020 – 2022	166
G McGrath	R Clohessy (BSc Honours)	Prof J Awange (Curtin University)	Evaluating satellite remote sensing of wetland water levels	2021 – 2022	166
G McGrath	L McCauley (MSc)	A/Prof S Thompson (The University of Western Australia), Dr G Skrzypek (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)	The dynamic demography of water ages our trees are using	2020 – 2020	167
G McGrath	J Barrett (MSc)	A/Prof M Leopold (The University of Western Australia)	Resistivity geophysics assessment of hyporheic exchange	2019 – 2020	167
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	167
B Miller	E Cowan (PhD)	Dr J Fontaine (Murdoch University), Dr R Standish (Murdoch University)	Assessing ecological resilience of post-mining restoration: testing fire recovery across a restoration chronosequence	2019 – 2022	168
B Miller, K Ruthrof	A Brace (PhD)	Dr A Hopkins (Edith Cowan University), Dr J Fontaine (Murdoch University)	Shifting soil fungal communities in response to fire and weed management in urban banksia woodlands	2019 – 2022	168
B Miller, D Merritt	R Miller (PhD)	Dr J Fontaine (Murdoch University), Prof N Enright (Murdoch University)	Ecologically tolerable fire regimes for key banksia woodland plant species	2015 – 2019	169
B Miller, D Merritt	R Tangney (PhD)		Fire intensity, seasonal variation and seeds traits may influence seed fates in banksia woodlands	2015 – 2020	169
K Ottewell	K Rick (PhD)	Dr N Mitchell (University of Western Australia)	Understanding patterns of phenotypic and genetic divergence in island mammals to improve conservation outcomes	2020 – 2023	170
K Ottewell, R Shaw	E Skey (BSc Honours)	Dr P Spencer (Murdoch University)	Landscape genomic analysis of three co-occurring small mammals in the Pilbara	2020 – 2020	170
A Pinder	K Webzell (PhD)	Dr J Chaplin (Murdoch University)	Can feathers be used to understand Australasian bittern populations?	2021 – 2021	171
A Pinder	M Rahman (PhD)	Dr J Chaplin (Murdoch University)	Taxonomy and evolutionary history of *Australocypris* giant ostracods from Australian salt lakes	2019 – 2022	171

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A Pinder	A Lawrie (PhD)	Dr J Chaplin (Murdoch University)	Taxonomy, ecology and evolutionary history of the salt lake gastropod *Coxiella*	2019 – 2022	172
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	172
I Radford	C Penton (PhD)	Dr L 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	173
C Ross	A Dixon (PhD)	Dr M Beger (University of Leeds)	Projecting combined thermal stress and tropical cyclone exposure on coral reefs	2019 – 2023	173
C Ross	E Haskin (MSc)	Dr J Prince, Dr M O'Leary	Coral recruitment at Ningaloo, Montebello Islands and Onslow	2021 – 2022	173
C Ross	J Walker (MSc)	R Hovey (UWA), Dr J Prince	Coral health and *Drupella cornus* at Rottnest Island, Western Australia	2020 – 2021	174
K Ruthrof	T Rasmussen (BSc Honours)	Dr J Fontaine (Murdoch University), Dr L Walden (Murdoch University)	Regeneration of canopy species following drought-induced die-off in the Northern Jarrah Forest	2020 – 2020	174
K Ruthrof, W Lewandrowski	N Anderson (BSc Honours)	Dr L Walden (Murdoch University), Dr J Fontaine (Murdoch University)	Effects of drought and wildfire on ecophysiological functioning in the Northern Jarrah Forest	2020 – 2020	175
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	175
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	175
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	176
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	176
K Trayler	N Stephens (PhD)	Dr K Warren (Murdoch University), Dr C Holyoake (Murdoch University), Dr P Duignan (University of Calgary)	Dolphin health - toxicogenomics and pathology investigations	2020 – 2022	177

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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	177
R Van Dongen, R Palmer	B Lkhagvasuren (MSc)	Dr T Robinson (Curtin University)	Improved species distribution models for feral cats in the Pilbara region using machine learning and behavioural change point analysis.	2021 – 2021	178
R Van Dongen	M Sage (PhD)	Dr T Robinson (Curtin University)	Dieback mapping in the Kalbarri National Park using satellite imagery.	2020 – 2020	178
K Waples, H Raudino	A D'Cruz (BSc Honours)	Dr C Salgado Kent (Edith Cowan University)	Home range, site fidelity and social structure of snubfin dolphins in Roebuck Bay, Western Australia	2020 – 2021	178
A Wayne	N Harrison (PhD)	A/Prof N Mitchell (The University of Western Australia), A/Prof B Pillips (University of Melbourne), A/Prof J Hemmi (University of Western Australia), Dr L Valentine (The University of Western Australia)	Quantifying the loss of antipredator traits in havened mammal populations and their relationship with population density and resource competition.	2021 – 2024	179
A Wayne	M Taylor (PhD)	Dr M Calver (Murdoch University), Dr K Bryant (Murdoch University), Dr N Armstrong (Murdoch University)	Survey methods and population estimates of the chuditch across its range	2020 – 2023	179
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	180
A Wayne	S Thorn (PhD)	A/Prof N Mitchell (The University of Western Australia), Dr R Firman (The University of Western Australia)	The population and spatial ecology of the numbat in the Upper Warren	2018 – 2021	180
A Wayne	A Seidlitz (PhD)	Dr M Calver (Murdoch University), 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	180
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	181
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	181

DBCA Officer	Student	Academic	Project Title	Duration	Page
S Wilson	D Ellis (PhD)	Dr C Fulton (Australian National University)	Habitat quality as a driver of epinepheline serranid productivity and replenishment	2018 – 2021	182
S Wilson	R Harris (MSc)	Dr C Fulton (Australian National University)	How does environmental disturbance effect macroalgal assemblages at Ningaloo	2019 – 2021	182

Student Project Reports

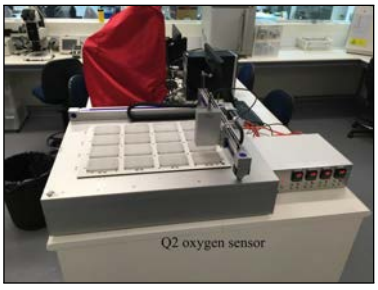
Ecology of the feral cat in coastal heaths of the south coast of Western Australia

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 project is investigating habitat use, movement, dietary preferences and prey availability in important conservation reserves of the region. In addition, the relationship of landscape fragmentation to these factors is being examined. The aim is to provide information essential to optimising the effectiveness of feral cat control programs in south coast ecosystems. Collection of stomach and tissue samples has been completed with further samples from south coast reserves added to the assemblage and analysed for dietary preferences.

Movement patterns have been modelled for all feral cats, with significant differences found in activity patterns and home range size across environmental gradients and fragmented and intact ecosystems. Resource selection data from fragmented landscapes have been used to design predator management for Bush Heritage's Fitz-Stirling feral cat control project. Prey preference data have indicated significant differences between reserves across the south coast, with native mammals the major preference in the eastern part of the region but less important in the west.



Characterisation of mitochondrial function in the cryopreservation of threatened flora

STP 2020-066

Scientist(s): B Funnekotter, R Bunn
Student: L Whelehan (PhD)
Academic(s): Prof R Mancera (Curtin University)

This project aims to examine the effects of cryopreservation on metabolism of plant tissues, with emphasis on mitochondrial function as these organelles are the primary sources of energy molecules (ATP) that drive all

cellular processes including the ability to recover from injury sustained to cells and tissues during the various steps of cryopreservation. A better understanding of the effects of cryogenic injury will enable better optimisation of cryopreservation for sensitive species, including many threatened taxa where ex situ storage remains a problem. Initial trials measuring oxygen consumption of Daucus carota cells have been completed on the Seahorse XF analyser at Curtin University. Follow-up experiments will test the viability of this method using respiratory inhibitors to determine specific parameters of mitochondrial function, which previously has not been attempted on terrestrial plant cells. Preparing for these experiments has included developing and maintaining *D. carota* and *Arabidopsis thaliana* liquid cell cultures and callus cultures, optimising cryopreservation protocols for *D. carota* cell cultures and developing a protocol for protoplast isolation. These species will be used to optimise methods to attempt the same with threatened species of native WA plants from the Kings Park tissue culture collection.


Araucaria bidwillii seeds (arrow) being extracted from seed cones

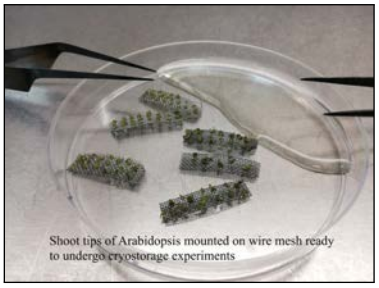
Conservation of Australian rainforest plant species utilising cryopreservation

STP 2020-065

Scientist(s): B Funnekotter, R Bunn
Student: L Hardstaff (PhD)
Academic(s): Prof R Mancera (Curtin University)

This project has focussed on developing novel cryopreservation protocols for a range of recalcitrant-seeded (i.e. unable to be desiccated or stored at low temperatures) Eastern Australian rainforest taxa where conventional ex situ seed storage is not possible.

Progress has been made on the development of cryopreservation of embryonic axes for *Araucaria bidwillii*, a threatened recalcitrant seeded species from eastern Australia. Development of cryopreservation of Macadamia species has progressed with survival of embryonic axes after liquid nitrogen (LN) immersion and further refinement of the protocol is continuing. Development of cryopreservation of another threatened rainforest species *Syzygium paniculatum* continues, with refinement of the encapsulation-desiccation (ED) protocol to allow shoot tip recovery after desiccation.


Shoot tips of Arabidopsis mounted on wire mesh ready to undergo cryostorage experiments

Role of redox homeostasis in recovery from cryopreservation in *Arabidopsis thaliana*

STP 2020-064

Scientist(s): B Funnekotter, R Bunn
Student: M Lukic (PhD)
Academic(s): Prof R Mancera (Curtin University)

This project examines the effects of oxidative stress on cryopreserved plant material, using the model species Arabidopsis thaliana, including mutant variants. Oxidative stress is a primary impediment to successful cryopreservation of plant material, and a better understanding of this will be a crucial step forward in designing more efficient cryopreservation protocols for ex-situ conservation of threatened plant species.

An optimised cryopreservation method for wild type A. thaliana was applied to vitamin C- and GSH-deficient mutant plants (vtc2-1, vtc2-4, pad2-1 and cad2). Visualisation of roGFP via Confocal microscopy confirmed redox changes in both the wild type and mutant plants after cryopreservation was consistent with the expected non-down effect of mutation for Vit C deficiency.

Development of cryopreservation for the recalcitrant seeded Australian plants *Syzygium australe* and *S. paniculatum*

STP 2020-063

Scientist(s): R Bunn, B Funnekotter
Student: L Hou (MSc)
Academic(s): Prof R Mancera (Curtin University)

Syzygium paniculatum and *Syzygium australe* are two rainforest species with recalcitrant seeds that are not storable by seed banking, with *S. paniculatum* currently threatened in its native habitat. The objective of this project is to develop a viable cryopreservation protocol for these species. Tissue cultured shoots offer an alternative explant source for cryopreservation and ex situ conservation of these and other threatened recalcitrant-seeded Australian species. Syzygium species have a strong tolerance to long incubation times in cryoprotective agents (CPAs) but exhibit a complete lack of survival following liquid nitrogen (LN) exposure, which could indicate that post-cryogenic failure is primarily due to either insufficient vitrification promotion and/or insufficient suppression of ice formation. This study on Syzygium cryopreservation is focussed on investigations using thermo-analytical assessments (differential scanning calorimetry) to measure the extent of ice formation in shoot tissues, permitting the differentiation between cell death by actual ice damage or other stress factors such as CPA toxicity and reactive oxygen species (ROS) damage.

Many shoot tips showed excessive browning after cryopreservation, indicating oxidative stress. Antioxidants, glutathione (GSH) and ascorbic acid (AsA), were tested and alleviated oxidative damage but did not improve shoot tip survival after cryopreservation.

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 (*Pezoporus occidentalis*) is an enigmatic 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. This project is now being done part time.

Progress has been made to improve software recognisers for recorded calls, and one paper has now been published. Analyses of historical occurrences, which will assist in planning future survey work, were published recently.

Assisted colonisation of the western swamp tortoise (*Pseudemydura umbrina*): the role of energy requirements in translocation decisions

STP 2020-061

Scientist(s): M Byrne
Student: B Nordstrom (PhD)
Academic(s): A/Prof N Mitchell (The University of Western Australia), S Jarman (The University of Western Australia)

The western swamp tortoise (*Pseudemydura umbrina*) is endemic to south-west Australia and occupies

seasonal wetlands where hydroperiods are shortening due to declining rainfall. Trial translocations 300-400 kilometres south of their current habitat began in 2016 to test whether *P. umbrina* can grow in cooler climates where hydroperiods are likely to be more suitable in the future. Such intentional translocations of a species outside its indigenous range to mitigate the effect of climate change is known as assisted colonisation. Results of the recent assisted colonisation trials were mixed, and suitable food availability was thought to be a key component of a successful short trial in the east Augusta region. The main aim of this research is to understand whether energy requirements of the western swamp tortoise can be met in cooler climates. This will be achieved by: 1) developing novel environmental DNA methods to detect the species and determine tortoises' diet in new habitats; 2) documenting foraging behaviour in a southern wetland in relation to water temperatures and prey availability; and 3) linking metabolic processes and food intake to predict long-term growth rates and reproduction of individuals released into new environments. This project will provide greater certainty on whether southern wetlands can provide viable habitat for this critically endangered species in the near future.

Candidate wetlands were evaluated in the East Augusta region in 2020, which resulted in the selection of release sites for the third western swamp tortoise assisted colonisation trial. Release sites were chosen based on water quality parameters and potential prey availability. The release will take place August 2021. Environmental DNA (eDNA) methods will be tested as a monitoring tool during the assisted colonisation trial. Western swamp tortoise specific eDNA assays have been developed and are undergoing optimisation and specification tests.

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.

Analysis of adaptive variation and phylogeographical patterns has been completed for all four species. A stronger genomic signal of selection was observed in the host-specific parasite (*Amyema gibberula* var. *tatei*) compared to its primary host species (*Hakea recurva* subsp. *recurva*), but this was not observed for the generalist parasite (*Nuytsia floribunda*) compared to a co-occurring autotroph (*Melaleuca rhaphiophylla*). Patterns of local adaptation to climate show adaptive genomic diversity in parasitic species to be associated more with temperature than precipitation variables, while the opposite is observed for the non-parasitic species. Phylogeographical analysis showed the parasitic plants to have lower genetic diversity and greater population structuring than co-occurring autotrophic plants. Spatial modelling has been used to predict patterns of adaptive genetic variability in all four species and the development of tool to guide seed sourcing for restoration is currently underway. The project has been completed and the thesis submitted.

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, whereby 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 it 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.

Molecular clock dating with the chloroplast DNA markers *rbcL*, *trnL* and the *trnL-F* intron has provided strong evidence that the lineage *Reedia* is Gondwanan, and that *Reedia* itself diverged from its sister taxa during the increased aridification of the southern portion of the Australian continent approximately 20 million years ago. Haplotype networks of the chloroplast markers *psbE-petL* and *trnS-trnG-trnG* show little variation and shared haplotypes between populations. The microsatellite analyses detected 13 genetic groups among the 15 geographic populations sampled. Significant departure from Hardy Weinberg Equilibrium was found across all populations indicating the 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 moderately high and sexual reproduction appears to be more important to recruitment than clonality. This data indicates a previously more widespread and panmictic distribution for *Reedia* that has now become a series of isolated populations. The project has been completed and the thesis has been passed.

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 south-west 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 the long-term.

The pollination study showed that cross-pollination by hand produced a ten-fold increase in seed production compared to natural pollination. Increased seed set using pollen sourced from different populations showed that small populations are producing approximately 50 percent 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. Genetic analysis of populations using 19 microsatellite loci revealed weak genetic structure, and

levels of genetic diversity and differentiation indices indicate high levels of gene flow prior to fragmentation. These results suggest that habitat fragmentation may result in patches that are too small and isolated to be attractive for pollinators and to allow long-term population viability based on reproduction by seed. Pollinator assessment showed *C. undulatum* has evolved pollen with resistance to the usually negative effect of ant secretions on pollen grains, with ants providing effective pollination services to this threatened species. The project has been completed and the thesis has been submitted.

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 the success of translocation in *Banksia brownii* and *Acacia rhetinocarpa* 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 also improving translocation design and establishment technologies.

Mating system and genetic diversity analysis has been completed for one translocated *B. brownii* population and four wild populations to benchmark mating system performance and genetic diversity in the translocated population. Reproductive output and pollination studies are complete and data has been combined with mating system and genetic diversity data to produce a draft manuscript for publication. Fitness trait studies are ongoing in a common garden experiment involving 500 seedlings to assess the performance of the translocated population in comparison to wild populations. Reproductive output measurements, seed and adult leaf material were collected from three natural and two translocated populations of *Acacia rhetinocarpa,* to benchmark genetic diversity and reproductive output in the translocated populations. Fitness traits were measured for 800 seeds and the subsequent seedlings from two wild and two translocated populations of *A. rhetinocarpa* and the glasshouse fitness study is now complete. Leaf samples were collected from the 800 seedlings and DNA extraction is complete. Microsatellite marker selection for this species is underway.

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)

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.

The meta-analysis investigating factors influencing success of past plant translocations in Western Australia is in the final stages of model refinement, with a paper describing this work in early draft. A paper on genetic diversity values and mating system parameters of translocated compared to wild source populations of *Lambertia orbifolia,* has been published in *Restoration Ecology*. 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 model to determine the trajectory of translocated populations compared to wild populations. A glasshouse cross pollination study of *Schoenia filifolia* to evaluate whether the genetic

composition of the founder populations contributes to translocation success has been completed and a paper describing this work is being drafted.

Tracking seagrass condition: development and application of novel molecular biomarkers

STP 2020-005

Scientist(s): J Cosgrove, K Trayler
Student: M Jung (PhD)
Academic(s): Dr M Fraser (The University of Western Australia), Dr B Martin (The University of Western Australia)

Seagrass communities are under threat at a global scale, yet molecular physiological responses of seagrass to key stressors – such as eutrophication and sediment stress - remains largely unknown. The central aim of this project is to investigate cellular stress responses of the key seagrass species *Halophila ovalis* in the Swan Canning Estuary on a seasonal scale using novel molecular biomarker techniques such as metabolomics.

Samples of *Halophila ovalis* were taken in both February and October 2020 in order to identify potential 'early warning bioindicators' of nutrient loading and sediment sulfide stress. Metabolomics analyses of October 2020 leaf samples have been conducted and chemical analyses of the isotopic composition of both seagrass and sediment samples are underway. Results will be related to the February 2020 sediment, seagrass and environmental data supplied by DBCA annual monitoring. Additional water column dissolved oxygen data at each of the six study sites will complement the data set.

Dirk Hartog Island fauna reintroductions disease risk analysis

STP 2021-033

Scientist(s): S Cowen, C Sims
Student: Dr F Knox (PhD)
Academic(s): Dr R Vaughan-Higgins (Murdoch University), A/Prof K Warren (Murdoch University)

This project aims to develop disease risk analyses (DRAs) for several species in the series of fauna translocations to Dirk Hartog Island (DHI). By identifying key disease risks related to these translocations, mitigation measures such as screening for specific pathogens can be put in place.

A DRA for rodents (both extant and those species to be translocated) was completed and a DRA for boodies has commenced. Based on the recommendations from the rodent DRA, a screening program for pathogens in rodents on DHI is being developed and sampling of house mice and *Pseudomys* spp. is occurring for this purpose.

Conservation genetics and population modelling to secure wild populations of the Shark Bay mouse (*Pseudomys fieldi*)

STP 2021-032

Scientist(s): S Cowen
Student: R Quah (MSc)
Academic(s): Dr D White (University of Western Australia)

In order to optimise the translocation outcomes for the proposed translocation of Shark Bay mice to Dirk Hartog Island, the population genetics of the three extant populations of the species will be investigated. This

work will be used in a population viability analysis (PVA) model to inform optimal founder size and ratios, while minimising the impact on the source population(s).

Results of this work found that all three Shark Bay mouse populations have relatively low genetic diversity and differentiation between populations, with marginally more variability present in the original source on Bernier Island. The PVA suggested that the optimal ratio of founders was 80 from Northwest Island and 40-50 from Bernier Island in a female-biased (1.5:1) sex ratio, the first stage of which has now been implemented.

Comparative analysis of diet in island populations of banded and rufous hare-wallabies in Shark Bay

STP 2021-031

Scientist(s): S Cowen
Student: R Stover (MSc)
Academic(s): Dr A Hopkins (Edith Cowan University), Dr R Davis (Edith Cowan University), Dr H Mills (The University of Western Australia)

Banded and rufous hare-wallabies are threatened species that have been the subject of conservation translocations to Dirk Hartog Island as part of the Dirk Hartog Island National Park Ecological Restoration Project (DHINPERP). These species co-exist on Bernier and Dorre Islands but little is known of their inter-specific interactions. It is hypothesised that they niche partition through their habitat preferences and the project seeks to understand if this is also reflected in their diet and what function these species may perform in the ecosystem. Neither species has been confirmed as having previously occurred on Dirk Hartog Island and have been treated as conservation introductions. This makes understanding their potential effect on the vegetation of the island even more important, to ensure there are no potentially adverse consequences. Furthermore, the role of these species as seed dispersers is not well understood but could be important for the restoration of ecosystem function and management of weeds on Dirk Hartog Island, both of which are key goals of DHINPERP. This project seeks to understand how the diet of banded and rufous hare-wallabies may influence the outcomes of the ecological restoration of Dirk Hartog Island.

A project proposal has been drafted and reconnaissance trip to the island undertaken.

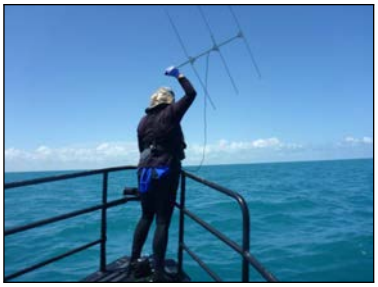
The influence of invasive predators and fire regimes on northern quolls in the Pilbara

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 (*Dasyurus hallucatus*) 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 more protected rocky habitat.

This project is now complete with three papers published to date. Results reported in the first paper indicated the species has declined across most of its range (except the Pilbara), and that persisting populations were most likely to occur in high-quality habitat, characterised by topographical ruggedness and high annual rainfall. The second paper compared vertical and horizontal camera traps as northern quoll survey tools. While equal in terms of detectability, vertical cameras were likely superior in providing images suitable for individual identification. The third paper showed quolls are more likely to use rocky patches with less habitat edge, higher vegetation and more potential denning crevices.



Ecology of flatback turtles (*Natator depressus*) at a coastal foraging ground, Western Australia

STP 2020-025

Scientist(s): S Fossette-Halot
Student: J Hounslow (PhD)
Academic(s): Dr A Gleiss (Murdoch University)

This project aims to improve our understanding of flatback turtles using bio-logging tools such as daily diaries and animal-borne video cameras that collect accelerometry, orientation and swimming performance data. Data will be used to analyse the turtles' fine-scale vertical and horizontal movements at a recently discovered foraging ground. The anticipated outcome of this project is to assess how flatback turtles might be impacted by anthropogenic disturbances at their foraging grounds.

Two field trips to Roebuck Bay were completed. Twenty-two flatback turtles were tagged, 15 cameras and 7 daily diaries were deployed, adding 40 days of diary data and 59 hours of video. A paper describing novel anti-predator behaviour was published in the journal *Ecology*. Analyses of turtle diving behaviour using state-of-the-art machine learning algorithms has been completed. All video has now been encoded using customised software to create a behavioural ethogram (catalogue).

Understanding predator-prey interactions between ghost crabs and marine turtles for better management of an endangered species

STP 2020-024

Scientist(s): S Fossette-Halot, S Whiting
Student: C Avenant (PhD)
Academic(s): A/Prof G Hyndes (Edith Cowan University)

This project will examine predator-prey interactions between ghost crabs and hatchling sea turtles on the Ningaloo coast to better conserve these threatened turtle species and manage a native predator. It will provide critical information for the management of marine turtles and their rookeries and help fill a gap in the scientific literature regarding the potential impact of native ghost crabs on turtle eggs and hatchling survival. This will help assess vulnerability of different nesting sites and determine if there is need for human intervention.

In the second summer two more field trips were completed to Gnaraloo Bay and Cape Range National Park, totaling 58 days in the field. An additional 1100 ghost crab burrows were counted and measured. Start- and end-of-season inventories were conducted on 34 loggerhead turtle nests. Hatchling emergence and predation were recorded at 25 loggerhead turtle nests from which the fate of 575 hatchlings was determined. The data is being analysed and two journal publications are being prepared.

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 University of Western Australia), G McGrath

This project aims to predict the vulnerability of flatback turtle rookeries on the North West Shelf to increasing sand temperatures, sea level rise and increased storm frequency. It will provide critical information for the management of marine turtles and their rookeries by assessing vulnerability and long-term conservation value of different nesting sites and determine if there is need for human intervention.

Two field trips were successfully completed. Six egg clutches were collected from Cemetery Beach at Port

Hedland and incubated in the lab to identify this population's pivotal temperature and transitional range of temperatures for sex determination. Over 100 blood plasma samples were collected from these embryos to trial a new method of determining hatchling sex from blood samples. Methods were trialled on Thevenard Island to develop a mechanistic model of the microclimate experienced by each embryo within a nest. A literature review was submitted to *Frontiers in Ecology and Evolution*. Software has been procured to simulate the coupled water and temperature dynamics of a turtle nest. Initial finite element modelling has been completed and compared to observed nest temperature data. A full model to contribute to a better understanding of climate change impacts on nest temperatures, feminization and mortality is in preparation.

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: E Rastion (PhD)
Academic(s): Prof E Harvey (Curtin University)

In 2016, 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 sought 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 fish in both locations.

All data has been collected and analysed. One manuscript examining the ability of diver operated stereo-video (stereo-DOVs) to characterise reef fish spawning aggregations has been accepted by the journal *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 systems 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 second manuscript assessing the biogeography of benthic and pelagic fish communities of the Galapagos Islands has been submitted to the *Journal Of Biogeography*.

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)

Tropical herbivorous fish continue to expand their ranges poleward as seawater temperature increases due to global climate change. Such fish can have significant impacts on temperate reef ecosystems dominated by fleshy macroalgae and interwoven seagrass meadows. This project examines the effects of these fish groups on temperate coastal ecosystems in the mid-west and Perth metropolitan area. Results have shown that tropical herbivorous fish that have settled in temperate coastal ecosystems have modified life-history traits relative to those in tropical waters, benefiting their ability to persist in these locations. They also can potentially increase detritus production in metropolitan coastal waters and fill a novel herbivorous function relative to their temperate counterparts, increasing local consumption of macroalgae. This work greatly assists the ability to predict future changes to WA's temperate marine ecosystems as a result of future climate change effects.

The project has to date resulted in the publication of three journal articles and the recent submission of a PhD

thesis at the University of Western Australia.

Environmental DNA as a tool to monitor fish movement in the Canning River

STP 2021-038

Scientist(s): J Hyde, S Thompson
Student: E Stevens (MSc)
Academic(s): Dr L Beesley (The University of Western Australia), Dr D Gleeson (The University of Western Australia)

This project investigates the potential of eDNA to monitor fish in the Canning River. It will compare fish assembly data from (1) traditional fyke netting, (2) active filtration eDNA, and (3) passive eDNA to explore the sensitivity of eDNA survey techniques and the role that barriers play in limiting distribution of feral fish. It is hypothesised that eDNA will detect the same range of fish species as fyke netting and will have a greater sensitivity in detecting species in low densities. This research will further the development of an eDNA monitoring protocol to complement traditional methods, leading to the potential for improved stewardship of biodiversity in waterways.

Ten sites, spaced between dams and weirs, were surveyed in April 2021. DNA extractions are complete and PCR analysis and sequencing are underway.

Environmental DNA detection in sediment from RAMSAR wetlands to indicate presence of species, past and present

STP 2021-028

Scientist(s): J Hyde, M Venarsky
Student: B Scott (PhD)
Academic(s): Prof J Mitchell (Flinders University)

This project is investigating the potential of eDNA to monitor animals in wetlands, as well as the potential for nanopore sequencing to be used for eDNA. Due to the technology involved, this project has the potential to monitor all animal groups present, as well as microbes and plants from a single sample which would greatly enhance monitoring capabilities.

Initial experiments have been conducted to determine the best sampling protocol, DNA extraction method and sequencing protocol. Additionally, the RAMSAR wetlands that will be investigated have been selected for sampling.

Mapping the distribution of *Hydromys chrysogaster* in the Southwest of Western Australia

STP 2021-004

Scientist(s): J Hyde
Student: E Dowley (MSc)
Academic(s): Dr D Gleeson (The University of Western Australia)

This project is investigating the potential of GIS mapping to predict sites where rakali (*Hydromys chrysogaster*) may be present in the southwest of Western Australia. It will compare sites where rakali is likely to be found as predicted by the maps with the evidence of rakali as found via surveys (looking for middens and footprints) and eDNA. It is anticipated that these maps will help focus resources of where rakali are likely to be now as opposed to where they were during earlier surveys and where preferred habitat has declined. Progress has been made on development of maps of occurance, and once completed eDNA testing will be undertaken at sites where rakali are predicted to be present. A qPCR test has been developed to detect rakali in the environmental samples.

A genecological assessment of seed sourcing strategies for plant community restoration under environmental change

STP 2019-003

Scientist(s): S Krauss, J Stevens
Student: B Mirfakhraei (PhD)
Academic(s): Dr E Veneklaas (The University of Western Australia)

This research aims to comprehensively test 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.

All experimental work is now completed with the thesis being prepared for submission. Key findings included glasshouse studies that showed seeds sourced from wetter regions resulted in higher growth but showed mortality when exposed to drought, whereas plants from drier seed sources had lower growth and did not show mortality when exposed to drought. Soil microbiome community and physicochemical analysis from remnant populations of *Banksia menziesii* across its range showed significant correlations between soil microbiome, soil physicochemical and climate distances. Results of a field trial identified that seed from drier provenances did not show superiority under initial field conditions. All results are now being considered for to better inform seed sourcing strategies under changing environmental conditions.

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.

Genetic fingerprinting of mala suggests the population is slowly increasing and inter-specific competition between the species was not detected. This research is complete, and a paper has been published in *Ecological Management and Restoration* highlighting the potential competition for resources between two threatened mammals released inside a fenced enclosure.

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 1) undertaking a review of faunal translocations in Australia, 2) investigating how boodie warrens alter soils and vegetation communities, and whether foraging diggings facilitate native or introduced plant species. 3) whether the presence of digging mammals alters soils and vegetation communities at landscape scales and 4) 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.

This research is complete and three journal articles have been published. The first paper, published in *Mammal Review*, reported that at least 208 translocations of 24 digging mammal species have been conducted in Australia, and 74% of those planned for post-2018 included a goal relating to the restoration of ecological processes. Research in a second paper published in *Ecology and Evolution* confirmed that digging by boodies (*Bettongia lesueur*) alters other environmental characteristics, including soil characteristics and vegetation structure. A third paper published in *Wildlife Research* reported that seeds consumed by Australian digging mammals could remain viable and germinate, indicating that digging mammals play a more important role in seed dispersal than previously considered.

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).

The growth study has largely been completed, with requirement to re-run the analysis to account for known sex and unsexed animals in separate groups and include age as a factor to account for the growth curve flattening. The growth study section of the research design chapter has been fully drafted. The nutritional content of the two diets has now been determined allowing completion of a nutritional analyses.

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.

All Sumatran tigers (*Panthera tigris sumatraeare*) faecal samples have been analysed to determine cortisol and sex hormone levels. Behavioural observations have been collected and data is being analysed. Laboratory analyses have been completed and the thesis submitted for examination.

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)

Cockatoo hindlimb paralysis syndrome (CHiPS) has been recognised as a new threat to Carnaby's cockatoos. Although a definitive diagnosis has not been obtained, the hypothesized etiology is an organophosphate-induced delayed-onset neuropathy. The syndrome may indicate that interaction between the cockatoos and inland agricultural practices are affecting this migratory species in ways that are, so far, poorly understood. The syndrome is confined to Carnaby's cockatoos and affects cockatoos regardless of gender or age, and is typically seen in the austral summer and autumn with a peak in presentations in February. The reason for the sudden emergence of the CHiPS is unknown. This study aims to characterise and investigate the cause of CHiPS in Western Australian black cockatoos.

Serum and plasma analysis has been undertaken and the assay was validated. The statistics have been calculated for this and showed a lack of statistically significant difference between CHiPS and non-CHiPS groups of cockatoos. Work progressed on developing an assay to measure delayed organophosphate neuropathy in the blood from Carnaby's cockatoos so that live CHiPS cases can be tested for delayed organophosphate toxicosis rather than only for deceased animals. There have been some issues with the development of the assay that are currently being resolved.

The prevalence of arenavirus, bornavirus, nidovirus/coronavirus, sunshinevirus and ferlavirus 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 projet is investigating the prevalence of arenavirus, bornavirus, nidovirus/coronavirus, 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 laboratory analyses are complete. Thesis submission should occur before the end of 2021.

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: S 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 provide a variety of values including 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.

For both species, thinning has a positive impact on growth, with stand growth optimised at intermediate densities (10-20 m^2 ha^{-1}) over multi-decadal time periods, consistent with findings from previous studies. Thinning also influences allometry of stem diameter with height, ratio of height and diameter, crown width and bark thickness. Two papers reporting the effects of stand density and competition from neighbouring trees on the growth of jarrah have been published in *Forest Ecology and Management*. Stand density and competition effects on the growth of karri have been examined with two manuscripts currently in review. A fifth manuscript reporting growth of marri (*Corymbia calophylla*) is also in review.

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 was 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 and amplification of the fungal ITS2 region, to estimate relative abundance of fungal taxonomic entities. A paper reporting the response of overstorey trees and understorey floristic composition to varying levels of fire severity was published in *Forest Ecology and Management.* Fungal community and functional responses to fire were

analysed, demonstrating the significant impacts fire severity had on fungi and how closely this correlated with impacts on plant communities. A paper reporting the impacts of fire severity across the four vegetation types has been prepared, and will be submitted to the *Journal of Vegetation Science.* A paper reporting the impacts on fungal communities has been prepared for submission to *the Journal of Ecology.*

Modelling mosquito development at Ashfield Flats

STP 2021-018

Scientist(s): G McGrath
Student: K Staples (PhD)
Academic(s): Dr P Neville (Edith Cowan University / Department of Health)

Ashfield Flats Reserve hosts a threatened Temperate Costal Saltmarsh community as well as active management of mosquitoes by State and local government. Hydrological modelling by DBCA suggests the potential for significant changes to the surface water at the flats in coming decades as a result of sea level rise and the populations and species of mosquitoes present at the site may shift. This project seeks to develop a salinity and temperature model of water at the site and determine key drivers of larval development, in order to model the species composing of populations under present and future scenarios. The results of the study will provide a better understanding of the drivers of mosquito populations at this and similar sites, enabling better management of the TEC in collaboration with other agencies.

Based upon the monitoring data collected as part of the Ashfield Flats Hydrological study, a temperature model was developed for a mosquito developmental model. Modelling of mosquito populations at Ashfield Flats is incorporating sea-level rise projections and other IPCC scenarios.

Evaluating satellite remote sensing of wetland water levels

STP 2021-014

Scientist(s): G McGrath
Student: R Clohessy (BSc Honours)
Academic(s): Prof J Awange (Curtin University)

Hydrological monitoring of wetlands to support the assessment of the health of vulnerable flora and fauna is an expensive and time consuming activity. Various satellite remote sensing methods offer opportunities to add value to collected data and to supplement future monitoring efforts. This project seeks to evaluate how data from satellites utilising radar and gravity methods for identifying open water, water beneath canopies, soil moisture and large scale regional water storage may be used as a means to correlate with water levels. It aims to use various remote sensing techniques (Sentinel-1 SAR, GRACE FO, and SMAP) to correlate with daily resolution water level data collected at wetlands of importance to the Australasian bittern over a 6 years period.

A time-series of various products is being generated at a selection of wetlands as an initial evaluation to inform application of techniques.

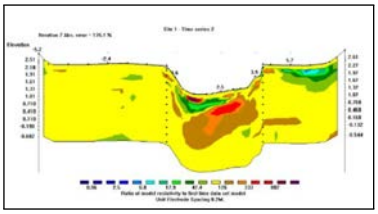
The dynamic demography of water ages our trees are using

STP 2020-017

Scientist(s): G McGrath
Student: L McCauley (MSc)
Academic(s): A/Prof S Thompson (The University of Western Australia), Dr G Skrzypek (The University of Western Australia), Dr E Veneklaas (The University of Western Australia)

The age of water utilised by trees may prove to be a useful indicator of the resillience of forests to drought and heat stress, and for assessing impacts of forest management to the unsaturated zone hydrology experienced by trees. Isotope methods have been previously developed to identify potential different water sources used by tress, e.g. groundwater versus shallow soil moisture, when these sources have distinct isotopic signatures. This method seeks to use isotopes to establish how long since the water fell as rain did it reside in the soil before it was used by the plant for transpiration. The project will implement a multidisciplinary laboratory experiment to establish the potential of the method.

A total of eight plants were installed in gas chambers and over a period of two weeks the isotopic composition of chamber air was measured at 1 second intervals. The results demonstrated the ability of the method to quantify the proportion of "new" water transpired by each sapling. A model to simulate the full distribution of water ages from the results of the experiment is in development. A journal article to report on the model and the experiment is in preparation.



Resistivity geophysics assessment of hyporheic exchange

STP 2020-016

Scientist(s): G McGrath
Student: J Barrett (MSc)
Academic(s): A/Prof M Leopold (The University of Western Australia)

The exchange of water between urban drains and wetland groundwaters is a significant issue for the management of urban wetlands health. At Ashfield Flats reserve, urban drains were installed across the Temperate Coastal Saltmarsh community to lower water tables for urban development and to convey storm-water to the Swan River. Drains like these bring freshwater and contaminants such as nutrients and heavy metals that may adversely impact the condition of the TEC. In order to evaluate how the waters conveyed by the Chapman St drain interact with groundwater this study aimed to evaluate whether resistivity geophysics could detect changes in electrical conductivity beneath the drain following runoff and flooding events.

A combination of surface and borehole resistivity methods were applied at two sections of the Chapman St drain in addition to nests of pore water samplers. Soils sediments and pore waters were characterised in the laboratory and geophysics measurements evaluated for changes over time. The results indicated there were very small amounts of hyporheic (surface water - groundwater) exchange taking place. The resistivity methods validated these measurements by indicating no significant change in subsurface electrical conductivity. While a null result, the study demonstrated there is little need to manage potential impacts of contaminated drain waters entering the wetland groundwaters.

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)

Sowing seeds for restoration using direct seeding machinery is challenging as seeds of many native species have complex morphological features that impede their flow through the machinery. This project aims to design, construct and test new seeding machinery compatible with seeds of diverse native species. Increasing the precision of sowing depth across sloped and rocky landforms common to mine sites is a primary objective.

Four field trials were conducted at mine sites in the Pilbara and in the south-west to test variants of seeding machinery designs across different soil and landform types. The trials included a focus on stress testing the machinery across large areas of harsh mining landscapes. An opinion paper was published in *Ecological Engineering* advocating the benefits of collaboration between engineers and ecologists to address challenges to restoration.

Assessing ecological resilience of post-mining restoration: testing fire recovery across a restoration chronosequence

STP 2019-060

Scientist(s): B Miller
Student: E Cowan (PhD)
Academic(s): Dr J Fontaine (Murdoch University), Dr R Standish (Murdoch University)

Ecosystem resilience is the ability of an ecosystem to return to its former state following a disturbance, and is a key factor in evaluating the success of ecological restoration efforts. But resilience is difficult to measure and is unknown for many restored communities. This project investigates the resilience of banksia woodlands restored after sand mining to fire, specifically seeking to determine an age when restoration is resilient to fire. Investigations include; assessment of resprouting capacity, and soil seedbank dynamics across a chronosequence of ages between three and 27 years since restoration. Small scale burns are also being conducted in this fire adapted ecosystem.

Smoke treatments (via smoke tents) applied in different aged restoration identified a diverse soil seedbank that changes in restoration ages. Small scale burns were conducted across the restoration chronosequence with the assistance of Parks and Wildlife (Swan Coastal) fire crew, and regeneration responses will be assessed in following years. A review of restoration projects assessing ecological characteristics following a disturbance has been published, including a framework of attributes to measure when assessing the responses of restoration projects to disturbances.

Shifting soil fungal communities in response to fire and weed management in urban banksia woodlands

STP 2019-052

Scientist(s): B Miller, K Ruthrof
Student: A Brace (PhD)
Academic(s): Dr A Hopkins (Edith Cowan University), Dr J Fontaine (Murdoch University)

Issues arising from habitat fragmentation are exacerbated by a warming and drying climate, land use changes and invasive species. To maintain biodiversity, various management methods are employed, such as prescribing burning or herbicide application. Many of these strategies are macro-organism focused, with less attention paid to microorganisms. Soil fungi play instrumental roles in ecosystem functioning, yet in many ecosystems little is known about how soil fungi respond to prescribed burning and weed control. The Swan Coastal Plain's banksia woodland is one such ecosystem where there is a gap in knowledge. This project will help fill that knowledge gap and better inform management decisions.

Analysis on soils collected from different areas of fire and/or herbicide management has been undertaken. Bioinformatics have been completed and the fungal, bacterial, archaeal and eukaryotic diversity have been described. How these change across banksia woodland and under various fire and herbicide regimes is currently being investigated.

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 N Enright (Murdoch University)

Fire is a dominant disturbance that shapes species and ecosystems. Many plant species have developed strategies and adaptations to cope with certain fire regimes. 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.

Demographic surveys have identified changes in population size structures, flowering and canopy seed bank accumulation for six woody plant species. Some species have evidence of inter-fire recruitment. Juvenile periods ranged from 1.3-4.1 years and varied by fire response, seed bank storage mode and growth form. Canopy seed banks were not observed to accumulate over time, consistent with observations of weak serotiny in banksia woodlands. A field experiment showed how 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. Data collection and analysis has been completed, and writing is close to completion. One review paper and a few response letters to this review have been published. One experimental paper is in press.

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):

In fire-prone ecosystems, recruitment from seeds following fire is prolific and provides a pathway for populations to expand into new niches and 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.

Key research from this project are: 1) a new method was developed for measuring soil temperatures during fire using distributed temperature sensing within optic fibre to sample spatial and temporal patterns with a much greater extent than previously possible; 2) a negative relationship was identified between seed moisture and lethal temperature thresholds of seeds; and 3) relationships between fuel loads and temperature penetration into soils were analysed, as well as the depth from which seeds are able to emerge from soils and their lethal temperature thresholds. These results have been published in three papers. In particular, this study has discerned than even though larger seeds can emerge from deeper within the soil, they are not necessarily better at surviving elevated soil temperatures.

Understanding patterns of phenotypic and genetic divergence in island mammals to improve conservation outcomes

STP 2021-030

Scientist(s): K Ottewell
Student: K Rick (PhD)
Academic(s): Dr N Mitchell (University of Western Australia)

Small populations, particularly those on islands, lose genetic diversity as a result of strong genetic drift and may accumulate genetic load (deleterious genetic mutations). Fauna declines on mainland Australia mean that threatened species conservation requires effective management of different types of "island" populations – continental islands, mainland remnants resulting from range collapse, and increasingly, translocations into predator-free environments (fenced exclosures or pest-free islands). Management aimed at reinstating gene flow between isolated populations via population mixing (through translocation or augmentation) is advocated to halt genetic diversity decline. However, it may risk impacts to population fitness through outbreeding depression or maladaptation when source and recipient environments are very different. This project will focus on several threatened mammals restricted to "islands" (offshore islands and mainland fenced reserves): the burrowing bettong (*Bettongia lesueur*), rufous hare-wallaby (*Lagorchestes hirsutus*), golden bandicoot (*Isoodon auratus*) and the dibbler (*Parantechinus apicalis*). The aims are to quantify phenotypic and genetic divergence amongst island and mainland populations to determine whether genetic and morphological differentiation between remnant populations reflects divergent adaptation or are artefacts of genetic drift, and the consequences for mixing populations of each species. In addition, this information will help assess the taxonomy and delimitation of conservation units of focal species to assist in developing appropriate conservation actions.

Genomic analyses have been completed for the golden bandicoot and a draft manuscript is in preparation. Morphological measurements for museum specimens of dibblers have been completed and specimens sourced for burrowing bettong and rufous hare-wallaby for morphological assessment.

Landscape genomic analysis of three co-occurring small mammals in the Pilbara

STP 2020-057

Scientist(s): K Ottewell, R Shaw
Student: E Skey (BSc Honours)
Academic(s): Dr P Spencer (Murdoch University)

Identifying and protecting core habitat and dispersal corridors is the cornerstone of best-practice conservation in multi-use landscapes. While genetic methods are regularly employed to identify historical refugia (core habitat) for species, information on dispersal and landscape connectivity is hampered by the lack of empirical data on species dispersal to inform mechanistic models. Landscape genetics is an emerging research field that quantifies gene flow as a proxy for realised dispersal to assess landscape connectivity and infer dispersal corridors (or landscape barriers) to aid in spatial conservation planning. The aims of this project are to 1) determine landscape barriers to dispersal in the Pilbara for three mammal species (*Pseudomys hermannsbergensis, Ningaui timealeyi and P. chapmani*), 2) identify landscape attributes that are linked to gene flow, 3) compare two different genetic markers, and 4) use simulation modelling to validate empirical landscape genetic findings. Genomic markers (SNPs) were employed to identify population structure using three non-Bayesian population clustering methods implemented in R and compared to results from microsatellite data.

Landscape genetic effects were tested using constrained pairwise commute-time distances in a linear mixed model. Two genetically distinct *N. timealeyi* populations were resolved using the SNP data that were not detected in the microsatellite data. The rodents exhibited no signs of spatial genetic structure. South-facing slopes possibly facilitate gene flow in *N. timealeyi* and *P. chapmani*, perhaps due to higher protection against solar radiation and higher moisture content, whereas sandy substrate seemed to facilitate gene flow in *P. hermannsburgensis*. Further landscape genetic analyses are being undertaken and a manuscript is currently in preparation.

Can feathers be used to understand Australasian bittern populations?

STP 2021-019

Scientist(s): A Pinder
Student: K Webzell (PhD)
Academic(s): Dr J Chaplin (Murdoch University)

The Australasian bittern (*Botaurus poiciloptilus*) is listed as endangered in Western Australia. Once quite widespread in south-western Australia, it is now known from a small number of near coastal sedge/reed dominated wetlands from the Swan Coastal Plain to just east of Esperance, with breeding known from a subset of these. It is thought that fewer than 150 individuals inhabit these wetlands but there is little reliable data on population size and composition. A recovery plan for this species is being implemented by DBCA and Birdlife Western Australia. An action in the plan is to "develop and implement an Australasian bittern population monitoring program". Monitoring for this species is time consuming and challenging because of its cryptic nature and rarity. Genetic methods have the potential to assist with local and regional population estimates, understanding how bitterns move across their range, and population monitoring. This project aims to investigate the potential for extracting and analysing DNA from shed feathers.

Protocols are being developed to extract DNA from a number of feathers collected in recent years by DBCA and Birdlife Australia. DNA has been obtained from some feathers but it is not yet clear whether this is from bitterns or microbial sources. DNA barcoding is being used to confirm (or otherwise) the source of the DNA.

Taxonomy and evolutionary history of *Australocypris* giant ostracods from Australian salt lakes

STP 2020-012

Scientist(s): A Pinder
Student: M Rahman (PhD)
Academic(s): Dr J Chaplin (Murdoch University)

Salt lakes are a distinctive feature of Western Australian inland areas. Several invertebrate groups appear to be far more diverse in Western Australia than anywhere else in Australia and even globally, probably reflecting the long history of aridification and the now disjunct occurrence of this type of wetland in the State. Salt lakes and their biota are threatened by altered hydrological processes and changes in water quality associated with land clearing (especially in the Wheatbelt) and increasingly, by mining on or near the lake bed. The first goal of the project is to use mitochondrial DNA data and, if necessary, nuclear DNA data, to assess the validity of the morpho-taxonomy of genus *Australocypris*, which is one of the most diverse genera in Australian salt lakes. The second goal is to use molecular data to test alternative hypotheses about species radiations in *Australocypris*, whose evolutionary history is largely unknown. The final goal is to develop a protocol for hatching and raising adult ostracods from resting eggs in mud samples collected from dry lakes, as a substitute for collecting active ostracods.

A review article on giant ostracods is in the final stages of preparation. Most specimens for taxonomic work have been collected except for one species of *Australocypris* and some outgroups. Morphological assessment of taxonomy is complete, genetic data has been generated and preliminary data analyses have been undertaken. A study of phylogeography and evolutionary history is underway with half of genetic data generated. The first phase of hatching experiments is complete for investigations into the utility of and methods for raising invertebrates from dry lake sediments for biological survey.

Taxonomy, ecology and evolutionary history of the salt lake gastropod *Coxiella*

STP 2020-010

Scientist(s): A Pinder
Student: A Lawrie (PhD)
Academic(s): Dr J Chaplin (Murdoch University)

Salt lakes are an iconic feature of Western Australian semi-arid and arid landscapes, with a flora and fauna that have adapted and diversified within these extreme environments. Western Australia has a very diverse halophilic fauna, higher than anywhere else in Australia. Salt lakes and their biota are threatened by altered hydrological processes and changes in water quality associated with land clearing (especially in the Wheatbelt) and increasingly, by mining on or near the lake bed. One of the most intriguing invertebrate groups is the snail genus *Coxiella*, which tolerates both periodic drying and high salinities and is the only mollusc occurring in temporarily filled salt lakes. This project focusses on the taxonomy, ecology and evolutionary history of this genus.

A literature review collating information on the biology of halophilic crustaceans and gastropods of Australian salt lakes has been accepted for publication in *Marine and Freshwater Research*. The taxonomic work has essentially been completed, with samples obtained from 70 salt lakes from across Australia. The analysis included five of nine described species and identified a total of 14 species, five being new to science. It raises interesting questions regarding the validity of *Coxiella* as a genus as several highly divergent lineages were identified by the genetic data.

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)

According to ecological theory, sympatric species cannot occupy the same niche space. Therefore, the coexistence of sympatric species is thought to be facilitated by the partitioning of resources, differing patterns of habitat utilisation, or both. However, in the tropical savannas of northern Australia 3 sympatric grass finches co-exist. It is thought that the threatened Gouldian finch has a specialised diet of grass seeds and also morphological adaptations for greater dispersal. In contrast, the more common Long-tailed and Masked Finches have a generalist diet, including a greater range of herbaceous seeds and invertebrates, and are also more sedentary in their habitat use and movements. Fire regimes leading to increased movements to locate specialist food resources may increase risks to Gouldian finches, including starvation and/or lost body condition. This study uses stable isotope analysis and novel radio telemetry methods to test hypotheses on diet specialisation, and foraging behaviour in the Kimberley savanna as resource bottlenecks increase as grass seeds become more scarce into the late dry season.

Movement data using novel automated radio telemetry and VHF nanotags show that Gouldian finches respond to dry season declines in grass seed availability by spending less time at foraging sites and more time travelling between sites. Redetection rates using radio telemetry is high (92%) compared to only 1.7% using conventional waterhole counts. Core areas of finch activity correspond to areas frequently burnt in the early dry season. Statistical modelling will reveal the fire mosaics' relative importance compared to other environmental influences. Isotope analyses of finch blood and radio tracking revealed significant niche differentiation between co-occurring finches. Gouldian finches have a narrower dietary range and greater movements between foraging areas than the less specialised masked and longtail finches. Isotope analysis also revealed Gouldian finches have lower dietary nitrogen, supporting the hypothesis that they are more strictly granivorous.

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 Penton (PhD)
Academic(s): Dr L Woolley (Charles Darwin University), Dr B Murphy (Charles Darwin University)

Arboreal nest box/camera studies suggest that the greatest benefit of using nest boxes in augmenting nesting sites is gained in intermediate savanna/forest habitats where large tree and hollow density is medium. Arboreal species overlap in their hollow and tree use; however the brush tailed rabbit rat build their dens closer to the ground in dead trees and hollow logs, and forages at ground level. This makes it more susceptible to terrestrial threatening processes (fire, feral cats, cattle and buffalo) compared to larger, more arboreal species including black footed tree rat, brush tailed possum and savanna gliders. Despite the importance of arboreal habitat features like hollows, the strongest explanatory variables for presence of threatened arboreal mammals were terrestrial factors including fire regimes, presence of cats, shrub density and vegetation damage by cattle and water buffalo.

One journal paper has been published and one accepted for publication.

Projecting combined thermal stress and tropical cyclone exposure on coral reefs

STP 2021-007

Scientist(s): C Ross
Student: A Dixon (PhD)
Academic(s): Dr M Beger (University of Leeds)

Projections of future climate-related impacts to coral reefs are important for management decisions. For coral reefs, climate-related projections have largely focused on temperature stress and less so on other climate stressors, such as cyclones. Tropical cyclones can generate large waves that cause long-term physical damage to reefs and at the same time cause mixing and upwelling of deeper waters, thus reducing thermal stress. Tropical cyclone projections exist at a relevant spatial scale for management but are rarely included in assessments of future climate exposure. To assess the combined effects of tropical cyclones and thermal stress on coral reefs under future climate change, this study will model the impacts of future changes in tropical cyclones and thermal stress events on the cover of coral reefs in Australia using high-resolution tropical cyclone and thermal stress products. This research will identify specific areas of low vulnerability (low exposure and/or low sensitivity) and areas for more targeted conservation strategies.

Coral recruitment at Ningaloo, Montebello Islands and Onslow

STP 2021-006

Scientist(s): C Ross
Student: E Haskin (MSc)
Academic(s): Dr J Prince, Dr M O'Leary

An important aspect of coral reef resilience is reproduction and the supply of coral recruits that settle onto reefs. Most hard coral species around the world reproduce via broadcast spawning and in Western Australia the main spawning event occurs in March/April with a smaller spawn in October-November. In addition to these two annual spawning events, the production of larvae via internal fertilisation of gametes in brooding corals can

occur throughout the year. It is unknown if production of larvae by brooders differs between the main spawning season and the remainder of the year. To assess seasonal variation in coral recruitment by brooders, this study will investigate rates of coral recruitment during the main spawning season (March-April) and the remainder of the year at Onslow, Ningaloo Marine Park and the Montebello Islands Marine Park. The project will analyse coral recruitment data collected biannually from 2014-2018 at Onslow and from 2019-2021 at both Ningaloo and the Montebello Islands Marine Parks.

A project proposal has been submitted and the proposal seminar has been presented. Data from coral recruitment tiles are currently being analysed.

Coral health and *Drupella cornus* at Rottnest Island, Western Australia

STP 2021-005

Scientist(s): C Ross
Student: J Walker (MSc)
Academic(s): R Hovey (UWA), Dr J Prince

Coral predators, such as the corallivorous gastropod, *Drupella cornus*, pose a threat to coral communities depending on their abundance and distribution. In recent years, feeding aggregations of *Drupella* have been reported in subtropical coral communities at Rottnest Island for the first time. This could negatively impact coral communities, particularly following thermal stress events, as *Drupella* species aggregate on stressed coral. There is minimal information on the feeding rates of *D. cornus*, which is required to calculate the densities of *D. cornus* that can be sustained by a coral community.

This study has quantified the feeding rates of *D. cornus* collected from Rottnest using controlled aquaria experiments and showed that *D. cornus* feeding rates increased at higher temperatures. *In-situ* coral health and *D. cornus* surveys were conducted at sites around Rottnest Island. The surveys conducted around Rottnest Island provide a benchmark for monitoring future changes in the density and distribution of *D. cornus* and the potential impacts on coral health.

Regeneration of canopy species following drought-induced die-off in the Northern Jarrah Forest

STP 2020-015

Scientist(s): K Ruthrof
Student: T Rasmussen (BSc Honours)
Academic(s): Dr J Fontaine (Murdoch University), Dr L Walden (Murdoch University)

Forests are an essential asset for the provision and regulation of ecosystem services and culture and heritage. Parts of the Northern Jarrah Forest were affected by the 2010/2011 drought/ heatwave event, and the 2016 Waroona/Yarloop wildfire. This project aimed to determine how drought, wildfire, and prescribed burning influence tree regeneration in the Northern Jarrah Forest, by asking the following questions: 1) how does tree regeneration vary with fire severity and drought, 2) how do the growth stages of tree regeneration vary by drought, fire type and history, 3) how does seedling density change over time? and 4) how do understorey and overstorey regulate recruitment?

Results indicate that regeneration of the key canopy species was high following drought and fire. Lignotuberous seedlings and seedling coppice were the most dominant growth stage identified, with significantly higher densities following moderate severity fire. Moderate severity wildfire resulted in high densities over the three years since wildfire overall, and high severity fire and prescribed burning resulted in lower regeneration abundance by comparison.

Effects of drought and wildfire on ecophysiological functioning in the Northern Jarrah Forest

STP 2020-014

Scientist(s): K Ruthrof, W Lewandrowski
Student: N Anderson (BSc Honours)
Academic(s): Dr L Walden (Murdoch University), Dr J Fontaine (Murdoch University)

The south-west of Western Australia is predicted to become drier and hotter in the future. Knowing how forest ecosystems will respond to both drought and fire is critical for informed forest management, particularly for vulnerable sites. The Northern Jarrah Forest (NJF) experienced droughts in 2010 and 2015 and a wildfire in 2016 (Waroona). This project used established monitoring plots from within the Waroona fire scar to measure the ecophysiological response of the canopy species jarrah (*Eucalyptus marginata*) to drought and fire.

Results showed that the high probability drought/ high severity wildfire plot had the lowest pre-dawn leaf water potentials and reduced stomatal conductance. A number of trees adjacent to this plot died or had canopy contractions between the summer and winter measurements. The combination of observed tree death and low pre-dawn leaf water potentials suggests that for jarrah, the interplay of drought and fire is pushing vulnerable portions of the forest close to and beyond, their threshold of survival.

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.

Data analysis has progressed and synthesis of a glasshouse trial investigating how preconditioning seedlings to water stress influences tolerance to subsequent drought has been completed. Water availability during the first five months of seedling growth strongly influenced physiological performance under subsequent terminal drought; however, shifts in biomass allocation did not account for this variation. Frequency and amounts of water provided during preconditioning are critical factors in determining subsequent drought tolerance of outplanted seedlings.

Near-surface remote sensing of plant condition in mine site restoration environments

STP 2018-146

Scientist(s): J Stevens
Student: J Ruscalleda 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 a 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, potentially establishing the foundation for scaling up remote imaging platforms that allow monitoring of larger areas in shorter timeframes.

Experiments explored hyperspectral reflectance and thermal imaging as two near-surface remote sensing methods. These experiments, conducted on a range of banksia woodland seedlings under controlled environment conditions, enabled plant condition responses to be linked to environmental conditions.Both methods were assessed to determine the combined capacity of different proxy-indicators of plant condition to track seasonal change in plants growing in a restored mine site of Western Australia.

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 (for example through 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 applied to Western Australian natural systems via inoculations. The project also aims to elucidate the mechanisms involved in the positive effects of microorganisms on plants and explore how these findings can be integrated to improve mine site restoration strategies.

Results revealed that plant species exhibited varied response to the experimental conditions. Benefits conferred by the microbial inoculation treatments on physical growth (biomass) of the plants were minimal and watering regime appeared to have more significant impact. Foliar nutrient (carbon and nitrogen) and stable isotope (^{13}C, ^{15}N) analysis also indicated minimal benefits conferred by the inoculation treatment. Plant xylem sap phytohormone analysis conducted on *Banksia menziesii*, *B. attenuata* and *Eucalyptus todtiana* although indicated differences between inoculated and non-inoculated plants. Overall, results seem to suggest that application of microbial inoculation on plants beyond the seedling stage may not deliver the full benefit as the plants may harbour established microbiome that hinders beneficial interaction(s) and/or symbiosis with the introduced microorganisms.

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.

Results indicate that wind in Australian vegetation communities logically progress between the logarithmic profile of low, open landscapes, and complete attenuation within the canopy, with near-ground wind speeds decreasing with increasing structural complexity in the canopy. An assessment of banksia woodland restoration systems highlighted that older rehabilitation sites (6+ years) showed a return to wind speed profiles more closely aligned with those of undisturbed systems. Controlled studies involving the installation of wind tunnels in the field lab trials, show *Banksia attenuata* seedlings grown under high wind exposure are significantly inhibited compared to their low wind exposure counterparts, with marked decreases in biomass accumulation. However there was no clear link to leaf level physiology, and this is still to be resolved.

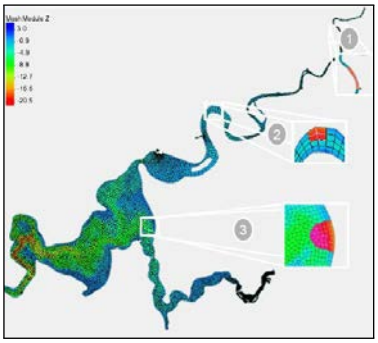
Dolphin health - toxicogenomics and pathology investigations

STP 2020-069

Scientist(s): K Trayler
Student: N Stephens (PhD)
Academic(s): Dr K Warren (Murdoch University), Dr C Holyoake (Murdoch University), Dr P Duignan (University of Calgary)

Following the 2009 deaths of six dolphins in the Swan Canning Riverpark, a collaborative project with Murdoch University was established for post-mortem investigations (PMs) of strandings and unusual mortality events. That work was instrumental in understanding the underlying factors in the 2009 deaths. As part of this project, contaminant exposure in both live and deceased dolphins is being assessed. The data will be contextualised in comparison to a non-urban 'control population' (Shark Bay Western Gulf) and another estuarine population (Peel-Harvey Mandurah). Evidence of sub-lethal adverse effects on various body systems, particularly the immune system will be compared in order to evaluate the potential threats faced by and overall health of dolphins in the Riverpark community.

PMs and analyses of deceased cetaceans in 2019 confirmed the return of cetacean morbillivirus to the Riverpark. The virus affected dolphins between Bunbury and Shark Bay and impacted both Indo-pacific bottlenose dolphins and striped dolphins.



Identification of controls on the metabolism of the Swan Canning Estuary using numerical modelling and high-frequency data

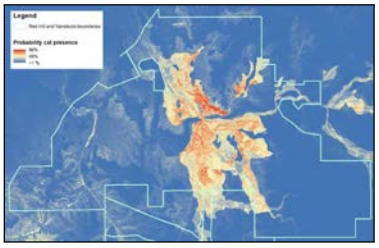
STP 2018-093

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 captures well the seasonal and spatial variability in some physico-chemical parameters but could be improved. 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.

Successful deployment of two high-frequency monitoring buoys in the lower Swan and Matilda Bay has provided high frequency data at the new monitoring sites at 10 minutes intervals and this has been used as an input for estuary metabolism estimation. Preliminary *in-situ* productivity and respiration results were found to

be comparable to USA estuaries. Time series comparison of wind data at four locations showed variations in magnitude, potentially influencing air-water exchange across the river. This can be accounted for through a scaling factor in the SCERM model.



Improved species distribution models for feral cats in the Pilbara region using machine learning and behavioural change point analysis.

STP 2021-027

Scientist(s): R Van Dongen, R Palmer
Student: B Lkhagvasuren (MSc)
Academic(s): Dr T Robinson (Curtin University)

Predation by feral cats continues to pose a major threat to native wildlife on the Australian mainland, and affective control remains an ongoing challenge for conservation practitioners and ecologists. The aim of this study is to determine the spatial distribution and behavioral changes of feral cats relative to spatiotemporal movement and landscape features. Based on the result, the expected main outcome would be a species distribution model of feral cats in a semi-arid environment.

To date, a literature review has been carried out. This included some exploratory statistics from feral cat tracking data and identified several modelling techniques and data sets that could be utilised to generate a habitat model. One of these data sets included a high-resolution elevation model which is currently being sourced from Landgate.

Dieback mapping in the Kalbarri National Park using satellite imagery.

STP 2021-020

Scientist(s): R Van Dongen
Student: M Sage (PhD)
Academic(s): Dr T Robinson (Curtin University)

A report titled "Assessing vegetation cover change using remote sensing in Kalbarri National Park; an exploratory study", was completed by Mitchell Sage as part of a university work placement. The study aligned the current corporate fire record with observations of fire impacts determined from Landsat satellite imagery using imagery from 1974 to 2020. Fires not in the corporate fire record were added, these were found to be predominantly pre 1991.

This updated fire record was then used identify areas with similar fire frequency and make comparisons of post fire recovery rates in dieback affected and unaffected areas. While the study identified a range of fire impact and recovery trajectories no definitive differences between affected and unaffected areas was reported. The limited number of areas investigated restricted the completeness of the comparison.

Home range, site fidelity and social structure of snubfin dolphins in Roebuck Bay, Western Australia

STP 2020-042

Scientist(s): K Waples, H Raudino
Student: A D'Cruz (BSc Honours)
Academic(s): Dr C Salgado Kent (Edith Cowan University)

Yawuru Nagulagan/Roebuck Bay Marine Park (YNRBMP) is a known hotspot for snubfin dolphins, with this species recognised as a key ecological value of the marine park. As anthropogenic pressures increase from growing recreational use and increasing tourism and industrial activity, there is a need to better understand snubfin dolphin population dynamics in the reserve to inform sustainable management.

Analysis of data collected from a variety of resources over a thirteen-year period was used to assess snubfin dolphin range patterns, site fidelity, and social structure in Roebuck Bay at an individual and population level. Key findings that will inform management include a resident population of snubfin dolphins that regularly use Roebuck Bay with a broader population present at times. High use areas have been identified, including the northern part of the bay, the Port of Broome.

Quantifying the loss of antipredator traits in havened mammal populations and their relationship with population density and resource competition.

STP 2021-009

Scientist(s): A Wayne
Student: N Harrison (PhD)
Academic(s): A/Prof N Mitchell (The University of Western Australia), A/Prof B Pillips (University of Melbourne), A/Prof J Hemmi (University of Western Australia), Dr L Valentine (The University of Western Australia)

The aim of this project is to develop robust behavioural assays for quantifying anti-predator responses in woylies, and then use these methods to assess the potential extent of the loss of anti-predator responses, populations at risk, possible drivers and consequences for survival and reproduction. This information will assist in informing future management and translocation practices for woylies and potentially other critical weight range species.

Preliminary field trials have been undertaken for assay development to inform different methods to be formally trialled. A cage trap behaviour assessment protocol has also been developed to be used during the upcoming translocation of woylies from Perup to the Yorke Peninsula (SA).

Survey methods and population estimates of the chuditch across its range

STP 2020-048

Scientist(s): A Wayne
Student: M Taylor (PhD)
Academic(s): Dr M Calver (Murdoch University), Dr K Bryant (Murdoch University), Dr N Armstrong (Murdoch University)

Robust population estimates are fundamental to species conservation and management. This project aims to use lured remote sensor cameras and spatially explicit capture recapture modelling to improve the accuracy of density and abundance estimates for chuditch populations.

Appropriate sampling design including trap number, spacing and survey duration is being informed using existing camera trap data from the Upper Warren (Moopinup and Balban). A camera model comparison trial was conducted using lured paired Reconyx and Swift cameras in four positions (single and paired traps horizontally oriented and set 0.3 cm above ground and angled traps set 1m and 2m above ground) at 12 locations within Julimar State Forest. Cameras were left out for 6 weeks. Image processing and data analysis is underway to determine the best set up and model. The results from these two studies will be used to produce a reliable and sensitive density estimate of chuditch, firstly at Julimar and then for other important chuditch populations across it range.

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 of Western Australia, 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 and 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.

Dynamic occupancy models of red fox and feral cats across the Upper Warren have been built using the sand plot monitoring data in relation to predator baiting intensity and rainfall. Mark-recapture modelling has also been undertaken on woylie, chuditch, koomal and quenda to calculate transect-specific abundance estimates over time across the Upper Warren. Covariates for modelling have also been built that include baiting intensity, fire regime, timber harvesting and primary productivity. These environmental and management variables will be related to abundance estimates to identify strong correlates of abundance for each species.

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 (The University of Western Australia), 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.

Data from a camera trap survey deployed in two areas in the Upper Warren region were processed and analysis is underway. This survey allows comparison between two camera types (Swift 3C wide angle and Reconyx HC600/PC900). Preliminary results suggest that Swift cameras had higher detection rates than Reconyx cameras, and that numbat density between the two sites is estimated to be 0.018 per ha. GPS collar data was collected for a further nine numbats resulting in a total of 18 GPS data sets from 15 numbats (13 females and 2 males). Preliminary analysis suggests home ranges vary between 11 – 280 ha. Ground level habitat data was also collected from 120 plots to compare high use areas to available habitat. These data will be combined to investigate habitat use and whether this varies by season.

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 M Calver (Murdoch University), 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, 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.

Different camera-trap models and set up options were explored to improve numbat detection. Swift-3C wide angle camera-traps set at 25cm above ground performed best. Sign surveys detected numbats more efficiently than driven transects and camera trapping. To further improve camera trapping for Upper Warren native species including numbats, we established that Reconyx PC900/HC600 camera traps missed 54% of known animal visits while Swift 3C wide angle camera-traps missed only 0.5%. A broad scale survey of 78 study sites with varying habitat and management characteristics showed that numbats appear to be generalists with no clear preference for any key habitat or management type in the Upper Warren region."

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, 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.

This project has been on hold and is due to recommence later in 2021. The results of this project are already being used to design fox control actions for a key mainland flatback turtle rookery. All field work has been conducted and data analysis and write up of thesis chapters still needs to be completed.

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 aims to assess the health and disease status of sea turtles in Western Australia, with a focus on flatback turtles. For stranded dead and injured turtles, pathology is used to diagnose the causes of death and injury, with parasite infections and fibropapilloma virus being specifically investigated. For healthy turtles the project has established a blood chemistry reference baseline which can be used nationally by turtle care facilities.

A paper on a novel disease related to a multiple species mortality event in Broome (fish kill) has been published. The first comprehensive blood chemistry reference ranges from nesting and in-water turtles has been produced. A new parasite has been discovered and a range of pathology descriptions for flatback turtles have been produced.

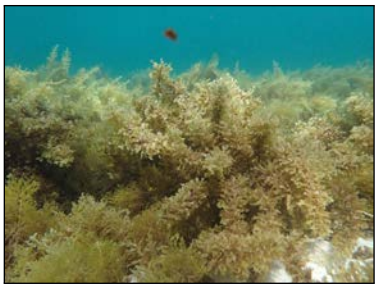
Habitat quality as a driver of epinepheline serranid productivity and replenishment

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 affect associated fauna. Epinephelid serranids are ecologically important predators on tropical reefs that are an attraction for recreational fishermen. This project will focus on the habitat requirements of epinepheline serranids at Ningaloo Marine Park, exploring mechanisms that influence their distribution, abundance and productivity. The project will examine fish within two prominent habitat types at Ningaloo, macroalgae and corals, that also represent extremes of the current regime shift paradigm on tropical reefs.

After describing broadscale habitat associations of epinephelids and finer scale habitat use by *Epinephelus rivulatus* in macroalgal habitats, the project is now focused on understanding how variation in fine scale habitat affects the condition and productivity of these fish. Accordingly, 5-8 *E. rivulatus* have been collected from fifteen macroalgal patches with different habitat characteristics (total 105 fish). Growth rates of these fish will be assessed by sectioning and reading otoliths (ear bones). Combined with local estimates of abundance, growth rates from each patch will provide an indication of how productivity varies among macroalgal habitats. Information that will help identify which patches are important for sustaining local recreational fisheries.



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 Marine Park. 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).

A manuscript that explores reasons for spatial variation in macroalgal assemblages has been submitted for publication in *Marine Biology*. The study shows that sediment depth/cover and abundance of the macroalgal grazing urchin *Tripneustes gratilla*, influence both community composition and physical structure of macroalgal patches. Algae from the genera *Sargassopsis, Caulerpa, Sirophysalis* and *Hormophysa* occurred where sediment depth cover was high, whilst canopy height was greater where sediment loads were high and urchin abundance was low. The findings emphasise the role of mobile sediments in directly shaping macroalgal communities and indirectly by altering urchin distributions.

Publications and Reports

Abbott I (2020). Book review: The future of the fringe: the crisis in peri-urban planning by Michael Buxton and Andrew Butt 2020. CSIRO Publishing, 184 pp. *Pacific Conservation Biology* **26** p. 315

Abbott I (2020). Book review: Saving the Tasmanian Devil: Recovery Through Science-Based Management. Edited by Carolyn Hogg, Samantha Fox, David Pemberton and Katherine Belov 2019. CSIRO Publishing. *Pacific Conservation Biology* **26** p. 430

Ahrens CW, Jordan R, Bragg J, Harrison PA, Hopley T, Bothwell H et al. [Byrne, M] (2021). Regarding the f-word: the effects of data filtering on inferred genotype-environment associations. *Molecular Ecology Resources* **21**, 1460-1474

Algar D, Morris K, Asher J, Cowen S (2020). Dirk Hartog Island, Return to 1616 Project: the first six years (2014 to 2019). *Ecological Management and Restoration* **21**, 173-183

Anderson N, Fontaine J, Walden L, Lewandrowski W, Ruthrof K (2020). Ecophysiological mechanisms underpinning resilience to climate change in the northern jarrah forest (Western Australia). (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 4-5

Andrzejaczek S, Vély M, Jouannet D, Rowat D, Fossette S (2021). Regional movements of satellite-tagged whale sharks *Rhincodon typus* in the Gulf of Aden. *Ecology and Evolution* **11**, 4920-4934

Arthur K, Whiting S, Pendoley K (2020). Light pollution guidelines to protect marine turtles. *Indian Ocean Turtle Newsletter* **32**, 47-49

Babcock RC, Thomson DP, Haywood MDE, Vanderklift MA, Pillans R, Rochester WA et al. [Shedrawi G, Field S, Evans R] (2021). Recurrent coral bleaching in north-western Australia and associated declines in coral cover. *Marine and Freshwater Research* **72**, 620-632

Barrett RL, Macfarlane TD, Keighery GJ (2021). Taxonomic revision of *Corynotheca* (Hemerocallidaceae / Asphodelaceae). *Telopea* **24**, 7-52

Bateman AM, Erickson TE, Merritt DJ, Veneklaas EJ, Muñoz-Rojas M (2021). Native plant diversity is a stronger driver for soil quality than inorganic amendments in semi-arid post-mining rehabilitation. *Geoderma* **394**: 115001

Beca G, Palmer B, Valentine L, Erickson T, Hobbs R (2020). Gut-passage time and viability of seeds consumed by Australian marsupials. (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 9-10

Beca G, Valentine LE, Hopkins AJM, Erickson TE, Power MWP, Beecham BC et al. (2020). The role of woylies as potential agents in restoring degraded landscapes. (ABSTRACT) In *Australasian Wildlife Management Society 33rd Annual Conference: 8-10 December 2020, Online Australia: Book of Abstracts* p. 21

Bentley BP, Stubbs JL, Whiting SD, Mitchell NJ (2020). Variation in thermal traits describing sex determination and development in Western Australian sea turtle populations. *Functional Ecology* **34**, 2302-2314

Bergstrom DM, Wienecke BC, van den Hoff J, Hughes L, Lindenmayer DL, Ainsworth TD et al. [Ruthrof KX] (2021). Combating ecosystem collapse from the tropics to the Antarctic. *Global Change Biology* **27**, 1692-1703

Berto B (2021). Fire and sulfuric acid: just another day in the seed lab. *For People & Plants* **114**, 31-33

Berto B, Erickson TE, Ritchie AL (2020). Flash flaming improves flow properties of Mediterranean grasses used for direct seeding. *Plants* **9**: 1699

Bhandari SK, Veneklaas EJ, McCaw L, Mazanec R, Whitford K, Renton M (2021). Effect of thinning and fertilizer on growth and allometry of *Eucalyptus marginata*. *Forest Ecology and Management* **479**: 118594

Bhandari SK, Veneklaas EJ, McCaw L, Mazanec R, Whitford K, Renton M (2021). Predicting individual tree growth in jarrah (*Eucalyptus marginata*) forest based on size and distance of neighbouring trees in thinned and non-thinned plots. *Forest Ecology and Management* **494**: 119364

Bieroza M, Dupas R, Glendell M, McGrath G, Mellander P-E (2020). Hydrological and chemical controls on nutrient and contaminant loss to water in agricultural landscapes. *Water* **12**: 3379

Binks RM, Steane DA, Byrne M (2021). Genomic divergence in sympatry indicates strong reproductive barriers and cryptic species within *Eucalyptus salubris*. *Ecology and Evolution* **11**, 5096-5110

Birt MJ, Cure K, Wilson S, Newman SJ, Harvey ES, Meekan M et al. [Goetze J] (2021). Isolated reefs support stable fish communities with high abundances of regionally fished species. *Ecology and Evolution* **11**, 4701-4718

Blythman M (2021). Predicting the hatching date of malleefowl *Leipoa ocellata* eggs without excavating the mound. *Australian Field Ornithology* **38**, 78-86

Blythman M, Lohr C, Sims C, Morris K (2020). Translocation of golden bandicoots, *Isoodon auratus barrowensis*, from a fenced enclosure to unfenced managed land on Matuwa (formally Lorna Glen) in September 2015: final report. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 43 p.

Bouchet PJ, Thiele D, Marley SA, Waples K, Weisenberger F, Balanggarra Rangers et al. [Raudino H] (2021). Regional assessment of the conservation status of snubfin dolphins (*Orcaella heinsohni*) in the Kimberley region, Western Australia. *Frontiers in Marine Science* **7**: 614852

Bougher NL (2021). Fungi of Perth, Western Australia: a visual guide to more than 600 species recorded at Kings Park & Bold Park. Version 5. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 231 p.

Bougher NL (2021). An observation of ants harvesting a fruit body of *Amanita*. *Western Australian Naturalist* **32**, 45-47

Bougher NL, Barrett MD (2020). Fungi and slime moulds recorded in surveys at Kings Park and Bold Park, urban bushlands, Perth, Western Australia. *Western Australian Naturalist* **31**, 191-251

Braby MF, Williams MR, Douglas F, Beardsell C, Crosby DF (2021). Changes in a peri-urban butterfly assemblage over 80 years near Melbourne, Australia. *Austral Entomology* **60**, 27-51

Bradbury D, Binks RM, Byrne M (2021). Genomic data inform conservation of rare tree species: clonality, diversity and hybridity in *Eucalyptus* series in a global biodiversity hotspot. *Biodiversity and Conservation* **30**, 619-641

Breshears D, Field JP, Law D, Barron-Gafford G, Acuna K, Barnes ML et al. [Ruthrof K] (2020). From chronic warming to acute heat waves: an under-appreciated threat for tree mortality? (ABSTRACT) In *ESA2020, Ecological Society of America: Harnessing the Ecological Data Revolution, August 3-6, 2020*, 1-2

Breshears DD, Fontaine JB, Ruthrof KX, Field JP, Feng X, Burger JR et al. (2021). Underappreciated plant vulnerabilities to heat waves. *New Phytologist* **231**, 32-39

Brockman G, French C (2021). *Pterostylis occulta* (Orchidaceae), a new species from the south-west of Western Australia. *Nuytsia* **32**, 51-54

Brown A (2020). *Eremophilas* of Western Australia. *Australian Plants* **30**, 298-301

Brown AP, Phillips RD (2021). *Caladenia multiplex* (Orchidaceae), a new, sexually deceptive species from the south-west of Western Australia. *Nuytsia* **32**, 55-58

Buirchell BJ, Brown AP (2021). *Eremophila rarissima* (Scrophulariaceae), a new rarity from Western Australia. *Nuytsia* **32**, 63-66

Burbidge A (2021). Threats to nesting tropicbirds. *Western Australian Bird Notes* **178** p. 7

Burrows N, Rampant P, Loewenthal G, Wills A (2020). Fire, plant species richness and plants of significance to Australian desert Aboriginal people. *International Journal of Wildland Fire* **29**, 939-942

Butcher R (2021). Two new, orange-flowered *Tephrosia* (Fabaceae: Millettieae) species from the Kimberley region, in Western Australia's monsoon tropics. *Nuytsia* **32**, 39-50

Butcher R, Cowie ID (2021). Redefinition of *Tephrosia supina* (Fabaceae: Millettiae), a north-west Western Australian endemic, and description of two similar species. *Nuytsia* **32**, 67-83

Butt N, Wenger AS, Lohr C, Woodberry O, Morris K, Pressey RL (2021). Predicting and managing plant invasions on offshore islands. *Conservation Science and Practice* **3**: e192

Byrne M (2021). Genetic analysis confirms the need to split *Leptospermum* into multiple genera (ABSTRACT). In *Program: Australasian Honey Bee 2021 Research Conference, 29 June-1 July 2021, Perth* p. 1

Byrne M, Murphy DJ (2020). The origins and evolutionary history of xerophytic vegetation in Australia. *Australian Journal of Botany* **68**, 195-207

Cale DJ (2020). Little Darkin Swamp aquatic invertebrate survey. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 28 p.

Chambers B, Dunlop J, Wayne A (2020). Felixer™ grooming trap non-target safety trial: numbats, July 2020. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 8 p.

Chapman J, Zdunic K (2020). Red Hill annual desktop fire regime monitoring, 2019. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 42 p.

Chapman J, Zdunic K (2020). Yarraloola annual desktop fire regime monitoring, 2019. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 43 p.

Chua M, Erickson TE, Merritt DJ, Chilton AM, Ooi MKJ, Muñoz-Rojas M (2020). Bio-priming seeds with cyanobacteria: effects on native plant growth and soil properties. *Restoration Ecology* **28**, S168-S176

Clementi GM, Bakker J, Flowers KI, Postaire BD, Babcock EA, Bond ME et al. [Goetze JS] (2021). Moray eels are more common on coral reefs subject to higher human pressure in the greater Caribbean. *iScience* **24**: 102097

Collett S, Crewe T, Radford I, Cambell H (2020). Sympatric finches use different foraging strategies to overcome resource limitations. (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 23-24

Comer S, Clausen L, Cowen S, Pinder J, Thomas A, Burbidge AH et al. [Algar D] (2020). Integrating feral cat (*Felis catus*) control into landscape-scale introduced predator control to improve conservation management for threatened fauna: a case study from the south coast of Western Australia. *Wildlife Research* **47**, 762-778

Comer S, Thomas A, Ford S, Hill S (2020). Department of Biodiversity, Conservation and Attractions (DBCA) western ground parrot spring update. *Friends of the Western Ground Parrot Newsletter* **87** p. 2

Commander LE, Merino-Martin L, Elliott CP, Miller BP, Dixon K, Stevens J (2020). Demographic, seed and microsite limitations to seedling recruitment in semi-arid mine site restoration. *Plant and Soil* **457**, 113-129

Coote M (2020). Celebrating 30 years of Ramsar wetlands in Perth-Peel. *Bushland News* **115**, 3-4

Cowan M, Birch N, Dunlop J (2020). Targeted surveys for northern quolls in the Chichester Ranges 2019: report prepared for Roy Hill Pty Ltd, August 2020. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 38 p.

Cowan M, Blythman M, Angus J, Gibson L (2020). Relocation and post-release monitoring of western grey kangaroos (*Macropus fuliginosus*) displaced from an urban development site. *Animals* **10**: 1914

Cowan M, Dunlop J (2020). Northern quoll targeted surveys in the Chichester Ranges: a six-year summary: report prepared for Roy Hill Pty Ltd, December 2020. 52 p.

Cowan M, Dunlop J, Moore H (2020). Northern quoll (*Dasyurus hallucatus*) home range synopsis . Department of Biodiversity, Conservation and Attractions, Kensington, WA. 33 p.

Cowan M, Moro D, Anderson H, Angus J, Garretson S, Morris K (2020). Aerial baiting for feral cats is unlikely to affect survivorship of northern quolls in the Pilbara region of Western Australia. *Wildlife Research* **47**, 589-598

Cowen S, Rayner K, Sims C, Friend T, Knox F, Ottewell K et al. [Gibson L] (2020). Dirk Hartog Island National Park Ecological Restoration Project: stage two, year two, translocation and monitoring report. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 64 p.

Cowen S, Sims C (2021). Conservation translocation of banded and Shark Bay rufous hare-wallaby to Dirk Hartog Island, Western Australia. In *Global Conservation Translocation Perspectives, 2021: Case-Studies from Around the Globe (ed PS Soorae)* pp. 189-193. IUCN SSC Conservation Translocation Specialist Group, Gland, Switzerland

Cowen S, Sims C, Ottewell K (2020). Monitoring and translocation of banded and rufous hare-wallabies. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **96/2020** . DBCA, Kensington, WA. 2 p.

Cowen S, Smith M, McArthur S, Ottewell K (2020). Scats all you got? Developing faecal monitoring techniques to evaluate translocation success of trap-shy mammal species. (ABSTRACT) In *Australian Mammal Society Online Conference, Lismore 2020: Book of Abstracts* p. 12

Crawford A, Cuneo P, Phillips G, Duval D, Guerin J, Wood J et al. (2020). Seed banks respond to the bushfires with collecting, research and restoration. *Australasian Plant Conservation* **29(1)**, 35-37

Crayn D, Lum M, Cantrill D, Syme A, Byrne M, Simpson L (2020). Genomics for Australian Plants consortium update. *Australasian Systematic Botany Society Newsletter* **184**, 8-9

Cross AT, Ivanov D, Stevens JC, Sadler R, Zhong H, Lambers H et al. (2021). Nitrogen limitation and calcifuge plant strategies constrain the establishment of native vegetation on magnetite mine tailings. *Plant and Soil* **461**, 181-201

Cross SL, Craig MD, Tomlinson S, Dixon KW, Bateman PW (2020). Using monitors to monitor ecological restoration: presence may not indicate persistence. *Austral Ecology* **45**, 921-932

D'Cruz E (2020). Water quality: seawater temperature monitoring in Lalang-garram marine parks. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 2 p.

D'Cruz E (2020). Water quality: seawater temperature monitoring in north Kimberley marine parks. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 2 p.

D'Cruz E, Raudino H, Waples K (2020). Lalang-garram Joint Management Body tropical inshore jigeedany (dolphin) survey in Lalang-garram marine parks, 10-18 Sept 2020. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 26 p.

Dadzie FA, Moles A, Erickson T, Muñoz-Rojas M (2020). Native microorganisms improve seedling emergence of *Acacia inaequilatera* but not *Triodia epactia* during dryland restoration. (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 26-27

Davis RA, Carter R, Burbidge AH (2021). Report on the first trial of remote camera monitoring for the Abrolhos painted button-quail (*Turnix varius scintillans*). Edith Cowan University, School of Science, Joondalup. 7 p.

Davis RW (2020). *Gomphrena verecunda* (Amaranthaceae), a modest new species from Western Australia's arid zone. *Nuytsia* **31**, 175-178

Davis RW, Hammer TA (2020). A key to the species of *Swainsona* (Fabaceae) in Western Australia and description of *S. katjarra* from the Little Sandy Desert region, Western Australia. *Swainsona* **33**, 143-148

Davis RW, Hislop M (2020). *Acacia lachnocarpa* (Fabaceae), a new, geographically restricted wattle from the Coolgardie bioregion of Western Australia. *Nuytsia* **31**, 213-216

Davis RW, Rye BL (2020). Life on the rocks: *Darwinia sphaerica* (Myrtaceae: Chamelaucieae), a new species currently known from one granite outcrop. *Nuytsia* **31**, 233-237

Davison EM, Giustiniano D (2020). *Amanita hiltonii* (Amanitaceae), a common but frequently misidentified mushroom in southwestern Australia and reconsideration of *A. albifimbriata* and *A. brunneibulbosa*. *Muelleria* **39**, 59-73

Daw B, Walley T, Keighery G (2020). Bush Tucker Plants of the South-West. Department of Biodiversity, Conservation and Attractions, Western Australia, Bush Books . Department of Biodiversity, Conservation and Attractions, Kensington, WA. 64 p.

DBCA (2020). Using remote piloted aircraft (RPA) to collect ground information for image analysis, 2020 edition: a technical guide for different environments in Western Australia. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 42 p.

de Tores PJ (2020). Native fauna response to large scale fox control in the northern jarrah forest of south-west Western Australia: Operation Foxglove. Thesis (Ph.D.) University of New South Wales. 360 p.

Delnevo N, van Etten EJ, Byrne M, Petraglia A, Carbognani M, Stock WD (2020). Habitat fragmentation restricts insect pollinators and pollen quality in a threatened Proteaceae species. *Biological Conservation* **252**: 108824

Delnevo N, van Etten EJ, Clemente N, Fogu L, Pavarani E, Byrne M et al. (2020). Pollen adaptation to ant pollination: a case study from the Proteaceae. *Annals of Botany* **126**, 377-386

Desbiens AA, Roff G, Robbins WD, Taylor BM, Castro-Sanguino C, Dempsey A et al. (2021). Revisiting the paradigm of shark-driven trophic cascades in coral reef ecosystems. *Ecology* **102**: e03303

Dillon SJ, Macfarlane TD (2020). Leeuwen's lily (*Arthropodium vanleeuwenii*: Asparagaceae), a remarkable new discovery from the Pilbara, Western Australia. *Nuytsia* **31**, 265-269

Dodd J, Rippey E, Harvey J (2020). Watching over Wadjemup: Rottnest Island's loyal volunteers. *Landscope* **36(2)**, 40-45

Duncan RP, Dexter N, Wayne A, Hone J (2020). Eruptive dynamics are common in managed mammal populations. *Ecology* **101**: e03175

Dundas SJ, Ruthrof KX, Hardy GE St J, Fleming PA (2021). Some like it hot: drought-induced forest die-off influences reptile assemblages. *Acta Oecologica* **111**: 103714

Dunlop J, Davie H, Nelson J, Read J (2020). Felixer™ feral cat grooming trap trials in the presence of northern quolls. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 10 p.

Dziminski M, Carpenter F (2021). Monitoring the abundance of greater bilbies. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **102/2021** 2 p.

Dziminski M, Carpenter F, Cowan M (2021). Occupancy monitoring of fauna at Warralong, 2019. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 73 p.

Dziminski MA, Carpenter FM, Morris F (2020). Range of the greater bilby (*Macrotis lagotis*) in the Pilbara region, Western Australia. *Journal of the Royal Society of Western Australia* **103**, 97-102

Dziminski MA, Carpenter FM, Morris F (2021). Monitoring the abundance of wild and reintroduced bilby populations. *Journal of Wildlife Management* **85**, 240-253

Eldridge MDB, Pearson DJ, Potter S (2021). Identification of a novel hybrid zone within the black-footed rock-wallaby (*Petrogale lateralis*) in Western Australia. *Australian Journal of Zoology* **68**, 98-107

Elliott C, Lewandrowski W, Turner S, Krauss S, Merritt D, Miller B et al. [Stevens J] (2021). *Tetratheca erubescens* translocation, annual research report 4 for Mineral Resources Limited, March 2020 to March 2021. Department of Biodiversity, Conservation and Attractions, Kings Park, W.A. 64 p.

Elliott CP, Turner S (2021). Experimental translocation of the threatened banded ironstone wedding bush in Western Australia. In *Global Conservation Translocation Perspectives, 2021: Case-Studies from Around the Globe (ed PS Soorae)* pp. 264-268. IUCN SSC Conservation Translocation Specialist Group, Gland, Switzerland

Erickson T (2021). Global Innovation Linkages: final report. Kings Park and Botanic Garden, West Perth. 14 p.

Evans RD, McMahon KM, van Dijk K-J, Dawkins K, Nilsson Jacobi M, Vikrant A (2021). Identification of dispersal barriers for a colonising seagrass using seascape genetic analysis. *Science of the Total Environment* **763**: 143052

Evans RD, Wilson SK, Fisher R, Ryan NM, Babcock R, Blakeway D et al. (2020). Early recovery dynamics of turbid coral reefs after recurring bleaching events. *Journal of Environmental Management* **268**: 110666

Feng S, Stiller J, Deng Y, Armstrong J, Fang Q, Hart Reeve A et al. [Cowen SJ] (2020). Dense sampling of bird diversity increases power of comparative genomics. *Nature* **587**, 252-257

Ferreira LC, Thums M, Fossette S, Wilson P, Shimada T, Tucker AD et al. [Loewenthal G, Whiting SD] (2021). Multiple satellite tracking datasets inform green turtle conservation at a regional scale. *Diversity and Distributions* **27**, 249-266

Fomichev CI, Macfarlane TD, Valiejo-Roman CM, Samigullin TH, Degtjareva GV, Briggs BG et al. (2021). Two centuries from species discovery to diagnostic characters: molecular and morphological evidence for narrower species limits in the widespread SW Australian *Anarthria gracilis* complex (Restionaceae s.l./Anarthriaceae, Poales). *PeerJ* **9**: e10935

Fossette-Halot S (2019). *Turtle Monitoring Field Guide: North West Shelf Flatback Turtle Conservation Program.* Edition 3 (reprint). Department of Biodiversity, Conservation and Attractions, Kensington, WA. 66 p.

Fossette S, Loewenthal G, Peel LR, Vitenbergs A, Hamel MA, Douglas C et al. [Tucker AD, Mayer F, Whiting SD] (2021). Using aerial photogrammetry to assess stock-wide marine turtle nesting distribution, abundance and cumulative exposure to industrial activity. *Remote Sensing* **13**: 1116

French B, Wilson S, Holmes T, Rule M, Ryan N (2021). Comparing five methods for quantifying abundance and diversity of fish assemblages in seagrass habitat. *Ecological Indicators* **124**: 107415

French B, Wilson S, Kendrick A, Rule M (2021). The mesh size effect: counting long thin fish in seagrass. *Fisheries Research* **242**: 106019

Friend JA, Hill R, Macmahon B, Bell L, Button T, Mosen C et al. [Hill S] (2020). Are red-tailed phascogales (*Phascogale calura*) at risk from Eradicat® cat baits? *Wildlife Research* **47**, 747-761

Gallagher RV, Allen S, Mackenzie BDE, Yates CJ, Gosper CR, Keith DA et al. (2021). High fire frequency and the impact of the 2019-2020 megafires on Australian plant diversity. *Diversity and Distributions* **27**, 1166-1179

Gammon M, Fossette S, McGrath G, Mitchell N (2020). A systematic review of metabolic heat in sea turtle nests and methods to model its impact on hatching success. *Frontiers in Ecology and Evolution* **8**: 556379

Geyle HM, Tingley R, Amey A, Cogger H, Couper P, Cowan M et al. (2021). Reptiles on the brink: identifying the Australian terrestrial snake and lizard species most at risk of extinction. *Pacific Conservation Biology* **27**, 3-12

Gibbons KL, Dillon SJ (2020). *Paranotis halfordii* (Rubiaceae: Spermacoceae), a new species from the Kimberley region of Western Australia, in a recently described Australian genus. *Telopea* **23**, 205-212

Gibson L (2021). Research update 2021: Subterranean Fauna Research Program: closing the knowledge gaps. Western Australian Biodiversity Science Institute, Perth. 20 p.

Gibson Vega A, Rayner K (2021). The secret life of grasswrens. *Landscope* **36(4)**, 28-32

Goldsworthy SD, Shaughnessy PD, Mackay AI, Bailleul F, Holman D, Lowther AD et al. [Waples K, Raudino H] (2021). Assessment of the status and trends in abundance of a coastal pinniped, the Australian sea lion *Neophoca cinerea*. *Endangered Species Research* **44**, 421-437

Golos PJ, Merino-Martín L, Commander LE, Elliott CP, Williams MR, Miller BP et al. [Stevens J] (2021). Interactions between soil covers and rainfall affect post-mining plant restoration in a semi-arid banded iron formation. *Ecological Engineering* **159**: 106101

Gosper CR, Coates DJ, Hopper SD, Byrne M, Yates CJ (2021). The role of landscape history in the distribution and conservation of threatened flora in the southwest Australian floristic region. *Biological Journal of the Linnean Society* **133**, 394-410

Gosper CR, Kinloch J, Coates DJ, Byrne M, Pitt G, Yates CJ (2021). Differential exposure and susceptibility to threats based on evolutionary history: how OCBIL theory informs flora conservation. *Biological Journal of the Linnean Society* **133**, 373-393

Gosper CR, Prober SM (2020). Using a multi-century post-fire chronosequence to develop criteria to distinguish Prior and Bowman's (2020) post-fire obligate coloniser and fire-intolerant flora. *Fire* **3**: 48

Grigg AH, Kinal J (2020). On the contribution of groundwater to streamflow in laterite catchments of the Darling Range, southwestern Australia. *Hydrological Processes* **34**, 5070-5084

Hampson H, Simpson T, Whiting S, Wilson P (2021). High predation of marine turtle hatchlings near a coastal jetty. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **104** 2 p.

Hardy G, Ruthrof K, Burgess T, Dunstan B (2020). Understanding the causes of *Eucalyptus rudis* decline in southwestern Australia. (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020* p. 45

Harvey ES, McLean DL, Goetze JS, Saunders BJ, Langlois TJ, Monk J et al. [Wilson SK, Holmes TH] (2021). The BRUVs workshop: an Australia-wide synthesis of baited remote underwater video data to answer broad-scale ecological questions about fish, sharks and rays. *Marine Policy* **127**: 104430

Hernandez-Santin L, Henderson M, Molloy SW, Dunlop JA, Davis RA (2020). Spatial ecology of the northern quoll in the Pilbara. (ABSTRACT) In *Australian Mammal Society Online Conference, Lismore 2020: Book of Abstracts* p. 25

Hernandez-Santin L, Henderson M, Molloy SW, Dunlop JA, Davis RA (2021). Spatial ecology of an endangered carnivore, the Pilbara northern quoll. *Australian Mammalogy* **43**, 235-242

Hickey SM, Radford B, Roelfsema CM, Joyce KE, Wilson SK, Marrable D et al. [Holmes TH, Kendrick AJ, Murray K] (2020). Between a reef and a hard place: capacity to map the next coral reef catastrophe. *Frontiers in Marine Science* **7**: 544290

Hislop M (2020). *Beyeria lateralis* (Euphorbiaceae), a previously overlooked new species from Western Australia's mallee region. *Nuytsia* **31**, 207-211

Hislop M (2020). Olearia adpressa (Asteraceae: Astereae), a new, geographically restricted species from shale breakaways in the mid west of Western Australia. *Nuytsia* **31**, 153-156

Hislop M (2020). *Stenanthera localis* (Ericaceae: Epacridoideae: Styphelieae), a new rarity from Western Australia. *Nuytsia* **31**, 271-275

Hislop M (2020). *Styphelia capillaris* (Ericaceae: Epacridoideae: Styphelieae), a formal name for a critically endangered species from Wandoo National Park. *Nuytsia* **31**, 147-151

Hislop M (2021). Interim key to, and composition of, species groups in Western Australian *Styphelia*. *Nuytsia* **32**, 29-37

Hislop M (2021). Key to the genera of Ericaceae subfamily Epacridoideae (formerly Epacridaceae) in Western Australia. *Nuytsia* **32**, 25-28

Hislop M, Wege JA (2020). A new wedding bush from the eastern goldfields of Western Australia (*Ricinocarpos digynus*: Euphorbiaceae). *Nuytsia* **31**, 169-173

Hoffmann EP, Cavanough KL, Mitchell NJ (2021). Low desiccation and thermal tolerance constrains a terrestrial amphibian to a rare and disappearing microclimate niche. *Conservation Physiology* **9**: coab027

Hopkins A, Fontaine J, Brace A, Ruthrof K (2020). Soil fungal responses to the stacked disturbances of drought and wildfire in a Mediterranean-type forest. (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 51-52

Hopper SD, Fiedler PL, Yates CJ (2021). Inselberg floristics exemplify the coast to inland OCBIL transition in a global biodiversity hotspot. *Biological Journal of the Linnean Society* **133**, 624-644

Hounslow JL, Jewell OJD, Fossette S, Whiting S, Tucker AD, Richardson A et al. (2021). Animal-borne video from a sea turtle reveals novel anti-predator behaviours. *Ecology* **102**: e03251

How RA, Cowan MA, Teale RJ, Schmitt LH (2020). Environmental correlates of reptile variation on the Houtman Abrolhos archipelago, eastern Indian Ocean. *Journal of Biogeography* **47**, 2017-2028

Huisman J (2020). Marmion Snorkel Trail. *Landscope* **36(2)**, 25-27

Huisman J (2020). My shots. *Underwater Photography* **116**, 75-76

Huisman J (2021). Diamondback squid (*Thysanoteuthis rhombus*). *Landscope* **36(3)** p. 11

Huisman J (2021). News from the Western Australian Herbarium. *Australasian Systematic Botany Society Newsletter* **186** p. 20

Huisman JM, Dixon RRM, Townsend RA, Belton GS (2021). Diversity and distribution of marine benthic algae and seagrasses in the tropical Kimberley, Western Australia. *Records of the Western Australian Museum Supplement* **85**, 185-200

Huisman JM, Guiry MD (2021). Recognition of *Dichotomaria major* (Decaisne) *comb. nov.* (Rhodophyta, Galaxauraceae) from Timor and Australia, based on *Galaxaura major* Decaisne. *Notulae Algarum* **201**, 1-4

Huisman JM, Saunders GW (2020). Out of the dark: *Leptofauchea lucida* (Rhodymeniales: Faucheaceae), a new red algal species from the Houtman Abrolhos, Western Australia. *Nuytsia* **31**, 163-167

Hyde J (2020). Using environmental DNA to conduct monitoring of rakali (*Hydromys chrysogaster*) in the SW of Western Australia. (ABSTRACT) In *AFSS 2020 Delegate Handbook, 8-10 December 2020* p. 24

Hyndman TH, Algar K, Woodward AP, Coiacetto F, Hampton JO, Nickels D et al. [Hamilton N, Algar D] (2020). Estradiol-17ß pharmacokinetics and histological assessment of the ovaries and uterine horns following intramuscular administration of estradiol cypionate in feral cats. *Animals* **10**: 1708

Ingram BA, McCowan C, Bradley T, Pinder AM (2020). First record of an aquatic oligochaete infesting fish. *International Journal for Parasitology: Parasites and Wildlife* **13**, 248-251

Irschick DJ, Bot J, Brooks A, Bresette M, Fossette S, Gleiss A et al. [Whiting S] (2020). Creating 3D models of several sea turtle species as digital voucher specimens. *Herpetological Review* **51**, 709-715

James SA (2021). Western Australian Herbarium (PERTH): reconnecting and reimagining Herbaria: recognising the diversity of WA's herbarium volunteers and local floras during National Volunteer Week. *Australasian Systematic Botany Society Newsletter* **187**, 14-15

Johansen MP, Child DP, Hotchkis MAC, Johansen A, Thiruvoth S, Whiting SD (2020). Radionuclides in sea turtles at the Montebello Islands former nuclear test sites: current and historical dose rates for adults and embryos. *Marine Pollution Bulletin* **158**: 111390

Johnston M, Algar D (2020). Glovebox Guide for Managing Feral Cats. Centre for Invasive Species Solutions, Canberra. 42 p.

Johnston M, Algar D, O'Donoghue M, Morris J, Buckmaster T, Quinn J (2020). Efficacy and welfare assessment of an encapsulated para-aminopropiophenone (PAPP) formulation as a bait-delivered toxicant for feral cats (*Felis catus*). *Wildlife Research* **47**, 686-697

Johnston T, Dziminski M, Renwick J (2021). 2020 annual report on the commercial harvest of kangaroos in Western Australia. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 31 p.

Jonsen ID, Patterson TA, Costa DP, Doherty PD, Godley BJ, Grecian WJ et al. [Whiting S] (2020). A continuous-time state-space model for rapid quality-control of Argos locations from animal-borne tags. *Movement Ecology* **8**: 31

Kallies A, Edwards ED, Williams AAE (2020). New and little known sun-moth species from Australia (Lepidoptera: Castniidae). *Zootaxa* **4895**, 151-195

Keighery B, Keighery G (2020). The vegetation and flora of the Goss Ave Bushland: a report for the City of South Perth. Wildflower Society of Western Australia, Floreat. 29 p.

Keighery BJ, Keighery GJ, Gunness AG, Longman VM, Clarke KA (2020). Wildflower Society of Western Australia, Bushland Plant Survey Program, wheatbelt surveys. Wildflower Society of Western Australia, Floreat Park. 95 p.

Keighery BJ, Keighery GJ, Longman VM, Clarke KA (2020). Wildflower Society of Western Australia, Bushland Plant Survey Program, Swan Coastal Plain surveys. Wildflower Society of Western Australia, Floreat Park. 94 p.

Keighery G (2021). *Lycopus europeus* L. (Lamiaceae), a new weed record for Australia . *Western Australian Naturalist* **32**, 48-50

Keighery G, Keighery B (2020). Illusive illyarrie. *Australasian Systematic Botany Society Newsletter* **185**, 56-57

Keighery GJ, Keighery BJ, Longman VM, McCreery K, Clarke K (2020). Floristics of reserves and bushland areas on the Dandaragan Plateau (System 6). Part 2, floristics of Chandala and Ioppolo nature reserves. Wildflower Society of Western Australia, Perth. 134 p.

Keighery G, Mitchell A (2021). A new weed alert for the north-west of Australia: mopane (*Colophospermum mopane*). *Western Australian Naturalist* **32**, 32-34

Kildisheva OA, Dixon KW, Silveira FAO, Chapman T, Di Sacco A, Mondoni A et al. [Turner SR] (2020). Dormancy and germination: making every seed count in restoration. *Restoration Ecology* **28**, S256-S265

Krauss S (2021). Kings Park summer scholars shine. *For People & Plants* **114**, 27-30

Langlois T, Goetze J, Bond T, Monk J, Abesamis RA, Asher J et al. [Holmes TH] (2020). A field and video-annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages. *Methods in Ecology and Evolution* **11**, 1401-1409

Latorre B, Moret-Fernández D, Lyons MN, Palacio S (2021). Smartphone-based tension disc infiltrometer for soil hydraulic characterisation. *Journal of Hydrology* **600**: 126551

Lewandrowski W, Stevens JC, Webber BL, Dalziell EL, Trudgen MS, Bateman AM et al. [Erickson TE] (2021). Global change impacts

on arid zone ecosystems: seedling establishment processes are threatened by temperature and water stress. *Ecology and Evolution* **11**, 8071-8084

Lindann K, Williams A (2020). Springtime butterflies around Perth: a photographic record of some urban bushland butterflies. *Newsletter of the Western Australian Insect Study Society* **Oct.**, 8-10

Lohr C, Algar D (2020). Managing feral cats in an arid landscape. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **99/2020** 2 p.

Lohr CA, Dziminski M, Dunlop J, Miller E, Morris K (2021). The reintroduction of bilbies (*Macrotis lagotis*) to Matuwa, an Indigenous Protected Area in Western Australia. *Rangeland Ecology and Management* **78**, 67-78

Lohr MT, Krauss SL, Spencer PBS, Anthony JM, Burbidge AH, Davis RA (2020). Widespread genetic connectivity in Australia's most common owl, despite extensive habitat fragmentation. *Emu: Austral Ornithology* **120**, 249-259

Lohr MT, Lohr CA, Burbidge AH, Davis RA (2020). *Toxoplasma gondii* seropositivity across urban and agricultural landscapes in an Australian owl. *Emu: Austral Ornithology* **120**, 275-285

Lowe JR, Williamson DH, Ceccarelli DM, Evans RD, Russ GR (2020). Environmental disturbance events drive declines in juvenile wrasse biomass on inshore coral reefs of the Great Barrier Reef. *Environmental Biology of Fishes* **103**, 1279-1293

Lowe M-A, McGrath G, Leopold M (2021). The impact of soil water repellency and slope upon runoff and erosion. *Soil and Tillage Research* **205**: 104756

Lyons MN, Markey A (2021). Fortescue Valley Dunes PEC, South East Marillana Station: botanical values, condition assessment and approaches to minimize stock impacts. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 33 p.

Ma H, Erickson TE, Walck JL, Merritt DJ (2020). Interpopulation variation in germination response to fire-related cues and after-ripening in seeds of the evergreen perennial *Anigozanthos flavidus* (Haemodoraceae). *International Journal of Wildland Fire* **29**, 950-960

Macfarlane TD (2020). Nowhere to be seen: *Deyeuxia abscondita* (Poaceae), a new but presumed extinct species from south-western Australia. *Nuytsia* **31**, 179-185

Macfarlane TD, Brown AP, French CJ (2020). *Wurmbea flavanthera* (yellow-anthered wurmbea: Colchicaceae), a new species from Western Australia's mid west region. *Nuytsia* **31**, 197-202

Macfarlane TD, Conran JG, French CJ (2020). *Caesia arcuata* (Hemerocallidaceae) from Western Australia, a new rarity with curved inflorescence branches. *Nuytsia* **31**, 239-242

Macfarlane TD, Degtjareva GV, Samigullin TH, Valiejo-Roman CM, Fomichev CI, Sokoloff DD (2020). *Althenia tzvelevii* (Potamogetonaceae), a new species from SW Western Australia with bilocular anthers: morphology and molecular phylogenetic relationships. *Phytotaxa* **471**, 193-207

Macfarlane TD, Ross JH, Smith J-A, Hearn RW (2020). Formal naming of *Bossiaea reptans* (Fabaceae), an endangered species from the Warren region, Western Australia. *Nuytsia* **31**, 157-161

MacNeil MA, Chapman D, Heupel M, Simpfendorfer CA, Heithaus M, Meekan M et al. [Goetze J] (2020). Global status and conservation potential of reef sharks. *Nature* **583**, 801-806

Manero A, Young R, Miller B, Jasper D, Kragt M, Standish R et al. (2020). A framework for developing completion criteria for mine closure and rehabilitation. *Journal of Environmental Management* **273**: 111078

Markey A, Comer S, Burbidge A (2020). Botanical surveys of western ground parrot habitat to inform translocation site selection: summary report, October 2020. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 9 p.

Maron M, Evans M, Walsh J, Leseberg N, Burbidge A, Murphy S et al. (2021). Better offsets for the night parrot: science for saving species, research findings factsheet, project 5.1. Threatened Species Recovery Hub, Canberra. 6 p.

Masarei M, Astfalck LC, Guzzomi AL, Merritt DJ, Erickson TE (2020). Soil rock content influences the maximum seedling emergence depth of a dominant arid zone grass. *Plant and Soil* **450**, 497-509

Masarei MI, Erickson TE, Merritt DJ, Hobbs RJ, Guzzomi AL (2021). Engineering restoration for the future. *Ecological Engineering* **159**: 106103

Maschinski J, Albrecht MA, Fant J, Monks L, Lange J, Coffey E et al. (2020). Rare plant reintroduction and other conservation translocations. Available at: https://tinyurl.com/48yjj2sk 59 p.

Mayne B, Tucker AD, Berry O, Jarman S (2020). Lifespan estimation in marine turtles using genomic promoter CpG density. *PLoS One* **15**: e0236888

Mazanec RA, Grayling PM, Doran J, Spencer B, Neumann C (2020). Provenance variation, genetic parameters and potential gains from selection for biomass and cineole production in three-year-old *Eucalyptus loxophleba* subsp. *gratiae* progeny trials. *Australian Forestry* **83**, 75-90

Mazanec RA, Grayling PM, Doran J, Spencer B, Turnbull P (2021). Genetic parameters and potential gains from breeding for biomass and cineole production in three-year-old *Eucalyptus polybractea* progeny trials. *Australian Forestry* **84**, 13.24

McCaw L, Tunsell V (2021). FORESTCHECK: report of progress, jarrah north west ecosystem, 2021. Department of Biodiversity, Conservation and Attractions, Manjimup. 26 p.

McCaw L, Tunsell V (2021). FORESTCHECK: report of progress, jarrah south ecosystem, 2020. Department of Biodiversity, Conservation and Attractions, Manjimup. 49 p.

McClanahan TR, Darling ES, Maina JM, Muthiga NA, D'agata S, Leblond J, et al. [Wilson SK] (2020). Highly variable taxa-specific coral bleaching responses to thermal stresses. *Marine Ecology Progress Series* **648**, 135-151

McClanahan TR, Maina JM, Darling ES, Guillaume MMM, Muthiga NA, D'agata S et al. [Wilson SK] (2020). Large geographic variability in the resistance of corals to thermal stress. *Global Ecology and Biogeography* **29**, 2229-2247

McGrath G (2020). Predicting flow and quality variability in growing urban drainage. Abstract of presentation at Hydropolis 2020: water sensitive stormwater is business as usual: what is next for WA? November 10-November 11, Maylands. p. 1

McKenzie NL, Bullen RD, Pennay M (2020). Echolocation and foraging ecology of the bristle-faced free-tailed bat, *Setirostris eleryi*, in central Australia. *Australian Mammalogy* **42**, 302-311

McKenzie NL, Bullen RD, Gibson LA (2019 (ie 2021)). Habitat associations of zoophagic bat ensembles in north-western Australia. *Australian Journal of Zoology* **67**, 243-259

Millar MA, Byrne M (2020). Variable clonality and genetic structure among disjunct populations of *Banksia mimica*. *Conservation Genetics* **21**, 803-818

Millar MA, Coates DJ, Byrne M, Krauss SL, Jonson J, Hopper SD (2021). Evaluating restoration outcomes through assessment of pollen dispersal, mating system and genetic diversity. *Restoration Ecology* **29**: e13335

Millar MA, Mezgebe K, Hagazi N, Cunningham P, Byrne M (2020). Genetic assignment, diversity and divergence of naturalised *Acacia saligna* (Fabaceae) in Tigray, Ethiopia. *Tree Genetics and Genomes* **16**: 54

Miller B, Miller R (2020). Adding fuel to the fire: invasive grass management and fire in urban fragments. *Landscope* **36(1)**, 45-49

Miller R, Merritt D, Miller B, Fontaine J, Enright N (2021). Experimental test of seedling recruitment response to season of fire. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **105** 2 p.

Moir ML, Brennan KEC (2020). Incorporating coextinction in threat assessments and policy will rapidly improve the accuracy of threatened species lists. *Biological Conservation* **249**: 108715

Monks L, Coates D (2020). Fire a vital ingredient for the recovery of a critically endangered wattle. *Science for Saving Species* **16** p. 19

Moore HA, Michael DR, Ritchie EG, Dunlop JA, Valentine LE, Hobbs RJ et al. (2021). A rocky heart in a spinifex sea: occurrence of an endangered marsupial predator is multiscale dependent in naturally fragmented landscapes. *Landscape Ecology* **36**, 1359-1376

Moore HA, Valentine LE, Dunlop JA, Nimmo DG (2020). The effect of camera orientation on the detectability of wildlife: a case study from north-western Australia. *Remote Sensing in Ecology and Conservation* **6**, 546-556

Muñoz-Rojas M, Erickson TE, Ooi MKJ, Merritt DJ (2020). Global change impacts on soil microbial diversity and function: implications for soil and ecosystem restoration. (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 80-81

Nistelberger HM, Binks RM, van Leeuwen S, Coates DJ, McArthur SL, Macdonald BM et al. [Hankinson M, Byrne M] (2020). Extensive genetic connectivity and historical persistence are features of two widespread tree species in the ancient Pilbara region of Western Australia. *Genes* **11**: 863

Nistelberger HM, Tapper SL, Coates DJ, McArthur SL, Byrne M (2021). As old as the hills: Pliocene palaeogeographical processes influence patterns of genetic structure in the widespread, common shrub *Banksia sessilis*. *Ecology and Evolution* **11**, 1069-1082

Novak PA, Fairfield CA, Miloshis M, Knight ZC, Lindsay R, King AJ (2021). Bank erosion in a macrotidal tropical river: exploring the relative impact of boat wash on riverbank erosion. *River Research and Applications* **37**, 3-16

O'Connor K, Fossette-Halot S, Hampson H (2020). Yoshi's journey: one turtle, two countries, thousands of kilometres. *Landscope* **36(1)**, 19-21

Ottewell K, Thavornkanlapachai R, McArthur S, Spencer PBS, Tedeschi J, Durrant B et al. [Byrne M] (2020). Development and optimisation of molecular assays for microsatellite genotyping and molecular sexing of non-invasive samples of the ghost bat, *Macroderma gigas*. *Molecular Biology Reports* **47**, 5635-5641

Pacioni C, Atkinson A, Wayne AF, Maxwell MA, Ward CG, Spencer PBS (2020). Spatially sensitive harvest design can minimize genetic relatedness and enhance genetic outcomes in translocation programmes. *Journal of Zoology* **312**, 32-42

Paianoa MO, Huisman JM, Cabrera FP, Spalding HL, Kosaki RK, Sherwood AR (2020). *Haraldiophyllum hawaiiensis sp. nov.* (Delesseriaceae, Rhodophyta): a new mesophotic genus record for the Hawaiian Islands. *Algae* **35**, 337-347

Palmer B, Beca G, Valentine L, Erickson T, Hobbs R (2020). Investigations into the role of Australian omnivorous marsupials as seed dispersers. (ABSTRACT) In *Australian Mammal Society Online Conference, Lismore 2020: Book of Abstracts* p. 29

Palmer BJ, Valentine LE, Lohr CA, Daskalova GN, Hobbs RJ (2021). Burrowing by translocated boodie (*Bettongia lesueur*) populations alters soils but has limited effects on vegetation. *Ecology and Evolution* **11**, 2596-2615

Palmer B, Valentine L, Lohr C, Hobbs R (2020). Soil disturbance by reintroduced digging mammals increases non-native seedling abundance. (ABSTRACT) In *Australasian Wildlife Management Society 33rd Annual Conference: 8-10 December 2020, Online Australia: Book of Abstracts* p. 18

Palmer R, Anderson H, Richards B, Craig MD, Gibson LA (2021). Does aerial baiting for controlling feral cats in a heterogeneous landscape confer benefits to a threatened native meso-predator? *PLoS One* **16**: e0251304

Pearson D, Thomson-Dans C, Wardell-Johnson G (2021). Frogs of Western Australia. Department of Biodiversity, Conservation and Attractions, Western Australia, Bush Books . Department of Biodiversity, Conservation and Attractions, Kensington, WA. 72 p.

Penton C, von Takach B, Davies H, Radford I, Woolley L-A, Murphy B (2020). The last *Conilurus*: insights into the drastic decline and future of the brush-tailed rabbit-rat (*Conilurus pencillatus*). (ABSTRACT) In *Australian Mammal Society Online Conference, Lismore 2020: Book of Abstracts* p. 3

Penton CE, Woolley L-A, Radford IJ, Murphy BP (2020). Overlapping den tree selection by three declining arboreal mammal species in an Australian tropical savanna. *Journal of Mammalogy* **101**, 1165-1176

Percy-Bower JM, Parker CM (2021). Updates to Western Australia's vascular plant census for 2020. *Nuytsia* **32**, 1-23

Pinder A, Cale D, Lewis L (2020). Aquatic invertebrate diversity of Lake McLarty in 2019. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 25 p.

Pinder A, Felton F, Venarsky M, Cale D, Barrett P (2021). Surveys of waterbirds using the Lake Warden and Lake Gore Ramsar sites in November 2020 and February 2021. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 37 p.

Plucinski MP, Sullivan AL, McCaw WL (2020). Comparing the performance of daily forest fire danger summary metrics for estimating fire activity in southern Australian forests. *International Journal of Wildland Fire* **29**, 926-938

Potter IC, Rose TH, Huisman JM, Hall NG, Denham A, Tweedley JR (2021). Large variations in eutrophication among estuaries reflect massive differences in composition and biomass of macroalgal drift. *Marine Pollution Bulletin* **167**: 112330

Pratchett M, Caballes C, Messmer V, Wilson S, Roelofs A, Penny S et al. (2020). Vulnerability of commercially harvested corals to fisheries exploitation versus environmental pressures. Fisheries Research and Development Corporation, Deakin, A.C.T. 96 p.

Pratchett MS, Caballes CF, Newman SJ, Wilson SK, Messmer V, Pratchett DJ (2020). Bleaching susceptibility of aquarium corals collected across northern Australia. *Coral Reefs* **39**, 663-673

Pratchett MS, Messmer V, Wilson SK (2020). Size-specific recolonization success by coral-dwelling damselfishes moderates resilience to habitat loss. *Scientific Reports* **10**: 17016

Price BA, Harvey ES, Mangubhai S, Saunders BJ, Puotinen M, Goetze JS (2021). Responses of benthic habitat and fish to severe tropical cyclone Winston in Fiji. *Coral Reefs* **40**, 807-819

Radford I, Corey B, Carnes K, Fairman R, Woolley LA (2020). Prescribed burning benefits threatened mammals in Kimberley tropical savannas. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **98/2020** . DBCA, Kensington, WA. 3 p.

Radford IJ, Woolley L-A, Corey B, Vigilante T, Wunambal Gaambera Aboriginal Corporation, Hatherley E et al. [Fairman R, Start AN] (2020). Prescribed burning benefits threatened mammals in northern Australia. *Biodiversity and Conservation* **29**, 2985-3007

Raudino H, D'Cruz E, Waples K, Menzies J, Murdoch J, Quartermaine T et al. (2020). Dry season dreaming: snubfin census on Yawuru sea country. *Landscope* **36(1)**, 41-44

Rayner K, Sims C, Knox F, Cowen S (2020). The 'coot of the problem: developing an effective method of radio-tracking Shark Bay bandicoots *Perameles bougainville*. (ABSTRACT) In *Australian Mammal*

Society Online Conference, Lismore 2020: Book of Abstracts p. 13

Reiter N, Phillips RD, Swarts ND, Wright M, Holmes G, Sussmilch F et al. [Davis BJ] (2020). Specific mycorrhizal associations involving the same fungal taxa in common and threatened Caladenia (Orchidaceae): implications for conservation. *Annals of Botany* **126**, 943-955

Richards B, Sullivan M, Mawson PR (2020). A case study of environmental offsets for the endangered Carnaby's cockatoo (*Calyptorhynchus latirostris*). *Pacific Conservation Biology* **26**, 269-281

Rick K, Mitchell N, Ottewell K, Travouillon KJ (2020). Understanding patterns of phenotypic and genetic divergence in island mammals to improve conservation outcomes. (ABSTRACT) In *Australian Mammal Society Online Conference, Lismore 2020: Book of Abstracts* p. 24

Ritchie AL, Stevens JC, Erickson TE (2020). Developing extruded seed pellets to overcome soil hydrophobicity and seedling emergence barriers. *Ecological Solutions and Evidence* **1**: e12024

Ritchie A, Svejcar L (2020). Banksia woodlands 30 years in review: research advances and priorities for a threatened ecological community. *For People & Plants* **111**, 34-37

Ritchie AL, Svejcar LN, Ayre BM, Bolleter J, Brace A, Craig MD et al. [Davis B, Krauss SL, Miller BP, Miller RG, Ramalho CE, Ruthrof KX, Stevens JC] (2021). A threatened ecological community: research advances and priorities for banksia woodlands. *Australian Journal of Botany* **69**, 53-84

Roberts JD, Danks A, Berryman A, Sidhu N, Burbidge AH, Comer S (2020). Population decline of the noisy scrub-bird is not correlated with territory size, marginal declines in rainfall or fire impacts. *Pacific Conservation Biology* **26**, 230-238

Robins TP, Binks RM, Byrne M, Hopper SD (2021). Contrasting patterns of population divergence on young and old landscapes in *Banksia seminuda* (Proteaceae), with evidence for recognition of subspecies. *Biological Journal of the Linnean Society* **133**, 449-463

Robins TP., Binks RM, Byrne M, Hopper SD (2021). Landscape and taxon age are associated with differing patterns of hybridization in two *Eucalyptus* (Myrtaceae) subgenera. *Annals of Botany* **127**, 49-62

Rodríguez-Prieto C, Afonso-Carrillo J, De Clerck O, Huisman JM, Lin S-M (2020). Systematic revision of the foliose Halymeniaceae (Halymeniales, Rhodophyta) from Europe, with the description of *Halymenia ballesterosii sp. nov.* from the Mediterranean Sea and *Nesoia hommersandii* from the Canary Islands. *European Journal of Phycology* **55**, 454-466

Ross C (2020). Monitoring the Montebello and Barrow islands marine life. *Monte-Barrow News* **6**, 6-7

Rutherford J (2020). Petrophysics of peat in the Muir-Byenup wetlands: why they dry, generate acid and burn (part 1). Department of Biodiversity, Conservation and Attractions, Kensington, WA. 104 p.

Rutherford J (2021). Impending loss of carbon from drying wetlands in southwestern Australia. (ABSTRACT) *Wetland Science and Practice* **38**, 50-51

Rutherford J, Ibrahimi T, Munday T, Markey A, Viezzoli A, Rapiti A et al. (2021). An assessment of water sources for heritage listed organic mound springs in NW Australia using airborne geophysical (electromagnetics and magnetics) and satellite remote sensing methods. *Remote Sensing* **13**: 1288

Ruthrof K, van Dongen R, Ruscalleda-Alvarez J, Tarrant D, Kala J, Fontaine J et al. [McCaw L] (2020). Cross-scale investigation of declining forest cover in southwestern Australia. (ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 96-97

Ruthrof K, van Dongen R, Tarrant D, Ruscalleda Alvarez J, Hardy GS St. J, Fontaine J et al. [McCaw L] (2020). Cross-scale investigation of declining forest cover in southwestern Australia. (ABSTRACT) In *ESA2020, Ecological Society of America: Harnessing the Ecological Data Revolution, August 3-6, 2020*, 1-2

Rycken S, Shephard JM, Yeap L, Vaughan-Higgins R, Page M, Dawson R et al. [Mawson PR] (2021). Regional variation in habitat matrix determines movement metrics in Baudin's cockatoos in southwest Western Australia. *Wildlife Research* **48**, 18-29

Rye BL, Barrett MD (2020). A new species that's worth its salt: *Verticordia elizabethiae* (Myrtaceae: Chamelaucieae), a salt-tolerant rarity from semi-arid Western Australia. *Nuytsia* **31**, 259-263

Samaniego A, Kappes P, Broome K, Cranwell S, Griffiths R, Harper G, et al. [Palmer R] (2020). Lessons learned from failed island rodent eradications redone successfully: implications for the second rat eradication attempt on Wake Atoll. APHIS Wildlife Services National Wildlife Research Center, Hilo, Hawaii. 97 p.

Samaniego A, Kappes P, Broome K, Cranwell S, Griffiths R, Harper G et al. [Palmer R] (2021). Factors leading to successful island rodent eradications following initial failure. *Conservation Science and Practice* **3**: e404

Saunders DA, Mawson PR, Dawson R (2020). Predation by southwestern carpet python *Morelia spilota imbricata* of Carnaby's cockatoo *Calyptorhynchus latirostris* in a breeding hollow. *Australian Zoologist* **41**, 54-57

Scaccabarozzi D (2021). Clever donkey orchids: a misleading advertisement for native bees. *For People & Plants* **113**, 30-33

Schramm KD, Marnane MJ, Elsdon TS, Jones C, Saunders BJ, Goetze JS et al. (2020). A comparison of stereo-BRUVs and stereo-ROV techniques for sampling shallow water fish communities on and off pipelines. *Marine Environmental Research* **162**: 105198

Seidlitz A, Bryant KA, Armstrong NJ, Calver M, Wayne AF (2021). Optimising camera trap height and model increases detection and individual identification rates for a small mammal, the numbat (*Myrmecobius fasciatus*). *Australian Mammalogy* **43**, 226-234

Semple L, Ottewell K, Sims C, Simianer H, Byrne M (2020). Genetic viability of a reintroduced population of south-western common brush-tail possum (*Trichosurus vulpecula hypoleucus*), Western Australia. *Pacific Conservation Biology* **26**, 282-292

Shepherd KA (2020). *Goodenia quartzitica* (Goodeniaceae), a new range-restricted species discovered in a remote part of the eastern Gascoyne bioregion . *Nuytsia* **31**, 193-196

Shepherd KA, Hislop M (2020). Between a rock and a hard place: *Quoya zonalis* (Lamiaceae: Chloantheae), a new threatened foxglove from Western Australia's Pilbara region. *Nuytsia* **31**, 217-221

Shepherd KA, Hislop M (2020). Crystal clear: *Dampiera prasiolitica* (Goodeniaceae), a distinctive new Western Australian species with translucent sepals . *Nuytsia* **31**, 249-252

Shepherd KA, Lepschi BJ, Johnson EA, Gardner AG, Sessa EB, Jabaily RS (2020). The concluding chapter: recircumscription of *Goodenia* (Goodeniaceae) to include four allied genera with an updated infrageneric classification. *Phytokeys* **152**, 27-104

Shepherd KA, Wilkins CF (2020). Persistence pays off: resolution of *Lasiopetalum hapalocalyx* (Malvaceae: Byttnerioideae), a new species from south-western Australia. *Nuytsia* **31**, 229-232

Sherwood AR, Huisman JM, Paianoa MO, Williams TM, Kosaki RK, Smith CM et al. (2020). Taxonomic determination of the cryptogenic red alga, Chondria tumulosa sp. nov., (Rhodomelaceae, Rhodophyta) from Papahânaumokuâkea Marine National Monument, Hawai'i, USA: a new species displaying invasive characteristics. *PLoS One* **15**: e0234358

Silcock J, Collingwood T, Llorens T, Fensham R (2021). Action Plan for Australia's Imperilled Plants 2021. NESP Threatened Species Recovery Hub, Brisbane. 342 p.

Sims C, Cowen S, Garretson S, Gibson Vega A, Friend T (2021). Monitoring source populations of fauna for the Dirk Hartog Island National Park Ecological Restoration Project, 2020. Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 21 p.

Sinclair EA, Edgeloe JM, Anthony JM, Statton J, Breed MF, Kendrick GA (2020). Variation in reproductive effort, genetic diversity and mating systems across Posidonia australis seagrass meadows in Western Australia. *AoB Plants* **12**: plaa038

Sinclair E, Oxenham T, Lewandrowski W (2021). Seagrass science inspires Malgana artist. *For People & Plants* **114**, 24-26

Skates L (2021). How carnivorous are carnivorous plants? *For People & Plants* **113**, 26-29

Skey E, Shaw R, Ottewell K, Spencer P (2020). Landscape genetics and simulation approach to understanding connectivity in small mammals in the Pilbara, WA. (POSTER ABSTRACT) In *Book of Abstracts: Ecological Society of Australia, 60th Anniversary Conference, 30 Nov.-4 Dec. 2020*, 105-106

Spencer B, Mazanec R, Abadi A, Gibberd M, Zerihun A (2020). Flowering phenology in a *Eucalyptus loxophleba* seed orchard, heritability and genetic correlation with biomass production and cineole: breeding strategy implications. *Scientific Reports* **10**: 15303

Spencer B, Mazanec R, Gibberd M, Zerihun A (2021). Sapling and coppice biomass heritabilities and potential gains from *Eucalyptus polybractea* progeny trials. *Tree Genetics and Genomes* **17**: 15

Strydom S, Wilson S, Murray K (2020). Loss of seagrass driven by marine heatwave in Shark Bay Marine Park and world heritage area. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **97/2020** . DBCA, Kensington, WA. 2 p.

Stubbs JL, Marn N, Vanderklift MA, Fossette S, Mitchell NJ (2020). Simulated growth and reproduction of green turtles (*Chelonia mydas*) under climate change and marine heatwave scenarios. *Ecological Modelling* **431**: 109185

Subroy V, Barnes M, Monks L, Crawford A, Coates D, Pandit R et al. [Gosper C, Yates C] (2021). Trade-offs and synergies between in situ and ex situ taxa conservation to support practical decision-making: report to the National Environmental Science Programme, Department of Environment, Canberra. Centre for Environmental Economics and Policy, Crawley. 104 p.

Sun R, Ottewell K, Byrne M (2021). Genetic relationships of *Isoodon bandicoot* species in southern and western Australia. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **103** 2 p.

Svejcar L (2020). Grasses give a helping hand. *For People & Plants* **111**, 38-41

Tan YM, Dalby O, Kendrick GA, Statton J, Sinclair EA, Fraser MW et al. (2020). Seagrass restoration is possible: insights and lessons from Australia and New Zealand. *Frontiers in Marine Science* **7**: 617

Tangney R, Merritt DJ, Callow JN, Fontaine JB, Miller BP (2020). Seed traits determine species responses to fire under varying soil heating scenarios. *Functional Ecology* **34**, 1967-1978

Tangney R, Merritt D, Miller B, Easton S (2020). Not too shallow, not too deep: the Goldilocks zone for seedling emergence in fire-prone ecosystems. *For People & Plants* **112**, 25-28

Tangney R, Miller RG, Enright NJ, Fontaine JB, Merritt DJ, Ooi MKJ et al. [Ruthrof KX, Miller BP] (2020). Seed dormancy interacts with fire seasonality mechanisms (LETTER). *Trends in Ecology and Evolution* **35**, 1057-1059

Thavornkanlapachai R, Armstrong K, Hanrahan N, Ottewell K (2020). A new diagnostic tool for non-invasive genetic monitoring of the ghost bat, Macroderma gigas: custom-designed SNP arrays using the Agena MassArray platform. (ABSTRACT) In *Australian Mammal Society Online Conference, Lismore 2020: Book of Abstracts* p. 24

Thavornkanlapachai R, Levy E, Li Y, Cooper SJB, Byrne M, Ottewell K (2021). Disentangling the genetic relationships of three closely-related bandicoot species across southern and Western Australia. *Diversity* **13**: 2

Thavornkanlapachai R, Mills HR, Ottewell K, Friend JA, Kennington WJ (2021). Temporal variation in the genetic composition of an endangered marsupial reflects reintroduction history. *Diversity* **13**: 257

Thomas A, Speldewinde P, Roberts JD, Burbidge AH, Comer S (2020). If a bird calls, will we detect it? Factors that can influence the detectability of calls on automated recording units in field conditions. *Emu: Austral Ornithology* **120**, 239-248

Thomas WJW, Anthony JM, Dobrowolski MP, Krauss SL (2021). Optimising the conservation of genetic diversity of the last remaining population of a critically endangered shrub. *AoB Plants* **13**: plab005

Thomson DP, Babcock RC, Evans RD, Feng M, Moustaka M, Orr M et al. [Wilson SK] (2021). Coral larval recruitment in north-western Australia predicted by regional and local conditions. *Marine Environmental Research* **168**: 105318

Thomson DP, Babcock RC, Haywood MDE, Vanderklift MA, Pillans RD, Bessey C et al. [Wilson SK] (2020). Zone specific trends in coral cover, genera and growth-forms in the World-Heritage listed Ningaloo Reef. *Marine Environmental Research* **160**: 105020

Tomlinson S (2020). The construction of small-scale, quasi-mechanistic spatial models of insect energetics in habitat restoration: a case study of beetles in Western Australia. *Diversity and Distributions* **26**, 1016-1033

Townsend RA, Huisman JM (2021). Nomenclatural considerations of names associated with the euglenoid flagellate genera *Strombomonas* and *Trachelomonas* (Euglenaceae, Euglenophyceae) in Australia. *Notulae Algarum* **203**, 1-56

Trayler K, Cosgrove J (2021). Blooming surprise: toxic algal blooms in Perth rivers. *Landscope* **36(3)**, 50-52

Trayler K, Hipsey M (2020). Understanding and predicting riparian decline: ecohydrology and hydro-climatological change. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **101/2020** 2 p.

Trayler K, Hyndes G (2020). Investigating habitat values of seagrass, macroalgae and wrack in Swan Canning Riverpark. Department of Biodiversity, Conservation and Attractions, Western Australia, Information Sheet **100/2020** 2 p.

Treloar S, Davis R, Hopkins A, Lohr C (2020). Potential for resource competition between co-existing threatened mammals in a fenced reserve in Western Australia. Abstract of presentation at Ecological Society of Australia, 60th anniversary conference, 30 Nov.-4 Dec. 2020. p. 1

Turner SR, Bunn E, Elliott CP (2021). Experimental translocation of the endangered pearl-like *Androcalva* in south-west Western Australia. In *Global Conservation Translocation Perspectives, 2021: Case-Studies from Around the Globe (ed PS Soorae)* pp. 322-326. IUCN SSC Conservation Translocation Specialist Group, Gland, Switzerland

Valentine LE, Shackelford N, Johnson BA, Craig MD, Perring MP, Hulvey KB et al. [Erickson TE, Ritchie A, Ramalho CE] (2020). Richard J. Hobbs: how one ecologist has influenced the way we think about restoration ecology. *Restoration Ecology* **28**, 1042-1046

van Dongen R (2020). Dirk Hartog Island National Park Ecological Restoration Project: vegetation restoration: remote sensing monitoring program report, 2019/20. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 90 p.

van Dongen R (2020). Vegetation cover change assessment on Yarraloola and Red Hill: remote sensing monitoring program report, 2019. 61 p.

van Dongen R, Huntley B, Zdunic K (2020). Bernier and Dorre Islands vegetation cover report, 2019. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 26 p.

van Dongen R, Ruscalleda Alvarez J, Zdunic K, Chapman J (2020). Great Victoria Desert fire scar mapping report, 2020. Department of Biodiversity, Conservation and Attractions, Kensington, WA. 60 p.

Vanderklift MA, Babcock RC, Barnes PB, Cresswell AK, Feng M, Haywood MDE et al. [Holmes TH, Tucker AD, Waples K, Wilson SK] (2020). The oceanography and marine ecology of Ningaloo, a World Heritage Area. *Oceanography and Marine Biology: an Annual Review* **58**, 143-178

Vanderklift MA, Pillans RD, Robson NA, Skrzypek G, Stubbs JL, Tucker AD (2020). Comparisons of stable isotope composition among tissues of green turtles. *Rapid Communications in Mass Spectrometry* **34**: e8839

Vaughan EJ, Wilson SK, Howlett, SJ, Parravicinni V, Williams GJ, Graham NAJ (2021). Nitrogen enrichment in macroalgae following mass coral mortality. *Coral Reefs* **40**, 767-776

von Takach B, Penton CE, Murphy BP, Radford IJ, Davies HF, Hill BM et al. (2021). Population genomics and conservation management of a declining tropical rodent. *Heredity* **126**, 763-775

Ward B, Wills A, Tunsell V (2020). Silviculture and fire effects on understorey flowering in jarrah forest. *Australian Forestry* **83**, 152-160

Ward-Fear G, Brown GP, Pearson D, Shine R (2021). Untangling the influence of biotic and abiotic factors on habitat selection by a tropical rodent. *Scientific Reports* **11**: 12895

Wayne AF, Read E, Maxwell MA, Ward CG (2021). Breeding patterns for western brush wallaby (*Notamacropus irma*) in the southern jarrah forest. Department of Biodiversity, Conservation and Attractions, Manjimup, WA. 5 p.

Wege J (2020). A golden year for Nuytsia. *Australasian Systematic Botany Society Newsletter* **185**, 46-49

Wege J (2020). Leeuwen's lily: a botanical tribute to Stephen van Leeuwen. *Yarning Time* **7** p. 21

Wege JA (2020). *Stylidium shepherdianum* (Stylidiaceae), a new boomerang triggerplant from Western Australia's mallee bioregion. *Nuytsia* **31**, 253-257

Wege J (2020). Summer stylewort. *Landscope* **36(2)** p. 11

Wege J (2021). Western Australian Herbarium (PERTH): Ben Anderson returns to Australia. *Australasian Systematic Botany Society Newsletter* **187** p. 15

Wege JA, Davis RW (2020). A case of mistaken identity: *Isotropis iophyta* (Fabaceae), a new Western Australian lamb's poison previously confused with *I. forrestii. Nuytsia* **31**, 187-191

Wege JA, Orchard AE (2020). Shining some light on a poorly known species: *Haloragis luminosa* (Haloragaceae), a new Western Australian species from a threatened ecological community . *Nuytsia* **31**, 203-206

Wege J, Shepherd K (2020). A golden year for Nuytsia. *Landscope* **36(2)**, 18-22

Wege JA, Shepherd KA (2020). A golden year for Nuytsia, the journal of the Western Australian Herbarium. *Research Matters: Newsletter of the Australian Flora Foundation* **32**, 2-8

Wege JA, Start AN (2020). Snakewood mistletoe (Amyema xiphophylla: Loranthaceae), a distinctive new species from Western Australia's arid zone. *Nuytsia* **31**, 277-281

Wheeler J, Davis R (2021). Wildflowers of the South Coast. Department of Biodiversity, Conservation and Attractions, Western Australia, Bush Books . Department of Biodiversity, Conservation and Attractions, Kensington, WA. 72 p.

White DJ, Ottewell K, Spencer PBS, Smith M, Short J, Sims C et al. (2020). Genetic consequences of multiple translocations of the banded hare-wallaby in Western Australia. *Diversity* **12**: 448

White LC, Thomson VA, West R, Ruykys L, Ottewell K, Kanowski J et al [Byrne M] (2020).Genetic monitoring of the greater stick-nest rat meta-population for strategic supplementation planning. *Conservation Genetics* **21**, 941-956

Wilkins CF, Sandiford EM (2020). *Gompholobium glabristylum* (Fabaceae), a new native pea from montane habitats in Stirling Range National Park. *Nuytsia* **31**, 223-227

Williams AAE, Williams MR, Heterick BE (2020). Notes on the distribution, habitat, behaviour and flight times of the large bronze azure *Ogyris idmo* (Hewitson, 1862) (Lepidoptera: Lycaenidae) a rare myrmecophilous butterfly from south-western Western Australia. *Australian Entomologist* **47**, 221-247

Williams AAE, Williams MR, Bishop CL, Gamblin T, Fissioli J, Coppen RAM (2021). Notes on the biology, ecology, life history and conservation of the graceful sun-moth *Synemon gratiosa* Westwood 1877 (Lepidoptera: Castniidae). *Australian Entomologist* **48**, 17-32

Wilson P, Thums M, Pattiaratchi C, Whiting S, Meekan M, Pendoley K (2021). Nearshore wave characteristics as cues for swimming orientation in flatback turtle hatchlings. *Journal of Experimental Marine Biology and Ecology* **535**: 151475

Wilson S (2021). A seaweed summer house for fish. *Ningaloo Coast News* **Winter 2021** p. 2

Wilson S, Holmes T, Goetze J (2020). Department of Biodiversity, Conservation and Attractions (DBCA): research and monitoring by the Marine Science Program. *Lateral Lines: Australian Society for Fish Biology Newsletter* **50(2)**, 60-61

Wilson TC, Hislop M (2020). *Microcorys elatoides* (Lamiaceae), a new species from the Coolgardie bioregion of Western Australia. *Nuytsia* **31**, 243-248

Woinarski JCZ, Legge SM, Woolley LA, Palmer R, Dickman CR, Augusteyn J et al. (2020). Predation by introduced cats *Felis catus* on Australian frogs: compilation of species records and estimation of numbers killed. *Wildlife Research* **47**, 580-588

Woolley L-A, Murphy BP, Geyle HM, Legge SM, Palmer RA, Dickman CR et al. (2020). Introduced cats eating a continental fauna: invertebrate consumption by feral cats (*Felis catus*) in Australia. *Wildlife Research* **47**, 610-623

Wysong ML, Iacona GD, Valentine LE, Morris K, Ritchie EG (2020). On the right track: placement of camera traps on roads improves detection of predators and shows non-target impacts of feral cat baiting. *Wildlife Research* **47**, 557-569

Young EJ, Bannister J, Buller NB, Vaughan-Higgins RJ, Stephens NS, Whiting SD et al. (2020). Streptococcus iniae associated mass marine fish kill off Western Australia. *Diseases of Aquatic Organisms* **142**, 197-201

Zarco-Perello S, Carroll G, Vanderklift M, Holmes T, Langlois TJ, Wernberg T (2020). Range-extending tropical herbivores increase diversity, intensity and extent of herbivory functions in temperate marine ecosystems. *Functional Ecology* **34**, 2411-2421

Summary of Research Projects

Biodiversity Information Office

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions	All Regions	BIO biodiversity data platform	4
All Regions	All IBRA Regions	All Regions	BIO data collation program	3

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	21
Pilbara	Pilbara		Building resilience to change for mammals in a multi-use landscape: identifying refugia and landscape connectivity for small mammals in the Pilbara	6
Pilbara	Pilbara	Rangelands	Conservation and management of the bilby in the Pilbara	19
South Coast, Warren	Jarrah Forest, Esperance Plains, Warren	South West, South Coast	Conservation of south coast threatened birds	23
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	10
Pilbara	Pilbara	Rangelands	Decision support system for prioritising and implementing biosecurity on Western Australia's islands	18
Pilbara, Midwest, South Coast	Carnarvon, Gibson Desert, Gascoyne, Murchison	Rangelands, Swan	Development of effective broad-scale aerial baiting strategies for the control of feral cats	26

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Midwest	Yalgoo, Shark Bay	Rangelands	Dirk Hartog Island National Park Ecological Restoration Project – fauna reconstruction	13
Pilbara	Pilbara	Rangelands	Ecology and management of the northern quoll in the Pilbara	24
Warren	Jarrah Forest	South West	Felixer grooming trap trial: Feral cat control for threatened fauna conservation in the southern forests.	7
Kimberley, Pilbara	Northern Kimberley, Central Kimberley, Dampierland, Pilbara	Rangelands	Genetic assessment for conservation of rare and threatened fauna	20
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	15
All Regions	Gascoyne	All Regions	Improving the use of remote cameras as a survey and monitoring tool	16
Midwest	Geraldton Sandplains	Rangelands	Monitoring of threatened birds on Dirk Hartog Island	15
Goldfields	Gascoyne	Rangelands	Rangelands restoration: reintroduction of native mammals to Matuwa (Lorna Glen)	22
South West	Jarrah Forest	South West, South Coast	South West Threatened Fauna Recovery Project: Southern Jarrah Forest	12
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Structured decision making for animal translocation	9
Kimberley	Northern Kimberley, Central Kimberley, Kimberley	Rangelands	Structured decision making for optimal feral herbivore management for biodiversity conservation in the Kimberley	8
South Coast	Warren	South Coast	Understanding and reducing python predation of the endangered Gilbert's potoroo	11

Plant Science and Herbarium

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions	All Regions	Biodiversity informatics at the Western Australian Herbarium	35
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	48
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Herbarium collections management	34
All Regions	All IBRA Regions	All Regions	Interactive key and taxonomic studies of Myrtaceae tribe Chamelaucieae	30
South Coast	Esperance Plains	South Coast	Is restoration working? An ecological genetic assessment	29

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
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	44
Pilbara	Pilbara	Rangelands	Molecular characterisation of stinking passionflower (*Passiflora foetida*)	28
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 *Tephrosia* in Western Australia	37
All Regions	All IBRA Regions	All Regions	Seed biology, seedbank dynamics and collection and storage of seed of rare and threatened Western Australian taxa	46
All Regions	All IBRA Regions	All Regions	Strategic taxonomic studies in families including Amaranthaceae and Fabaceae (*Ptilotus, Gomphrena, Swainsona*) and other plant groups	31
All Regions	All IBRA Regions	All Regions	Systematics of the triggerplant genus *Stylidium*	39
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	42
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	40
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Taxonomy of selected families including legumes, grasses and lilies	38
All Regions	All IBRA Regions	All Regions	Taxonomy of undescribed taxa in the Ericaceae subfamily Styphelioideae, with an emphasis on those of conservation concern	36
All Regions	All IBRA Regions	All Regions	The Western Australian Herbarium specimen database	33
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	The Western Australian Plant Census and Australian Plant Census	32
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	41
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	45

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
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	43

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	56
All Regions	All IBRA Regions	All Regions	Evaluating the application of eDNA and metabarcoding as biodiversity and monitoring tools	50
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	65
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	67
South West	Swan Coastal Plain, Jarrah Forest	South West	Hydrological function of critical ecosystems	55
Swan	Jarrah Forest	Swan, South West	Hydrological response to timber harvesting and associated silviculture in the intermediate rainfall zone of the northern jarrah forest	66
South West, Warren	Jarrah Forest	Swan, South West	Identification of seed collection zones for rehabilitation	64
South West	Jarrah Forest		Investigating the causes of change in forest condition	54
Swan	Swan Coastal Plain	Swan	Lifeplan: A planetary inventory of life	51
Swan, Warren	Jarrah Forest, Warren	Swan, South West	Long-term stand dynamics of regrowth forest in relation to site productivity and climate	62
Warren	Jarrah Forest, Warren	South West	Responses of terrestrial vertebrates to timber harvesting in the jarrah forest	60
Warren	Warren	South West	Restoring natural riparian vegetation systems along the Warren and Donnelly Rivers	59
All Regions	All IBRA Regions	All Regions	Taxonomy, zoogeography and conservation status of aquatic invertebrates	57
Kimberley, Wheatbelt, Swan, South Coast, South West, Warren	All IBRA Regions	Wheatbelt, Rangelands, Northern Agricultural, Avon, Swan, South West, South Coast	Tracking the condition of Ramsar wetlands in Western Australia	52
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	58

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
	Jarrah Forest	South West	Understanding the implications of a drying climate on forest ecosystem function to inform and improve climate change adaptation	53
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Western Australian flora surveys	61
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Western Australian wetland fauna surveys	63

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	74
Pilbara	Ningaloo		Do marine reserves adequately represent high diversity cryptobenthic fish assemblages in a changing climate?	70
Pilbara	Pilbara, Pilbara (Offshore)	Rangelands	Habitat use, distribution and abundance of coastal dolphin species in the Pilbara	73
Pilbara	Pilbara, Pilbara (Nearshore)	Rangelands	Improving the understanding of West Pilbara marine habitats and associated taxa: their connectivity and recovery potential following natural and human induced disturbance	76
Pilbara	Pilbara, Pilbara (Nearshore)	Rangelands	Long-term monitoring in the area of the proposed Dampier Archipelago marine reserves	73
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Marine monitoring program	79
Kimberley, Pilbara	Northwest Shelf	Rangelands	North West Shelf Flatback Turtle Conservation Program	80
Pilbara	Pilbara, Pilbara (Nearshore)	Rangelands	Primary productivity and energy transfer between marine ecosystems.	69
Warren	WA South Coast	South Coast	Spatial and temporal patterns in benthic invertebrate communities of the Walpole and Nornalup Inlets Marine Park	83
Pilbara	Carnarvon, Pilbara (Nearshore)	Rangelands	The influence of macroalgal fields on coral reef fish	77
Kimberley	All IMCRA Regions	Cocos Keeling Islands, Rangelands	Understanding movements and identifying important habitats of sea turtles in Western Australia	78
Swan, South West	Pilbara, Carnarvon, Yalgoo, Geraldton Sandplains, Swan Coastal Plain, Warren	Rangelands, Northern Agricultural, Swan	Understanding the key ecosystem services provided by the seagrass meadows of Western Australia	71
Kimberley	Oceanic Shoals, Bonaparte Gulf, Kimberley, Northwest Shelf, Cambridge-Bonaparte, Canning, King Sound, Eighty Mile Beach	Rangelands	WAMSI 2: Kimberley Marine Research Program	81

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	90
All Regions	All IBRA Regions	All Regions	Development of a systematic approach to monitoring and reporting on the outcomes of prescribed burns and bushfires	84
Swan	Geraldton Sandplains, Swan Coastal Plain	Northern Agricultural, Swan	Evaluation of synergies among fire and weed management in urban biodiversity and fire management	85
Goldfields, Wheatbelt, South Coast	Yalgoo, Avon Wheatbelt, Coolgardie, Mallee	Wheatbelt, Rangelands	Fire regimes and impacts in transitional woodlands and shrublands	89
	Jarrah Forest	South West	Long term response of jarrah forest understorey and tree health to fire regimes	87
Kimberley	Northern Kimberley	Rangelands	North Kimberley Landscape Conservation Initiative: monitoring and evaluation	88
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	86

Kings Park Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Conservation biotechnology	97
All Regions	All IBRA Regions	All Regions	Conservation genetics	94
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	95
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Restoration science	93
All Regions	All IBRA Regions	All Regions	Seed science	92

Perth Zoo Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Swan, South West	Swan Coastal Plain, Jarrah Forest	Swan, South West	*Geocrinia* frog breed and rear for release program	102
Swan	Swan Coastal Plain	Swan	Behavioural observations of Perth Zoo collection animals for animal welfare purposes and establishment of baseline data	101
Midwest, Swan, South Coast	Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Esperance Plains	Northern Agricultural, Swan, South Coast	Dibbler breed for release program	104

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Swan	Swan Coastal Plain	Swan	Memory of recent actions in large-brained mammals (*Elephas maximus*)	100
Wheatbelt, Swan, Warren	Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Warren	Northern Agricultural, Swan, South West	Numbat breed for release program	105
Swan	Swan Coastal Plain	Swan	Olfactory and auditory based behavioural enrichment for Perth Zoo's Asian elephants	100
Midwest, Swan, South Coast	Gascoyne, Murchison, Geraldton Sandplains, Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Mallee, Esperance Plains, Warren	Wheatbelt, Northern Agricultural, Swan, South West, South Coast	Survival and dispersal of black cockatoos in south-west Western Australia	105
Swan	Swan Coastal Plain	Swan	Using data loggers to determine the effects of handling and temperature on packages travelling along Australian postage routes used to illegally transport native fauna	99
Swan, South Coast	Swan Coastal Plain, Mallee, Esperance Plains	Swan, South Coast	Western ground parrot husbandry	98
Swan, Warren	Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Warren	Swan, South West	Western swamp tortoise breed for release program	103

Rivers and Estuaries Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
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Swan	Swan Coastal Plain	Swan	Apply acoustic technologies to investigate fish communities and movement	107
Swan	Swan Coastal Plain	Swan	Incident investigations, response and advice	111
Swan	Swan Coastal Plain	Swan	Investigate habitat connectivity in relation to environmental flows and barriers	108
Swan	Swan Coastal Plain	Swan	Investigating fish communities as an indicator of estuarine condition	114
			Investigations of contaminants in the Swan Canning	110
Swan	Swan Coastal Plain	Swan	Model frameworks for estuarine reporting	115
Swan	Swan Coastal Plain	Swan	Seagrass monitoring and evaluation	112
Swan	Swan Coastal Plain	Swan	Swan Canning Water Quality Monitoring	109

Remote Sensing and Spatial Analysis

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Midwest	Geraldton Sandplains		Novel methods combining ground-based monitoring and remotely sensed observations to inform management and measurement of ecosystem condition in the rangelands	117

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Midwest	Yalgoo, Shark Bay	Rangelands	Dirk Hartog Island vegetation monitoring	123
All Regions	All IBRA Regions	Rangelands, Northern Agricultural, Avon, Swan, South West, South Coast	Remote sensing and spatial analysis for fire management	119
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Remote sensing monitoring	122
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Spatial analysis and modelling	121
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Spatial data management	118

Species and Communities

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Ecological communities conservation and recovery	126
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Fauna conservation and recovery	131
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Flora conservation and recovery	129
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All Regions	All IBRA Regions	All Regions	Wetland conservation	125

Ecoinformatics

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	BioSys – the Western Australian Biological Survey Database	134
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Online GIS biodiversity mapping (*NatureMap*)	135

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