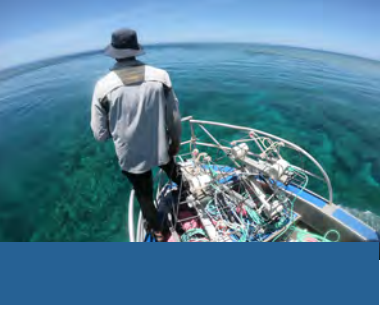


GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Biodiversity and **Conservation Science**

Biodiversity and Conservation Science Annual Report **2021–2022**

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

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

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The recommended reference for this publication is:
Department of Biodiversity, Conservation and Attractions, 2022,
Biodiversity and Conservation Science Annual Report 2021–22,
Department of Biodiversity, Conservation and Attractions, Perth.

Images

Front cover main photo:
Helena and Aurora Ranges.
Photo – Liz Grant/DBCA

Front cover top photos left to right:
Monitoring finfish using Baited Remote Underwater Video Systems, Rowley Shoals. *Photo - Tom Holmes/ DBCA*
Verticordia fimbrilepis ssp. *australis*. *Photo – Andrew Crawford/DBCA*
Numbat release in Dryandra Woodland. *Photo – Rick Dawson/DBCA*
WA Seed Centre, Kensington. *Photo – Andrew Crawford/DBCA*

Back cover top photos left to right:
Fire Behaviour Measurement. *Photo – Jen Hollis/DBCA*
Water quality sampling, Swan Canning Riverpark. *Photo – Kerry Traylor/DBCA*
Remote sensing monitoring using drone with LiDAR instrument attached. *Photo – Georg Wiehl, CSIRO*
Darwinia oxylepis. *Photo – Andrew Crawford/DBCA*

Department of

Biodiversity, Conservation and Attractions

Biodiversity and Conservation Science

Annual Report

2021–2022

GOVERNMENT OF WESTERN AUSTRALIA

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 2021-22 as we continue deliver on the government's commitment to build and share biodiversity knowledge for Western Australia. This is achieved through world-class applied 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.

We came together as Biodiversity and Conservation Science in 2018 and the science we have undertaken over the past four years has delivered excellent outcomes against the priorities identified in the Science Strategic Plan 2018-2021. These outcomes have been collated in a Report available on the department's website. A new Science Strategic Plan 2022-2025 has been produced and this articulates the outcomes science will deliver to achieve the Department's Strategic Directions 2022-2025. The Plan guides the work we do in Biodiversity and Conservation Science to continue to deliver scientific excellence to support biodiversity conservation.

Biodiversity and Conservation Science provides innovative science through the technical expertise and capability of our science staff and the excellent support of our administration staff. Once again, our staff have shown their professionalism in the face of ongoing challenges, and I am enormously proud of the Biodiversity and Conservation Science team and what we achieve together and with our partners.

Despite the challenges, we continue to be highly productive. A major achievement this year has been the launch of the biodiversity data platform, Dandjoo, through the work 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. Science staff have provided a large amount of scientific information and expertise to support development of the new Forest Management Plan 2024-2033. Other highlights of our scientific endeavours include survey of plastics in the Swan Canning Estuary to contribute to plastic free programs; extensive survey and monitoring of key values in marine parks; development of a fire severity mapping tool that is implemented into analysis and reporting of prescribed burn outcomes; development of historical fire impact and severity mapping layers; development of eDNA approaches to monitoring and species assessment; research and seed banking to support recovery of threatened plants and ecological communities in the Stirling Range following the bushfires of 2018 and 2019; translocation of animals to Dirk Hartog and other sites within Western Australia and captive breeding of species to support recovery programs of threatened fauna, including assisted migration to address climate change impacts.

We continue to pursue new opportunities and seek innovative ways to deliver science to underpin effective biodiversity conservation in Western Australia. Our current focus is on strategic planning, developing our people, engaging with our colleagues, communicating our scientific outcomes, and operating according to our shared values.

Our work is strengthened by our collaborations and partnerships both internally and externally. We continue to work collectively with conservation staff in the Parks and Wildlife Service, and at Kings Park and Botanic Garden, Perth Zoo and Rottnest Island. We 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 co-supervision of many Honours, Masters and PhD students.

We will continue to engage with all our partners to provide scientific excellence to support the Department's functions and contribute to delivery of the biodiversity science priorities for Western Australia. The scientific information we generate and the biodiversity knowledge we provide is fundamental to ensuring the unique biodiversity we have around us is conserved and valued.

Dr Margaret Byrne
Executive Director, Biodiversity and Conservation Science
October 2022

Contents

Service Delivery Structure

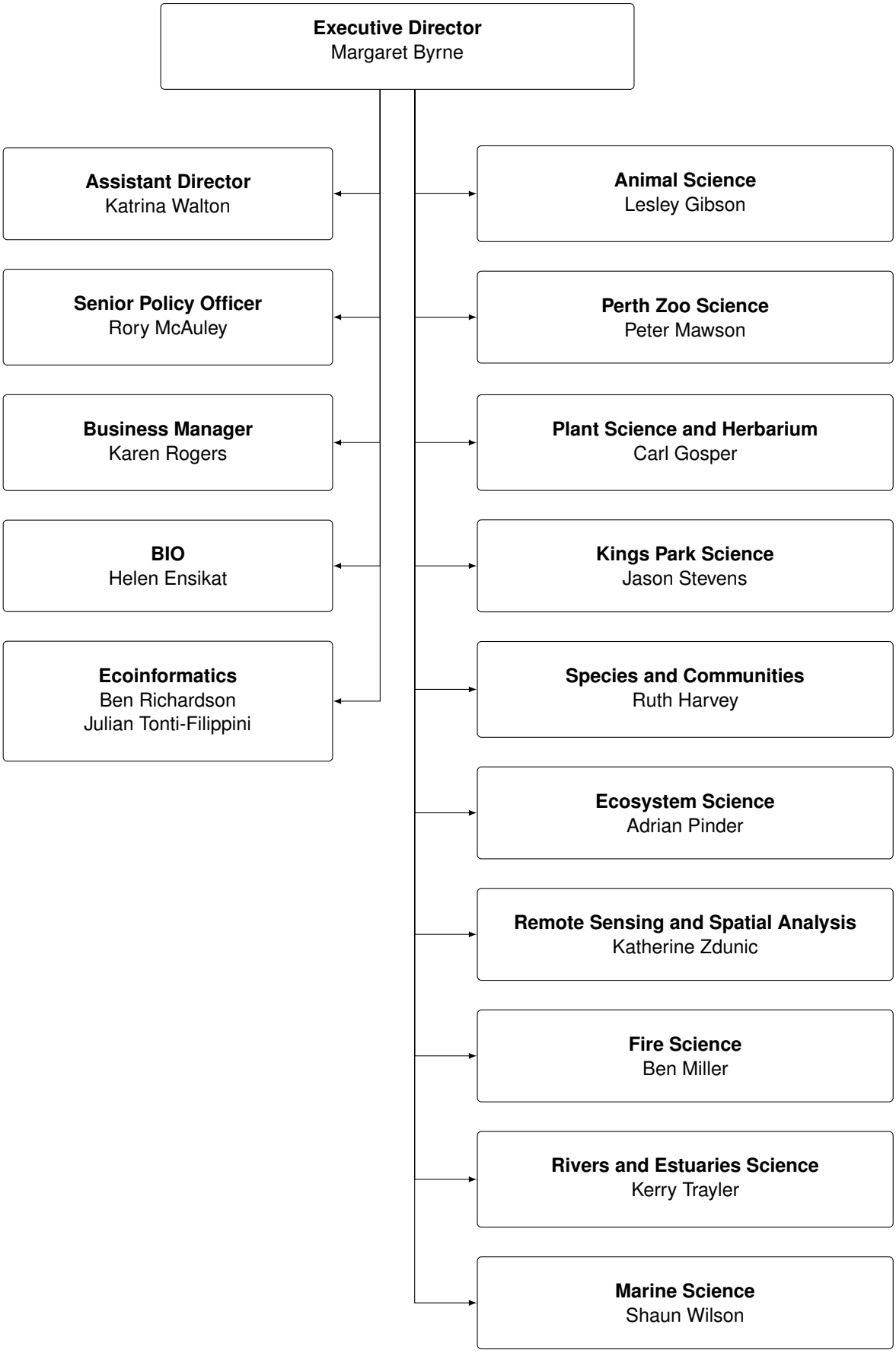
Science in the Department of Biodiversity, Conservation and Attractions is undertaken in accordance with the departmental Science Policy, where science refers to scientific research, scientific monitoring and science communication undertaken in relation to the biological, physical and social environments.

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, data science, 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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Plant Science and Herbarium
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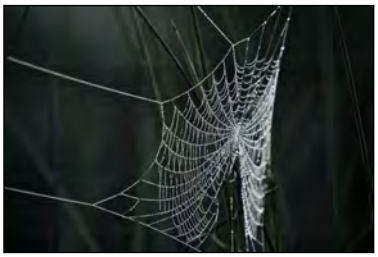
Kings Park Science
Jason Stevens
Species and Communities
Ruth Harvey
Ecosystem Science
Adrian Pinder
Remote Sensing and Spatial Analysis
Katherine Zdunic
Fire Science
Ben Miller
Rivers and Estuaries Science
Kerry Trayler
Marine Science
Shaun Wilson

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

A Barker, H Ensikat, K Grogan, Z Huq, D Murphy, C Piper, C Uehr, 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, government, the public, research sectors and community organisations. BIO is initially focusing 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 is ingested into the platform after passing automated quality assurance checks, where it is mapped to the Darwin Core biodiversity data standard and undergoes a human-mediated quality control process before being released to users.

The initial datasets ingested into BIO's Dandjoo biodiversity data sharing platform have been sourced directly from industry, DBCA repositories, the Western Australian Museum, and regulators such as the Department of Water and the Environment (DWER). New data will continually be ingested, through future automated delivery from regulators and BIO's 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 other sectors.

Progress

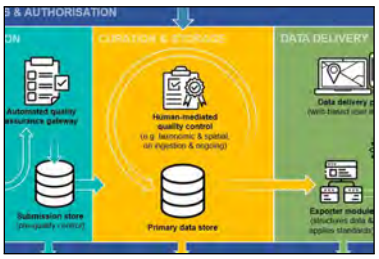
- Data sharing agreements have been negotiated with BHP, Rio Tinto, and Fortescue Metals to allow data provided by these companies to be hosted on Dandjoo.
- A range of high-priority DBCA-managed biodiversity data sets have been loaded into Dandjoo, with new data being added continually.
- Work is underway with peak industry bodies to promote opportunities for data sharing more broadly across member organisations.
- Continuing collaboration 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.

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

- Continue to ingest high quality datasets available within DBCA, and from the Western Australian Museum and DWER.
- Progress mapping of systematic survey data to the ABIS standard, enhancing the ways in which it can be ingested into, and visualised in, Dandjoo.
- Continue to co-design environmental assessment processes with DWER to embed data ingestion into the BIO platform including through 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

A Barker, H Ensikat, K Grogan, Z Huq, D Murphy, C Piper, C Uehr, N Panine, R Cechner

Context

The Biodiversity Information Office (BIO) has developed Dandjoo, a central platform that makes Western Australian biodiversity data more easily discoverable, searchable, and accessible. Dandjoo was launched in mid-2022, and will be enhanced with a range of new features and refinements during 2022-23. It has been designed to mobilise biodiversity data from all environment-related sectors, including industry, government and community organisations, and to support 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 also facilitates the exchange of biodiversity data between jurisdictions via with the Commonwealth's 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

- Dandjoo was launched in mid-2022 with the support of key data providers within DBCA, the broader public sector, and industy.
- A feed between Dandjoo and the Biodiversity Data Repository has been established, allowing data to be shared efficiently with the Commonwealth.
- Feedback has been gathered from key stakeholders including industry proponents, environmental consultants, researchers and government agencies, to prepare a scope of work for further development of the platform.
- Collaboration has continued 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.

Management implications

- Increased data availability for industry and government will support environmental impact assessments and facilitate transparent and evidence-based environmental decisions.
- Access to a broader range of high-quality biodiversity data will expand research opportunities and enhance the quality of research outputs.
- Biodiversity conservation outcomes will be enhanced by more information on the geographic distribution of species in Western Australia, supporting the effectiveness of conservation programs and identification of knowledge gaps that will inform priorities for future data collection efforts.

Future directions

- Rollout of high-priority enhancements, allowing public users to safely access conservation listed species data with an appropriate level of precision, and to export unique species lists.
- Ongoing development of Dandjoo to provide additional functionality, including expanded search options, additional data fields, and enhanced handling of systematic survey data.
- Ongoing consultation with data users and data custodians across all sectors to prioritise future enhancements and refinements of the platform and future years.

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.

Distribution and conservation status of the heath mouse (*Pseudomys shortridgei*) in Western Australia

SP 2021-046

L Gibson, S Cowen, K Nilsson, M Cowan

Context

The heath mouse *Pseudomys shortridgei* (50-80g) is one of several native rodent species that have declined in distribution and abundance since European colonisation. Originally collected in 1906 near Pingelly in WA's wheatbelt, the heath mouse was thought to be extinct in WA until its rediscovery in 1987. Until 2019, the last confirmed record of the heath mouse in WA was in 2004, from Lake Magenta. Targeted surveys in 2019 resulted in their detection at two locations, confirming that the heath mouse was still extant in WA. Further surveys in 2020 failed to detect the species despite sampling in areas where they had previously been recorded. As there is evidence of a significant decline in the distribution and abundance, further targeted survey is critical to determine the current conservation status of the species in WA and inform recovery action.

Aims

- Establish the current range and conservation status of heath mouse in WA.
- Identify populations that may be suitable for ongoing monitoring.
- Assess the possibility of sourcing heath mice for a captive breeding colony to provide founders for reintroductions.

Progress

- Targeted surveys undertaken in December 2021 in the vicinity of Ravensthorpe Range and the eastern edge of the Fitzgerald River National Park failed to detect heath mice.
- A further survey in Lake Magenta Nature Reserve in May 2022 also did not detect the species, although this was likely to be confounded by a high number of house mice, meaning trap availability for other native species was very low.
- A preliminary species distribution model was produced which included projections on future climate scenarios and this has been used to select survey locations.
- A structured decision-making process workshop, based on the Planning and Assessment for Conservation through Ex-Situ management (PACES) tool, was undertaken to assist with decisions in relation to in-situ and ex-situ management actions.

Management implications

- Failure to detect the heath mouse in areas where it was previously recorded suggests that this species may be experiencing a range contraction. Alternatively, consecutive years of low rainfall across the range of the heath mouse may have reduced numbers to levels that are difficult to detect. Survey provides information to clarify the conservation status of this species, and to inform decisions regarding the likely management and recovery actions required.
- In-situ conservation actions alone may not be adequate if the abundance of the heath mouse is determined to be critically low. The option of establishing a captive breeding program should be considered.

Future directions

- Undertake further surveys in areas where heath mice have previously been detected.
- Refine the species distribution model to take changes in climate into consideration to identify additional areas for survey.

Genetics of Pilbara threatened bats

SP 2021-024

K Ottewell, R Sun, L Umbrello, D Prada, S McArthur, R Shaw

Context

The orange leaf-nosed bat (*Rhinonicteris aurantia*) and the ghost bat (*Macroderma gigas*) were both once widespread across Australia but are now restricted to patchily distributed habitat across northern Australia. Isolated populations occur in the Pilbara bioregion, where a distinct form of the orange leaf-nosed bat is recognised (hereafter Pilbara leaf-nosed bat). Both species are considered to be declining in the Pilbara, being highly threatened by habitat loss through mining activity, and are consequently recognised as Vulnerable under State and Commonwealth environmental legislation. Genetic analyses are providing insight into landscape-scale and fine-scale patterns of genetic structure and connectivity in these species. The development of novel genetic techniques for non-invasive monitoring of ghost bats is providing rich insights into roost occupancy patterns and animal movement. Further research is required to address priority knowledge gaps for the species, including estimation of population size and identification and characterisation of critical habitat for each species.

Aims

- Understand the historical and contemporary genetic diversity and landscape-scale genetic structure of Pilbara bat species.

- Understand the fine-scale patterns of genetic connectivity of bat populations and sex-biased dispersal.
- Undertake SNP genotyping of non-invasive samples for genetic monitoring of ghost bat populations.
- Undertake development and refinement of mark-recapture analyses to assist development of standard monitoring protocols.
- Integrate genetic, spatial and distributional data to identify and understand critical habitat for Pilbara bat species.

Progress

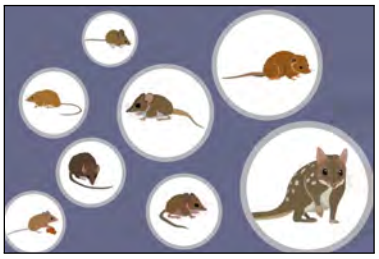
- Population genomic analysis of the Pilbara leaf-nosed bat (PLNB) has been completed and published in *Global Ecology and Conservation*.
- A manuscript on the genetic structure of Pilbara ghost bats is in preparation.
- Four genetic monitoring reports for ghost bats have been completed for industry.
- Two manuscripts have been completed on ghost bat research prioritisation, one is published in *Australian Mammalogy* and the other is submitted.
- The performance of alternative mark-recapture approaches for non-invasive genetic monitoring was evaluated and a report is being finalised.
- The development of ghost bat MassArray SNP genotyping panel was completed and a draft manuscript is being finalised.
- A draft report on the integration of genetic IDs from microsatellite and SNP genotypes for the ghost bat is nearly complete.
- First-pass draft reference genome and transcriptome assemblies have been completed.

Management implications

- Research indicated high contemporary genetic connectivity across roosts of the Pilbara leaf-nosed bat, and that planning decisions should consider preservation of critical roosting habitat and dispersal corridors between roosts to maintain that connectivity.
- Genetic analysis of non-invasively collected samples and refinement of robust mark-recapture protocols, will assist in monitoring of abundance and population trajectories, enabling better assessment of development impacts and/or mitigation approaches for the species.
- Spatial Distribution Models (SDM) will assist in identification of critical roosting and foraging habitat for both bat species and provide a guide for targeted surveys.

Future directions

- Complete draft manuscript on population genetic structure of ghost bats and submit manuscript on ghost bat MassArray SNP genotyping panels.
- Continue ghost bat genetic monitoring projects as required.
- Complete draft report on mark-recapture approaches for ghost bats and SNP genotyping.
- Undertake testing and validation of ghost bat MassArray panel.
- Further refine ghost bat genome and transcriptome assemblies and undertake genome annotation.
- Complete SDM for ghost bat and PLNB roosting and foraging habitat.



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 under current rates of environmental change, it is essential for best-practice conservation strategies to: (i) identify historical refugia, areas that offer temporal 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 climatic conditions by inferring locations of evolutionary refugia from population genomic data and spatial modelling of range dynamics under historical and predicted future environments.
- Identify strategies to enhance and protect these areas for optimal combinations of threatened and non-threatened species conservation.

Progress

- Pipelines have been generated for SNP filtering, population genetic analyses, landscape connectivity analyses, and species distribution modelling.
- Analyses has been undertaken to identify patterns of genetic diversity, landscape connectivity, evolutionary refugia, population expansion characteristics, and population genetic structure across all eight species for which genetic data are available.
- Species distribution models were generated for 19 small-medium sized mammal species in the Pilbara.
- The complete workflow for landscape and population genetics, species distribution modelling, and the creation of decision-making tools for end-users has been completed for northern quolls (*Dasyurus hallucatus)*. This work has been submitted to the journal *Conservation Biology*.
- A comparative landscape genetics analysis comparing two genetic marker types across three small mammal species has been completed and a manuscript is ready for submission.
- An exploration of evolutionary refugia and signals of population expansion across eight small mammal species in the Pilbara has been completed and is currently being prepared for publication.

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 environmental changes to maintain connectivity between populations locally adapted to different climatic conditions.

Future directions

- Complete ensemble modelling and model stacking for more robust species richness maps (and associated certainty maps)
- Submit the manuscript for the comparative landscape genetics study (Honours project)
- Finalise/submit the manuscript for the refugia and population expansion study (Honours project)
- Finalise/submit the manuscript for population genetics of Pilbara small mammals
- Prepare the publication for multi-species SDMs/species richness and landscape connectivity results
- Disseminate published papers and decision-support spatial products to stakeholders and other actors in the Pilbara

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 trials involving captive numbats in the Perth Zoo and wildlife in the field have demonstrated that the Felixer™ traps pose no risk to the non-target native wildlife. Of 5,681 detections, Felixer™ traps in conservative mode have misidentified one tammar wallaby as a target. An average sized tammar needs to consume the full contents of eight gels within 24 hours to receive a lethal dose of 1080, however this is extremely unlikely to ever occur given safety provisions and animal behaviour.
- Three large field trials have been completed. A total of 25 feral cats (33-67% of individuals detected on Felixer™ traps) and 42 foxes have been targeted. Preliminary results indicate that feral cat activity in these areas was reduced by 49%, 31% and 78% at the three trials sites, relative to comparative control sites. The reduction of feral cat activity at the treatment sites was sustained for up to five months after the Felixer™ traps were removed.

Management implications

- The Felixer units are safe to use in the presence of native fauna present 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 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

- A fourth and final large field trial will be conducted.
- More complete analysis of data from all trials and publication of results.

Ecology, threats and monitoring of the Pilbara Olive Python (*Liasis olivacea barroni*)

SP 2020-006

D Pearson

Context

The Pilbara olive python (*Liasis olivaceus barroni)* is a threatened species confined to the Pilbara and adjacent northern part of the Gascoyne IBRA region. Little is known about its ecology, habitat preferences and conservation threats. It is an apex predator consuming a diet of large birds, reptiles and mammals as an adult, including other threatened species such as northern quolls. A number of potential threats confront Pilbara olive pythons, but their relative importance is not understood. They include the loss of important prey items due to exotic predators; habitat loss and modification from mining activities and infrastructure development; and on a local scale, increases in road kills by vehicular traffic due to resource projects and tourism. The project will resolve some of the unknown life history parameters important for conservation of this species and for effective population monitoring. In particular, research will focus on important habitat elements, the reproductive cycle of the species and the predation of juvenile snakes.

Aims

- Collate and publish existing information on Pilbara olive python biology and management, including the proceedings of a 2013 workshop.
- Document the ecology of Pilbara olive pythons focusing on habitat preferences and life history characteristics (diet, shelter sites, juvenile mortality, reproductive frequency, etc.) likely to be influential in population dynamics and impacted by threats such as wildfire, grazing and mining activities
- Undertake experiments to determine threats to juveniles, the population cohort likely to be most affected by feral animal predation and habitat changes due to fire or grazing.
- Trial and improve existing and novel survey and monitoring techniques to enable more effective assessment and mitigation of potential impacts of resource projects and other land uses on Pilbara Olive Pythons.

Progress

- A reconnaissance trip was undertaken to select study sites and discuss the project with DBCA staff, mining companies and indigenous land councils to clarify land access and logistical issues.
- Fieldwork commenced with the capture and implanting of transmitters in pythons at Millstream-Chichester NP.
- An experimental trial using model snakes and automatic cameras was set up to identify potential predators of juvenile pythons.
- Existing genetic and morphometric data has been collated and a draft paper prepared on the taxonomy of the species.

Management implications

- Radio-telemetry results from this study and previous work indicate the importance of rocky spinifex areas adjoining watercourses during the winter months. This finding and maps of the location of telemetered pythons in Millstream-Chichester NP have been provided to regional staff to assist with the planning of prescribed burns to reduce impacts on pythons.

Future directions

- Radio-telemetry of Pilbara olive pythons at three or four sites to document habitat preferences, microhabitat use, diet, reproductive behaviour and sources of mortality in relation to land use.
- Collate records to refine distribution and better assess conservation status.

- Compare detection and monitoring techniques such as walked searches, head-torch surveys, eDNA and road transects.

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 native species in the Kimberley, particularly its small mammal fauna. Feral herbivore control comprises a large part of the Kimberley work program, and 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 a 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 continues to be 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.

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 structured decision making to inform feral herbivore management.

Structured decision making for animal translocation

SP 2019-067

M Barnes, A Wayne, L Gibson

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 for both source populations and release locations. Western Australia is at the forefront of translocations in Australia and has a number of animal translocation programs planned 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. It is important that 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 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

- Population viability analysis for a range of alternative harvest strategies is being undertaken for both woylies and boodies.
- Draft decision tree is being reviewed for application to 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 the sequence of harvests and meeting demands for translocation requests.
- The thresholds for sustainable harvest of boodies are influenced by abundance and productivity and knowledge of these factors enables better prediction of the conditions for sustainable harvest.
- Stochastic dynamic programming is a robust quantitative tool, which has scope for broader application for identifying appropriate harvest thresholds with 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

- Complete population modelling for boodies and woylies.

Investigation into the decline of Chuditch (*Dasyurus geoffroii*) in the south-west of Western Australia

SP 2019-029

A Wayne, M Drew, L Gibson, J Angus

Context

Comprehensive information about the distribution, abundance and genetic diversity of the chuditch in Western Australia is lacking. Information to date has largely been captured using Western Shield monitoring, and while this has provided some data for selected locations, the monitoring sites and methods used are designed to capture information on a range of species. Consequently, captures of chuditch are often sparse and monitoring

is not comprehensive across its distribution. Analysis of Western Shield data suggests that there has been a significant decline in the relative abundance of chuditch in the period 2013-17, although inconsistent trap effort in some years may have confounded this result. Further analyses suggested that the currently sparse data could not provide reliable population size estimates for the species. This project will undertake targeted surveys in poorly sampled areas to fill information gaps using an approach specific to chuditch. Concurrent DNA sampling will improve an understanding of the genetic structure across the entire species range. The information gained will help to inform decisions both in relation to the effective conservation management of chuditch, as well as sourcing animals for translocations to ensure newly established populations are genetically diverse and representative of the species.

Aims

- Evaluate survey and monitoring methods to improve future assessments of population change in chuditch.
- Improve knowledge on the distribution of the chuditch by undertaking targeted surveys in poorly sampled areas, and on the margins of its known range.
- Undertake concurrent DNA sampling to improve understanding of the genetic structure across the entire species range, and to identify source populations for translocations.
- Compile and interrogate all data to help identify potential processes influencing population change in chuditch.

Progress

- Several sites were surveyed within the South Coast, Goldfields, Swan, Warren, Wheatbelt and South West regions.
- Captures were significantly higher using an approach specific to chuditch (including using chicken instead of universal bait) compared to captures when traditional Western Shield methods were used.
- Chuditch were captured at Ravensthorpe, Cocanarup, Tone-Perup, Dryandra, Batalling and Jarrahdale, but not at Peak Charles, ex Jaurdi Station nor Helena and Aurora Ranges.
- Ravensthorpe and Jarrahdale yielded the lowest captures, and Dryandra, the highest.
- Tissue samples for genetic analyses were collected at Ravensthorpe, Cocanarup, Batalling, Dryandra, Tone-Perup and Jarrahdale.
- The use of a camera trap approach to monitoring chuditch is being investigated.

Management implications

- Knowledge on the current distribution of chuditch has been improved, although further surveys are needed to define the eastern extent of the species' range.
- Survey data collected to date will facilitate improvements in chuditch population estimates to inform the current conservation status of the species.
- Results of genetic analyses will inform population management, including future translocations to ensure newly established populations are genetically diverse and representative of the species.

Future directions

- Further surveys will be undertaken to define the eastern extent of the species' range at Dragon Rocks and Lake Magenta Nature Reserves.
- Repeat surveys using consistent and chuditch-specific methods to robustly estimate population size at all sites will be undertaken to determine population trends across the state.
- Analysis of tissue samples to determine genetic structure will be completed.

Conservation of the night parrot

SP 2017-036

A Burbidge

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

- Acoustic data continues to be collected from remotely deployed audio recording units.
- Contributed to factsheet on 'Better offsets for the night parrot', distributed nationally.
- Contributed to a manuscript on establishing effective conservation management actions for the night parrot, which has been submitted for publication in *Biodiversity and Conservation*.
- Advice on night parrot survey techniques and potential management actions has been provided in relation to several proposed resource development projects in areas known or suspected to contain night parrots.

Management implications

- Documentation of known night parrot calls will improve survey and monitoring for the species to facilitate a better understanding of their distribution and conservation status.
- Describing and prioritising conservation management actions will assist in effective recovery actions for night parrots.

Future directions

- Continue to 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

- All fieldwork, including searching, catching, translocation and radio tracking pythons, is complete.
- Results of the work have been communicated to the Gilbert's Potoroo Recovery Team for consideration in a proposed translocation of potoroos to Two Peoples Bay Nature Reserve and presented at the South Coast threatened fauna forum.
- The diet of different cohorts of pythons is being examined using collected faecal pellets to identify what sized pythons are potentially a risk to potoroos.

Management implications

- It is clear that carpet pythons are significant predators of Gilbert's potoroo and are constraining population growth in the Waychinicup enclosure, and pose a potential risk to translocations at Two Peoples Bay.
- The capture and relocation of large female carpet pythons from the Waychinicup potoroo enclosure and proposed potoroo translocation sites in Two Peoples Bay Nature Reserve will reduce the predation risk and increase population growth.
- 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).

Future directions

- Prepare papers on the threat that carpet pythons pose to Gilbert's potoroo and survey techniques for pythons.
- Map and analyse data obtained from radio-telemetry to guide efforts to reduce python predation of potoroos and prepare publications on python home ranges and habitat use.

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' is being finalised following review. This paper provides recommendations for improvements within an integrated and holistic invasive animals management framework to deliver better biodiversity conservation outcomes.
- Work has been undertaken on a second paper 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, L Van Der Weyde

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 and six as vulnerable under the *Biodiversity Conservation Act 2016*. The other three species are either conservation dependent or near threatened. Their successful re-establishment will contribute to improving the overall conservation status of these species. The translocation of 13 native species to an island 633 square km in area makes it the largest fauna reconstruction project in Australia and one of the largest in the world. 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

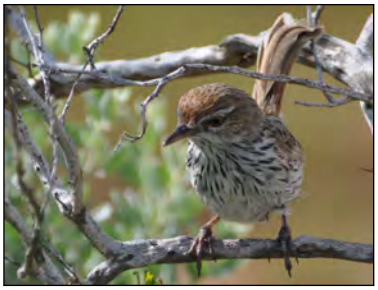
- Supplementation translocations of three species took place: dibblers, Shark Bay mice (SBM) and greater stick-nest rats (GSNR).
- Source population monitoring took place for these species, as well as boodies and Shark Bay bandicoots (SBB) on Bernier Island.
- Initial monitoring of SBM and GSNR was undertaken by radio-tracking, with survival rates of 92% and 85% respectively.
- Planning for the translocation of western grasswrens has been undertaken, including the development of a population viability analysis to support decision-making around the harvesting strategy for this species.
- Soft-release pens and nest-boxes were trialed for the dibbler translocation and resulted in improved monitoring efficacy.
- Monitoring of SBB and SBM showed ongoing increases in abundance and extent of occurrence.
- Methods developed to monitor banded hare-wallabies using faecal DNA and to monitor ecological restoration using remotely-piloted aircraft were published in peer-reviewed journals.
- Monitoring of naturally remaining small vertebrates on DHI indicated that populations remain stable, with native rodents remaining highly abundant.
- Genetic work on chuditch, brush-tailed mulgara, SBM and hare-wallaby faecal DNA is underway.

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.
- Genomic analysis informs population management strategies and provides a suite of novel, affordable monitoring tools to support the ongoing adaptive management of these populations.

Future directions

- A new translocation of western grasswrens is planned from Hamelin Station Reserve and Peron Peninsula.
- A new translocation of brush-tailed mulgara is planned from yet to be confirmed rangelands sites.
- Further supplementation translocation of dibblers will be undertaken.
- Monitoring of all translocated species on DHI and source populations will be undertaken.
- Population genomic analyses for several species will be progressed, high-throughput SNP arrays will be developed for SBB, Rufous Hare-Wallaby & Banded Hare-Wallaby and non-invasive sampling trialled for GSNR.



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 naturally remaining 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

- Species accounts for the DHI southern emu-wren, DHI rufous field-wren, DHI white-winged fairy-wren and Shark Bay purple-backed fairy-wren were published in the *Action Plan for Australian Birds 2020*.
- A manuscript on modelled species distribution and population sizes on the island is being developed.

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. Nevertheless, understanding of appropriate methods for general survey and species detection, particularly in the small to medium sized range of mammals, remains poor. 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 assess the temporal and spatial components of different survey designs, methods of deploying camera traps and interpretation of 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 methods of data capture and data storage, including emerging automated species recognition technologies.
- Develop analytical tools and methodologies for the interrogation and interpretation of camera trap imagery data.
- Undertake comparative trials on new models of cameras and trapping array designs to assess effectiveness and suitability for monitoring and survey programs.
- Provide analysis of trends and occurrence for critical weight range mammals and introduced predators at landscape scales within targeted reserves.

Progress

- Cameras mounted on platforms attached to trees have proven highly effective for monitoring the red-tailed phascogale.
- Trials of different models of Reconyx cameras (PC900 & HP2X) and Swift cameras (3C) showed that HP2X and 3C had higher detection rates than the PC900, though there was higher variability in detection rates for the 3C model. 3C cameras also had significantly higher false trigger rates than either of the Reconyx cameras, with the PC900 having the lowest.
- Support has been provided for over 38 camera trapping projects 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 methods for data analysis and reporting continue to inform threatened species recovery teams on the status of fauna.
- Camera trap networks are continuing to provide valuable information on long term trends for a range of species of conservation concern.
- A trial of a wireless camera trap network (15 Buckeye cameras) has been underway at Dryandra to examine reliability, efficacy, and potential for reducing time associated with managing camera traps in the field. One issue identified is the limited wireless communication distance achievable in undulating and vegetated habitats
- A manuscript focusing on methods to improve remote camera trap designs for monitoring native mammals and introduced predators has been prepared.
- Formal presentations on experimental design and field application of camera trap technology forms an important module in DBCA's annual fauna management course.

Management implications

- Assessment of variation in detection rates over time for all critical weight range species studied in this project provides essential data on population stability and trends, and the effectiveness of control measures on introduced predators.
- The camera array at Dryandra forms an essential reference location against which other sites, sampling methodologies and camera trap technology can be assessed.

- Remote camera survey methods (camera type, spatial arrangement, placement, duration, seasonality, use of lures etc.) should be carefully considered in relation to the targeted species and management questions, to ensure statistically valid inference around species occurrence and spatiotemporal and to provide a sound evidence-based approach to conservation planning and decision making.
- Reconyx camera traps have been among the most effective and dependable commercially available models for departmental requirements and the current model, the HP2X, remains recommended.

Future directions

- Continue to assess new and emerging camera trap technology against long term monitoring sites and camera deployments.
- Develop standalone software for camera trap data analysis for projects that generate long-term camera trap monitoring data.
- Compare conventional Western Shield trapping data to that from cameras where available data overlap.
- Utilise existing monitoring arrays to help inform management on the status and trends of conservation significant species and introduced predators within targeted DBCA managed estate.
- Compile data for conservation significant species from camera trap programs for inclusion in DBCA's primary threatened species database.
- Finalise publication on camera trap designs for monitoring native mammals and introduced predators.

Conservation and management of the bilby in the Pilbara

SP 2012-035

H Moore, F Carpenter, L Gibson

Context

The 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

- Strategic burning and feral predator control were used to investigate options for management of bilbies in two populations.
- Occupancy estimates within the Warralong Bilby Land Management Area (BLMA) derived from 2021 camera trap and 2ha plot data, indicated feral cat occupancy was high (psi = 0.80-0.86) in relation to other recent studies conducted in the Pilbara.
- Bilby abundance estimates within the BLMA were lower in 2021 than previous estimates, partly because only one of the two known bilby colonies could be located.
- Approximately 7000 Eradicat® baits were aerially deployed within the BLMA. Follow up surveys will estimate feral cat occupancy and bilby abundance/occupancy.

- A progress review of the bilby research program has commenced.

Management implications

- Improved understanding of the effectiveness of threat mitigation will help inform ongoing conservation management of the bilby across its range.
- Ongoing surveys for bilbies across the Pilbara will improve our understanding of their conservation status in this region and assist assessments of development proposals.

Future directions

- Continue the monitoring at Warralong to assess the effectiveness of threat management.
- Complete a progress review of 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 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 resolving 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

- Genomic analysis to resolve *Isoodon* bandicoot taxa has been completed. A manuscript on population genomic analysis of golden bandicoots is being finalised for submission.
- Population genomic analysis of black-flanked rock wallaby has been progressed. A manuscript on the Kalbarri National Park translocation of black-flanked wallaby is being finalised for submission.
- Bilby DNA extraction protocols have been refined for SNP array genotyping with further trials underway. A draft manuscript is in preparation.
- Refinements to the ScatMatch R package to incorporate analysis of microsatellite data for non-invasive genetic monitoring are ongoing.
- A manuscript on non-invasive genetic monitoring of mala at Matuwa has been submitted.
- Statistical analyses of wild, translocated and historical populations of Gilbert's potoroo has been undertaken.
- Microsatellite analysis of hairy marron samples to identify putative hybrids has been completed and a report provided.

Management implications

- Genetic analysis showed mixing divergent populations of black-flanked rock wallaby in translocations to Kalbarri National Park, increased genetic diversity. Parentage analysis also indicated successful interbreeding of wheatbelt and indigenous Kalbarri rock wallabies.
- High-throughput SNP genotyping methods have enabled rapid, cost-effective and reproducible screening of non-invasive DNA samples of bilbies to assist in population abundance monitoring.
- Genetic analysis of Gilbert's potoroo populations has indicated that Bald Island, in particular, retains a high proportion of the genetic diversity previously extant at Two People's Bay. Genetic results have underpinned a recent translocation proposal to reinforce the Two People's Bay population.
- Genetic mark-recapture analysis based on scat DNA provided a robust estimate of the population size of mala in the Matuwa fenced reserve, indicating a population increase since establishment.
- Genetic analysis of hairy marron samples indicated that the captive breeding population consists of pure hairy marron individuals with no contamination from smooth marron.

Future directions

- Finalise submission of golden bandicoot manuscript. Contribute to collaborative manuscript on *Isoodon* taxonomy.
- Finalise submission of Kalbarri black-flanked rock wallaby manuscript and complete genomic analyses.
- Contribute to collaborative manuscript on bilby genetic resources, outlining bilby SNP array development and analysis.
- Provide bilby SNP genotyping as required for genetic monitoring projects.
- Complete population genetic analyses for Gilbert's potoroo and develop SNP array for genetic monitoring.
- Provide further refinements to the ScatMatch R package to incorporate microsatellite data.

Barrow Island threatened and priority fauna species translocation program

SP 2012-025

L Gibson, A Burbidge, 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 fauna in areas where these species have become locally extinct.
- Develop and refine protocols for fauna translocation and monitoring.

Progress

- Boodies and golden bandicoots translocated from Barrow Island to a fenced enclosure at Matuwa continued to be monitored.

- Introduced predator control continued at Matuwa and Cape Range National Park.
- Planning has commenced for monitoring the populations of translocated birds and mammals on the Montebello Islands.
- A trial to test the susceptibility of golden bandicoots to Eradicat® feral cat baits at Matuwa was undertaken, with implanted transmitters tested.

Management implications

- Arid zone rangelands fauna reconstruction and conservation techniques developed by this project will have broad State and national application.
- 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.

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, that have 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 free-ranging, self sustaining populations 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 advantages and disadvantages of using camera-traps and track-transects to monitor feral cats was published in *Animals*.
- A manuscript comparing differences in feral cat diet at Matuwa and in the Kimberley was published in *Sustainability*.

- A project reassessing the genetic profile of the brushtail possums translocated to Matuwa has been completed and a manuscript is being prepared.
- Monitoring of boodies, golden bandicoots and mala inside the enclosure continued.
- 27 golden bandicoots were translocated from Matuwa to a fenced reserve, 'Wild Deserts', in NSW. This translocation marks the first time golden bandicoots have been present on the east coast of Australia since the natural population was extirpated.
- 25 boodies were translocated from Matuwa to the Australian Wildlife Conservancy's New Haven fenced reserve in NT. This translocation marks the first time boodies have been present in Australia's north since the natural population was extirpated.
- Introduced predator control via aerial baiting with Eradicat continued.
- Assessment of the susceptibility of golden bandicoots to the Eradicat bait was initiated.

Management implications

- Ongoing landscape scale feral cat baiting plus additional control techniques are required to successfully re-establish threatened vertebrate fauna in the rangelands.
- Long-term feral cat control is likely to confer benefits to small mammal species.
- At Matuwa, track counts proved to be cheaper to implement and more effective at detecting feral cats than camera traps, especially when feral cat density was very low.
- Increased involvement of traditional owner rangers with fauna monitoring has assisted collaborative management arrangements.
- Potential over-abundance of boodies in the enclosure needs to be carefully managed.
- Matuwa has become a source site for boodie and golden bandicoot translocations.

Future directions

- Ongoing monitoring of reintroduced species and introduced predators.
- Complete publications on the impact of fenced reserves on mulgara, the ecology of boodies, population genetics of brushtail possums, and the impact of baiting on golden bandicoots.
- Facilitate training in fauna handling in stakeholder groups.

Conservation of south coast threatened birds

SP 2012-022

A Burbidge, A Clarke, S Comer, G McGrath, 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 population and habitat trends.

Progress

- An analysis of the occurrence of western bristlebirds in relation to fire over several decades in Fitzgerald River National Park has been published in *Australian Field Ornithology* indicating the optimum fire age for bristlebird habitat in this area is about 30 years.
- A further seven western ground parrots were translocated from Cape Arid National Park to a site east of Albany, with their movements being tracked using a drone to deliver cost-effective monitoring.
- Extensive surveys for Australasian bitterns resulted in one capture and this bird was fitted with a satellite tracker.
- Sentinel 1 Radar satellite data sets have been curated and used to develop time series of open water extent for Australasian bittern wetlands on the south coast - in some wetlands these time series correlate well with measured water level times series.
- In addition, interferometric methods have been applied to directly estimate water level changes and ongoing work is being conducted to evaluate where and when this methodology can inform bittern wetland hydrology.

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 to inform stakeholders and land managers where to target management 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

H Moore, 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 monitoring and ecological research. 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 and artificial habitat.

Progress

- A comparison of camera trap and live trapping survey methods showed camera trap designs detected declines in northern quoll occupancy with greater statistical power than live trap designs, and were substantially cheaper over a 10 year period.
- An optimised camera-trap design has now been implemented as part of the Pilbara northern quoll monitoring program.
- An analysis of northern quoll habitat use was published in the journal *Landscape Ecology* and found quolls were more likely to use patches with high vegetation cover, high den availability, lower amounts of edge habitat relative to patch area, and larger amounts of surrounding rocky habitat.
- A similar analysis published in the journal *Landscape Ecology* found spatial configuration of rocky habitat was more important than the amount of habitat when predicting quoll occupancy and abundance; northern quolls were less abundant in landscapes that were more fragmented. In addition, northern quolls favoured areas that were topographically rugged and received more rainfall.
- A review of northern quoll research at the national level published in *Australian Mammalogy* found that while a considerable amount of research has been focused on the Pilbara population, more work is needed quantify the long term impacts of mining and to assess likely impacts of invading cane toads.
- Trials continued examining the efficacy of Felixer® feral cat grooming traps in toxic mode.
- A major review of progress of the Pilbara Northern Quoll Research Program is being finalised.

Management implications

- Relatively contiguous rocky patches of suitable habitat is likely to afford protection for northern quolls from threats such as introduced predators.
- Fine-scale habitat use of northern quolls indicates the importance of well-connected and vegetated rugged rocky outcrops and riparian areas as important habitat.
- Managing landscapes to create corridors of intact vegetation between rocky habitat patches is likely to facilitate dispersal, thereby reducing the vulnerability of isolated populations to local extinction, and increasing the likelihood of recolonisation should local extinctions occur.
- Monitoring designs using camera traps are more cost-effective than live-trapping.

Future directions

- Complete a progress review of the Pilbara Northern Quoll Research Program.
- Continue to refine the monitoring program.
- Further investigate the efficacy of Felixer™ feral cat grooming traps.

Impact of cane toads on biodiversity in the Kimberley

SP 2006-004

D Pearson

Context

The invasion of cane toads is impacting 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 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 and mainland sites 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 by 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 at 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 northern quolls and other toad-susceptible species continued using cameras on Adolphus Island and a number of mainland sites. Images are being examined and prepared for analysis. All toad-susceptible species are persisting on Adolphus Island.
- Further drops of CTA baits were undertaken by the Cane Toad Team with their effectiveness to be assessed by new camera arrays in the north Kimberley, established in conjunction with Indigenous Ranger groups.
- Northern quoll trapping and camera data from Mt Hart and Theda Station are being reviewed to gauge the effectiveness of aerial drops of CTA baits.
- Mitchell River National Park trials using tethered CTA baits, cameras and video are being written up for a publication on how the baits were developed and the challenges associated with their deployment.
- Toad taste aversion strategies developed for goannas are being rolled out with partners and Indigenous Ranger groups to protect populations of *Varanus panoptes*.

Management implications

- Aerial trials of the CTA baits have indicated the survival of northern quolls at low levels of survivorship following cane toad arrival in their habitat. Improvements to bait application is likely required to increase the uptake of baits by northern quolls and facilitate their persistence.

Future directions

- Publication of remaining data on CTA trials with recommendations on how baits could be employed to protect mainland and island northern quoll populations.
- Publication of information on the impact of cane toads on olive pythons and mulga snakes.

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 potential risks 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

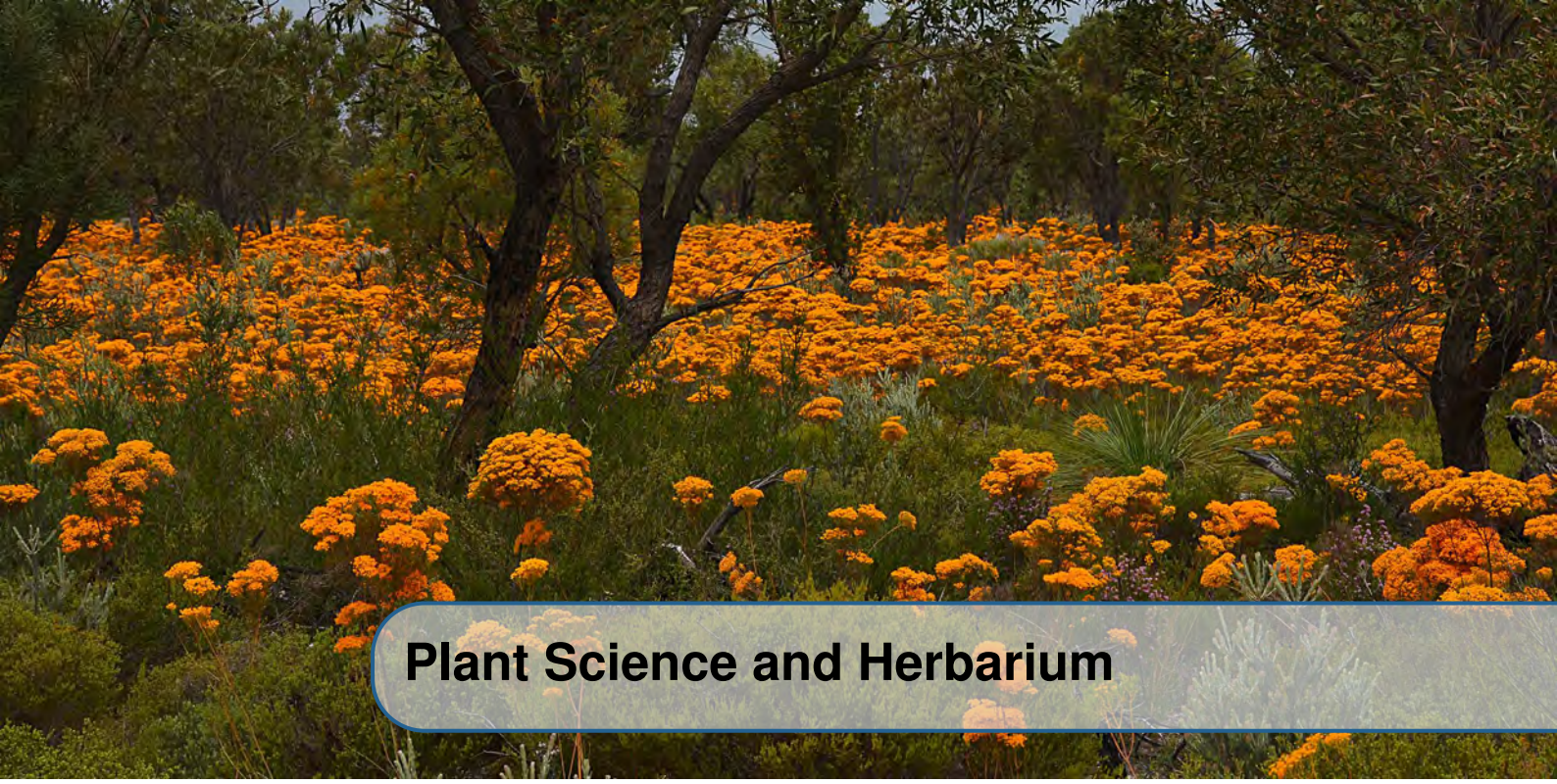
- The palatability of alternative meat products was tested and *Eradicat* Beef was found to compare favourably with kangaroo meat in these preliminary trials.
- A series of trials to monitor cat activity and movement patterns have commenced to enable targeting of bait delivery during large-scale aerial baiting campaigns. This information will be used to increase bait encounter rates when cats are hungry and result in improved baiting efficacy.
- Several novel lures are currently being tested for their utility as attractants to monitor cat abundance. Collaborative work with Murdoch University on an 'Artificial Intelligence' remote camera system and long-life lure to monitor cats was progressed.
- Field-testing of modifications to the trapping technique have demonstrated a reduction in capture and injury to non-target species.

Management implications

- Effective landscape-scale baiting methods, based on cat activity and movement patterns, across climatic regions will ultimately provide efficient feral cat control at strategic locations across mainland Western Australia and lead to significant conservation benefits.
- Development of effective monitoring and trapping techniques, that minimise injury risk to non-target species, will complement the control toolkit and improve data collection relevant to management options.
- Successful eradication of feral cats and maintenance of cat-free status on islands off the Western Australian mainland, allows persistence of 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 baiting operations and refine methodologies to optimise baiting efficacy.
- Continue investigation of attractants that could prove utility as a suitable lure for the reliable and accurate monitoring of feral cat populations.



Plant Science and Herbarium

Program Leader: Carl Gosper 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 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 the Australian and the international 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

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.
- Information on the relationships among species and the origins of the introductions in Australia has been published in *Frontiers in Plant Science*.
- 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, showed low diversity and confirm the expansion of one of the introduced lineages across northern Australia from the location of introduction in Queensland. Further analysis of samples collected to align with ecological analysis of populations in Western Australia show very low diversity.
- A manuscript on genetic diversity across the distribution 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 options for whole sequence analysis to determine adaptation, 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

- A paper on mating system and genetic diversity in *Hakea laurina* has been published in *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,* providing information on source of seed for these populations.
- 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 is complete.

Interactive key and taxonomic studies of Myrtaceae tribe Chamelaucieae

SP 2013-052

B Rye, J Wege, C Ely

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 significance and, in some cases also describe new genera or sections.
- Build a *Flora of Australia* treatment of tribe Chamelaucieae.
- Produce and continually update an interactive key to members of this tribe.

Progress

- A paper describing the new genus *Austrobaeckea* (8 species) and another revising the taxonomy of *Balaustion,* expanding the genus to include 18 species, were published in *Nuytsia*.
- Two papers on *Hypocalymma* were submitted for publication.
- Treatments of the following 7 genera were finalised, edited and transferred to the digital *Flora of Australia* platform: *Aluta*, *Anticoryne*, *Astartea*, *Astus*, *Austrobaeckea*, *Cheyniana* and *Enekbatus*.

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

This project is complete.

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 *Isotropis petrensis* (Fabaceae: Mirbelieae), a new species from arid Western Australia, in *Nuytsia*.
- Published a description of *Gomphrena axillaris and Gomphrena longistyla* (Amaranthaceae), from central and Northern Australia, in *Swainsona*.
- Published a description of *Ptilotus crinitus* (Amaranthaceae) a new species from the Kimberley, in *Swainsona*.
- Preparing *Common Wildflowers of the South-West Forest,* 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*, *Swainsona* and other genera (*Acacia* and *Eremophila*).
- Further field studies to assist in the resolution of problematic groups within *Ptilotus*.
- Progress interactive keys to *Ptilotus, Gomphrena* and *Swainsona*.

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 the flora (vascular and non vascular plants, algae and fungi) 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 now *Dandjoo* (Biodiversity Information Office).

The Australian Plant Census (APC) is a Council of Heads of Australasian Herbaria project, part of the National Species List infrastructure, 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. The Western Australian Plant Census is updated to reflect the consensus view, produced annually. 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 harmonize this with the national taxonomic consensus.

Progress

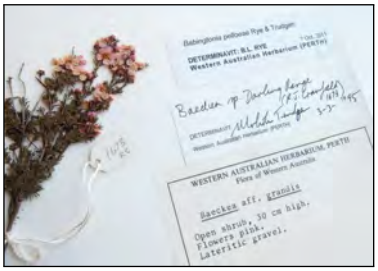
- Six hundred and twenty five plant names (604 formally published and 21 informal names) were added to the WACensus. The inclusion of fungal names is currently a focus for the WACensus.
- A total of 1,251 data updates were made to the WACensus.
- WACensus updates were regularly distributed to 214 registered Max users.
- More than 1,100 archived census forms, including descriptions of phrase name taxa, were scanned by volunteers and are now electronically available for internal use.
- Contributed to discussions on taxonomy and nomenclature to assist in the publication of a national consensus known as the APC for the National Species List (NSL).
- The State's contribution to maintenance of this national cooperative database continued with the addition of 183 new vascular plant names to the NSL database and the creation of 2,796 new instances (data on synonymy, authors and publications).
- Contributed to and tested a new electronic platform to better assess APC lists distributed nationally by the Australian National Herbarium for consultative input by state partners. In conjunction with this project, provided feedback on a new Australian Plant Name Index (APNI) platform.
- The Western Australian Plant Census is an integral part of the new Biodiversity Information Office platform, Dandjoo, which the Herbarium team assisted in the initial planning.

Management implications

- WACensus provides users with a single, authoritative official list of the flora of 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

Context
The Western Australian Herbarium collection management system (WAHerb) allows staff at the Herbarium to manage and maintain the Herbarium's botanical specimens and assets. It provides core data on the distribution, ecology and morphology of taxa for the department and the community, through *Florabase* and other biodiversity data aggregators. Data from the collections database is provided to researchers, consultants and community members on request, and to the Australasian Virtual Herbarium (AVH), Atlas of Living Australia (ALA), Global Biodiversity Information Facility (GBIF), and Dandjoo (Biodiversity Information Office) on a regular basis.

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

Progress
- The Western Australian Herbarium added 11,317 specimen records in 2021-22.
- More than 86,000 specimen records were edited ensuring the hebarium collection data is scientifically valid, up-to-date and aligned with the department's conservation codes.
- Customised specimen data reports (species lists and label data) were provided to departmental officers, researchers and the public regularly upon request.
- An instance of the Integrated Publishing Toolkit was established in 2022, enabling streamlined delivery of a Darwin Core Archive of the Herbarium data to biodiversity data aggregators on a regular basis.
- Through the Australasian Virtual Herbarium and Atlas of Living Australia, almost 33 million herbarium data records were downloaded in 17,000 download events. The Western Australian Herbarium dataset is also available via the Global Biodiversity Information Facility (GBIF - 875 million records in 19,650 download events) and through Dandjoo.
- Data cleaning and migration are underway to transfer records to a new collection management system. This includes the disambiguation of agents (collectors, determiners) and linkage to unique identifiers (ORCID, Wikidata). More than 1.7 million agent entries in WAHerb were linked to 13,923 unique agents.

Management implications
- WAHerb enables the management of the State's botanical collections assets; the migration to Specify will further increase productivity and provide management tools not previously available.

- WAHerb represents the most comprehensive vouchered specimen database for Western Australian plants available and provides a source of information that consultants, land managers, and policy makers 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 are informed by up to date and valid botanical species names.

Future directions

- Continue timely addition, editing and validation of specimen records to maintain currency and connectivity between the Herbarium collection, the Western Australian Plant Census and departmental and external biodiversity data providers, including Florabase, Dandjoo, AVH, ALA, and GBIF.
- Complete the migration of the collection management system to Specify.

Herbarium collections management

CF 2011-105

S James, C Parker, J Huisman, J Percy Bower, A Curtis, S Coffey, E Wood-Ward, M Hislop, R Davis, S Sinha, R Gugiatti, C Ely

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 science 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 and reference 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.
- Provide digital resources enabling open access to the botanical collections.

Progress

- The Western Australian Herbarium added 11,317 specimens to collections, including 946 specimens of priority taxa, 116 specimens of threatened taxa, and one specimen of a presumed extinct taxon (*Acacia prismifolia*), increasing the size of the collection to 833,034 catalogued items representing more than 18,600 taxa.
- The metadata of more than 86,000 specimens was updated during the year.
- The Western Australia Herbarium shared specimens with 9 national and 16 international institutions, and shipped 556 specimens in 22 transactions for scientific research. A total of 3508 exchange specimens were sent to collaborating institutions, and 26 requests for 579 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 (>900 specimens), and incorporation of specimens received from the South West Regional Herbarium (>1100 specimens) and Narambeen Regional Herbarium (280 specimens).

- Specimens and data were cited in more than 145 publications; the collection and associated data have been cited 2775 times since the early 1900s.
- The Herbarium received a significant donation of more than 5000 specimens from the extensive private collection of Allen Lowrie.
- A separate collection of Type specimen photographs was created (currently >1100 items), increasing the space within the Types Vault and improving care of the physical Type specimens.
- With the assistance of volunteers, 9600 specimens were mounted.
- Volunteer participation continues to be a significant and invaluable resource, despite the impacts of COVID-19 during the year, totaling 10,220 hours - equivalent to approximately 6.5 full time employees. The Herbarium was assisted by 40 regular volunteers and 17 Research Associates.
- The Reference Herbarium was accessed 2705 times by visitors and consultants for plant identifications and other scientific purposes.
- The Research Collection was accessed 1400 times by visitors for the study and identification of taxa.
- More than 6100 high resolution images of Herbarium specimens were captured and shared with departmental staff and industry consultants and a further 98 high resolution images of type specimens were captured and shared with the online Global Plants Initiative. Specimen imaging focussed on the West Kimberley and Pilbara Threatened and Priority taxa, an initiative to digitally transform the Herbarium collections.
- 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 10,080 specimen identifications in 328 transactions, along with 300 image-based identifications, were undertaken for external clients. A further 120 specimen re-identifications were undertaken for Species and Communities Branch.
- Educational programs consisted of 14 Herbarium tours and monthly induction sessions for departmental staff, tertiary institutions, environmental consultancies, community groups and the media (approximately 260 participants). The Herbarium also trained a UWA Work Integrated Learning intern.
- The Collections Management team was highlighted in the Winter 2022 Landscope; and the facebook page, with more than 7000 followers, shares a monthly 'Plant of the Month'.

Management implications

- Maintenance and curation of the Western Australian Herbarium botanical collections provides an authoritative inventory of the biodiversity of Western Australia, which underpins flora conservation and state, national, and international research programs.
- The collections are drawn upon constantly by DBCA staff, consultants and policy makers to validate specimen records from biological surveys, environmental impact assessments, 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 and field notes for online delivery and sharing.
- Continue to significantly reduce the currently unprocessed and uncatalogued specimen items in storage.
- Support implementation of a new collections management system (Specify) that will increase scope for the extended specimen initiative and improved and efficient management of the specimen collections.
- 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 warehouse 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 maintaining Florabase and contributing 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

- Published four updates to correct issues discovered after the launch of Florabase 3.
- Improved features in the Herbarium Agent Migrator to support its continued use in the WAHerb data migration project.
- Published seven updates to Publishing System to correct issues affecting Florabase 3 and general herbarium workflows.
- Provided support to migrate the MS Access-based application, WASeed, into Microsoft Remote Desktop Services and Azure to enable continuity of access for multiple staff.
- Replaced BioCASE with GBIF's Integrated Publishing Toolkit (IPT) application to feed data to Australian Virtual Herbarium, Atlas of Living Australia and Dandjoo.

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 3145 alga, fungi, 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.
- Rework Florabase following significant changes to WAHerb and WACensus.

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* (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 for *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 undulata*, a new geographically P2 restricted species was described in *Nuytsia*.
- Eight new species and one new subspecies of *Styphelia,* five with conservation codes were published in *Nuytsia*.
- Two new papers have been submitted to *Nuytsia* and *Swainsona*, in which four new species, all of conservation significance, will be described.
- A large paper is well-advanced, in which numerous species of *Styphelia*, many of conservation significance, are to be described.
- A new, uncommon phrase-named taxon, *Styphelia* sp. Watheroo, 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 appropriately manage the conservation-listed 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

- One paper describing a new species (*Tephrosia sabulosa*) was published in *Nuytsia*.

Management implications

- Taxonomic resolution has provided names for several previously undescribed species, clarified species identification features, assessed conservation status of all WA taxa to assist with conservation of the species.

Future directions

This project is complete.

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 and 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 *Thysanotus*, *Wurmbea*, *Caesia*, *Lomandra*, *Amphipogon* and *Trithuria*.

Aims

- Identify plant groups for which 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

- Paper on pollen structure, function and evolution in *Althenia* and its relative *Ruppia* was published in the *American Journal of Botany*.
- Undertook field sampling and contributed taxonomic information to conservation genetics project to resolve the *Wurmbea* species complex.
- Field research providing taxonomic clarification, including recognition of new species, was conducted on the *Thysanotus patersonii* group of twiners.
- Paper drafted reviewing the multi-ovulate group of non-twining *Thysanotus* species, with two new species described.
- Collected *Caesia* samples and participated in a completed molecular phylogenetic student project, to be extended and published.
- Contributed to the grass family (Poaceae) part of the international PAFTOL molecular phylogenetic study based at Kew, UK, which is currently being written.
- Co-authored a paper on the evolution of the ovary of Poaceae (the structure underlying the cereal grains), which was published in the *Journal of Experimental Botany*.
- Priority conservation species – Contributed taxonomic, identification and scientific name advice; participated in a departmental review of conservation actions; surveyed poorly known species.

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 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, Amphipogon* 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 non-technical 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. Furthermore, a high proportion of taxa 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 these data to inform taxonomic research and conservation management.

Progress

- A new, poorly known species from the Mogumber–Watheroo area was discovered at the WA Herbarium, relocated in the wild, and published as *Stylidium milleri*.
- Targeted field work in south-western Australia was conducted to collect voucher material, including type specimens of novel species and dried leaf material for DNA analysis.
- 548 *Stylidiaceae* specimens at the Western Australian Herbarium were annotated to correct or confirm their identity, improving our understanding of the distribution and rarity of the taxa.
- Samples, metadata and vouchers were prepared for a large phylogenomics project on Stylidiaceae for the Genomics for Australian Plants initiative.
- Taxonomic data continues to be generated and consolidated for the *Flora of Australia*, 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.
- A phylogenomic framework will provide an evolutionary context for conservation management.

Future directions

- Continue writing species profiles for the *Flora of Australia* and associated research papers, visiting select Australian herbaria as required.
- Conduct highly targeted field work to obtain necessary collections and images to advance or complete research publications.
- Advance phylogenetic papers.

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 biodiversity conservation programs. It includes floristic studies of the marine plants of several existing and 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 and the Maret Islands.

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 new species of red algae, *Hypnea corona*, has been published in *Pacific Science*.
- A paper resurrecting the Australian species *Plocamium pusillum*, previously thought to be conspecific with the seemingly widespread *Plocamium cartilagineum*, has been published in *Cryptogamie, Algologie*.
- A molecular and morphological analysis of the Western Australian endemic red algal genera *Austroepiphloea* and *Gelinaria* has been published in *Phycologia*, resulting in both genera being subsumed into *Halymenia*.
- Three new Australian species of the red algal genus *Asteromenia* have been described in a paper published in *Botanica Marina*.
- New species of *Rhipilia* (Halimedaceae) and *Vaucheria* (Vaucheriaceae) have been recognised in collections from south-west Western Australia.
- A study of historical Western Australian species of *Callithamnion* and *Corynospora* has led to several generic reassignments.

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 filamentous red algae.

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, C Ely

Context

This project is a direct successor to the *Western Australian Marine Plants Online* and will provide descriptions of the entire currently known Western Australian marine flora 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, 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

- Scoring of character states for the interactive key has been undertaken, with additional staff engaged.
- Numerous fact sheets describing morphological and reproductive features have been prepared for inclusion in the interactive key, to assist in character recognition.
- Additional fact sheets for individual genera have also been prepared for inclusion, including links to external information sources.
- Numerous additional *in situ* (particularly from the Perth region and Coral Bay) and microscopic images of marine algae have been taken.
- Data for 50 algal specimens, newly added to the Western Australia Herbarium collection, are now available via *Florabase*, improving taxonomic and distribution knowledge concerning the Western Australian marine flora.
- 310 existing WA Herbarium records of marine flora have been edited related to 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 and 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, B Anderson, M Hislop, B Rye, T Macfarlane, R Davis, S Dillon, C Wilkins

Context

Western Australia has a rich flora that is far from fully known. New species continue to be discovered through the taxonomic assessment of herbarium collections, floristic surveys and the botanical assessment of mineral leases. There are more than 1100 putatively new and undescribed taxa on Western Australia's vascular plant census, almost half of which are poorly known, geographically restricted and/or listed as threatened or priority flora. The lack of detailed information on these taxa makes accurate identification problematic and inevitably delays the department's ability to survey and accurately assess their conservation status.

Aims

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

Progress

- 26 conservation listed taxa in *Austrobaeckea*, *Balaustion*, *Convolvulus*, *Isotropis*, *Stylidium* and *Styphelia* were published in *Nuytsia*.
- Targeted field work to progress taxonomic research on an array of undescribed, conservation listed taxa was conducted.
- Expert advice on select monocot groups was contributed as part of an elicitation process for conservation action.
- Progress was made on taxonomic resolution of novel taxa in *Geleznowia*, *Isopogon*, *Synaphea* and *Wurmbea* as part of the Genomics for Australian Plants initiative. Associated field work has captured data to inform critical conservation assessments.
- 4 putatively new and poorly known species from the genera *Conostylis*, *Microcorys*, *Solanum* and *Styphelia* were discovered by team members and added to the State's vascular plant census under phrase names.

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, M Byrne

Context

The contribution of translocations (augmentation, introductions, reintroductions) 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 priorities 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 plan was developed to establish two multi-species seed orchard sites for threatened Stirling Range plant species impacted by fire and *Phytophthora* dieback. The second seed orchard, at Porongurup, was established with site infrastructure installed, and planting and initial monitoring completed following previous establishment of the first site, Redmond.
- The translocation proposal to establish a seed orchard for *Grevillea calliantha* was approved and the new site planted. Site infrastructure was installed and initial monitoring completed.
- Infill planting was undertaken at two sites for *Chorizema humile* to boost numbers of plants at the sites.

- Infill planting was undertaken at one translocation site for *Banksia cuneata*. Planting was done in long unburnt and burnt (4 years post fire) areas to add to an already established experiment to assess the benefits of translocation planting in post-fire environments.
- A paper describing the analysis of flora translocation data from 22 years of plantings and examining factors that contribute to translocation success is being drafted.
- A paper examining the impact of genetic composition of source populations on translocation success has been accepted for publication in *Australian Journal of Botany*.

Management implications

- Successful 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, and informs 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.
- Develop a PVA model for translocated and natural populations of *Acacia cochlocarpa* subsp. *cochlocarpa* using demographic data already collected.
- Continue to monitor plant survival and seed production at the newly established Redmond, Porongurup and *Grevillea calliantha* translocation sites, and continue to monitor plant survival and growth at the *Banksia cuneat*a translocation site.
- Establish monitoring of *Grevillea maxwellii* translocation and natural populations in order to develop a 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. In addition, a pollination study on a subset of four of the natural and one of the translocated populations, will assess the adequacy of pollination in the translocated population. A manuscript describing these studies has been submitted for publication.
- Assessment of fitness traits is ongoing in a common garden experiment involving 1100 seedlings of *Banksia brownii* from montane and lowland natural populations and a translocated population, to examine trait differences between montane and lowland populations, and implications for population mixing, and to benchmark the performance of the translocated population. A paper is being drafted for publication.
- 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. 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. A paper describing this work has been accepted for publication in *Australian Journal of Botany*.
- 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 *Banksia 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 *Lambertia 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 studies on translocated and natural populations of *B. brownii*, *A. cochlocarpa* and *B. anatona*.
- Develop and implement a monitoring plan for the *L. orbifolia* common garden experiment.

The population ecology of critically endangered flora

SP 2000-015

C Gosper, R Dillon

Context

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

Aims

- Determine the critical biological factors and the relative importance of contemporary ecological interactions and processes in limiting population viability and persistence, particularly for critically endangered species and other key plant species occurring in TECs.
- Improve understanding of patterns of distribution of threatened and priority flora, their ecological, evolutionary and genetic traits, and how these traits mediate susceptibility to key threats.

Progress

- Spatial analysis of the distribution of threatened and data deficient (priority 1-3) flora in the Southwest Australian Floristic Region showed high richness concentrated in specific locations which were mostly ancient geological features of restricted distribution. Data-deficient flora showed distinct patterns of distribution compared to the threatened flora, and 70% of threatened and data-deficient flora populations occurred outside of lands managed primarily for conservation. This work was published in *Diversity*.
- Monitored the Eastern Stirling Range Montane Heath and Thicket TEC following the May 2018 and December 2019 bushfires, allowing analyses quantifying the consequences of the bushfires and interacting threats on threatened flora populations and the TEC, and of the effectiveness of threat mitigation measures such as phosphite spraying to reduce the impact of *Phytophthora* dieback. Several Stirling Range case studies will feature in an upcoming book on the 2019-20 Australian wildfires.
- Contributed fire regime and plant trait data to national desktop syntheses of the putative consequences of the 2019-20 wildfires on plant species and ecological communities, which are reported in two papers published in *Global Ecology and Biogeography*.
- 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.*
- Analysis of remotely piloted aircraft photogrammetry linked to on-ground assessment of vegetation condition in the western Fitzgerald River National Park continued, to quantify the extent and severity of possible climate and disease-driven decline in *Banksia*.

Management implications

- Studies of the effects of fire interval, *Phytophthora* dieback and threat mitigation actions 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 *in situ* threat management and translocation.
- Demographic studies and experiments investigating the impact of disease, fire intervals and patchiness, and environmental weeds on *Banksia verticillata, 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. Differences in patterns of spatial distribution of data-deficient and threatened flora suggest that conservation activities directed at mitigating threats to natural populations of threatened flora will not be effective for the conservation management of a significant proportion of the data-deficient flora. This finding emphasises the value of threat mitigation actions in locations supporting numerous data-deficient flora.

Future directions

- Continue demographic studies investigating: (i) fire and interacting threat impacts and effectiveness of threat mitigation actions for threatened flora and TEC recovery in the Stirling Range; and (ii) environmental weed impacts and recovery actions for threatened flora within the Swan Region.
- Complete the analysis of spatial patterns of threat intensity in the Southwest Australian Floristic Region 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

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 130 seed collections (58 species) were banked at the Western Australia Seed Centre (Threatened Flora Seed Vault); 108 of these collections (46 species) were listed as critically endangered, endangered or vulnerable (threatened flora), 22 of these collections (12 species) were listed as priority flora.
- Twenty-seven seed collections from 15 Stirling Range species were collected as part of a post-fire recovery project.
- Forty seed collections from 16 threatened species were collected for the Rare Bloom Project™.
- The seed bank now contains 6181 collections (1925 taxa) representing 347 threatened flora, 747 priority flora and 831 restoration species.
- One hundred and fifty-six germination tests were conducted.
- Seedlings of 11 threatened and 1 priority flora species were provided for translocation.
- One species *(Schoenia filifolia* subsp. *subulifolia*) was planted into a seed production area at Woodlupine Primary School, whilst seed of the same species was provided to establish a seed production area at the Central Regional TAFE in Geraldton.
- Germination tests were conducted on seed from 10 species (33 collections) that had been in storage for over 10 years, adding to the viability dataset of collections after long-term storage.

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, focussing on species either not represented in the seed bank or with low quantities of banked seed, for long-term conservation and use in translocations.
- 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 Anderson, C Gosper

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

The primary aim is to provide genetic information for the conservation and management of Western Australian flora, especially rare flora. Current projects aim to:

- 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.
- Determine the genetic relationship between *Verticordia spicata* subsp. *spicata* and the critically endangered *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*.
- Determine the genetic relationships within four species complexes (*Geleznowia*, *Isopogon*, *Synaphea* and *Wurmbea*) as part of the GAP conservation genomics initiative

Progress

- Phylogenomic analysis of relationships in the *Leptospermum* genus has been published in *Taxon*. The analysis shows separation into five clades with other genera nested among them indicating polyphyly and the need for taxonomic revision of this genus. This revision is currently underway by external collaborators.
- Additional genomic analysis of one of the Western Australian *Leptospermum* clades (10 spp) showed that 3 species in this group are taxonomically sound, while two other pairs of species (*L. nitens* + *L. roei* and *L. incanum* + *L.* sp. Peak Charles) are indistinct. A more complex relationship between *L. erubescens* and *L. oligandrum* will require further morphological assessment to determine the appropriate taxonomic outcome. A paper has been published in *Botanical Journal of the Linnean Society* for the genomic data and a short communication in *Nuytsia* is currently being written to publish the taxonomic revisions.
- Genomic analysis of the nine species of the gimlet complex is near completion and a paper is in preparation.
- 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*. A paper is in preparation.

- Field collections and DNA extractions have been completed for *D. obovata* and genomic sequencing is currently underway.
- Field collections, sequencing and genomic analysis of the *C. caeruleum* species complex has been completed and a report has been written. A manuscript is in preparation. Genomic data warrant the recognition of at least three distinct species and three independent management units within the south-west species.
- Genomic analysis is largely complete for the four species complexes in the GAP project. Morphological assessments are currently underway and four papers are in preparation.

Management implications

- 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.
- 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.
- 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.
- Genomic analysis of the four species complexes in the GAP project will resolve the species within each group and identify those with conservation concerns to enable conservation listing and appropriate management.

Future directions

- Complete genomic analysis of the gimlet complex and write paper.
- Write paper on the *V. spicata* subspecies and revise taxonomy and conservation listing.
- Write paper on the *C. caeruleum* subspecies and revise taxonomy.
- Analyse genomic data for *D. obovata* and write paper.
- Complete genomic and morphological assessments for the four GAP species complexes and write papers.

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 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 for biodiversity

conservation.

Aims

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

Progress

- Soil and leaf litter and pitfall trap samples from FORESTCHECK fire chronosequence sites near Dwellingup are currently undergoing statistical analyses and a manuscript is in preparation. The eDNA detected higher vertebrate and invertebrate species diversity than traditional methods.
- Samples of zooplankton from the Pilbara have been extracted and sequenced and are currently undergoing bioinformatic analyses.
- Water samples collected from rivers in the south-west of Western Australia were analysed and the results show that pearl cichlids were detected along the entire sampling area, and that eDNA methods identified eleven fish species, as well as non-target species of birds, mammals and reptiles.
- Soil microbiome samples were collected from Yarragil experimental catchments statistical analyses of the metabarcoding data are underway. The shotgun data is still undergoing bioinformatic analyses.
- A collaboration with the Cane Toad management group is developing an eDNA tool for tracking cane toad movement.

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

- Continue to barcode species to add to the WA reference 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 standardised, 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

- Eleven months of sampling was completed at Lowlands Nature Reserve and the equipment moved to the site at Kings Park for sampling at that site.
- Samples of spores from the cyclone sampler and of soil are being sent to the Swedish University of Agricultural Sciences and insect samples to University of Guelph in Canada.
- Audio and camera trap imagery are being transferred to the project headquarters in Helsinki via a cloud file transfer service.
- The project team contributed to the audio machine learning process by verifying bird calls from an international database and are now identifying call samples from the Perth site.

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.
- Information collected 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 Kings Park and Lowlands Nature Reserve.
- Compile reference libraries of faunal images and assist with providing training data for machine learning of bird calls.
- 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

- Completed bibliography that includes digitally available reports and publications for Ramsar sites located in Western Australia.
- Completed first set of analyses using the data set from the South West Wetland Monitoring Programs and began assembling the first manuscript for publication.
- Conducted waterbird surveys at Lake Toolibin and Thompsons and Forrestdale Lakes.
- Conducted fish and aquatic invertebrate surveys in the Muir-Byenup system.
- Conducted baseline aquatic invertebrate survey of the Peel-Yalgorup system and resampled aquatic invertebrates at Lake Toolibin following the first winter fill event since 1996. Sample processing is complete and analyses is underway for Lake Toolibin and sample processing and identification is in progress for Peel-Yalgorup.
- Conducted water quality sampling at five Ramsar sites and statistical analysis of salinity and water level trends at monitored wetlands.
- In collaboration with DWER, Peel-Harvey Catchment Council and The University of WA, commenced fieldwork for a project describing the hydrology and salt budget for Lake Clifton (Peel-Yalgorup site), particularly with respect to the thrombolite TEC.

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

- Finalize UAV protocol and begin conducting vegetation monitoring at Ramsar sites.
- Conduct fish and invertebrate surveys at Muir Byenup and aquatic invertebrate surveys at the Peel-Yalgorup Ramsar site.
- Assist Birdlife Australia with a citizen science project to conduct monthly waterbird counts at select sites across the Peel-Yalgorup Ramsar site.

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

SP 2019-068

K Ruthrof, 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

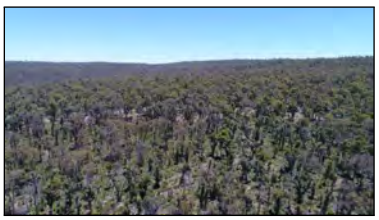
- To understand thresholds for drought-vulnerability in terms of soil depth, canopy height, and vegetation cover, three long-term drought die-off research sites in the Northern Jarrah Forest were examined using electrical resistivity equipment, and a remotely piloted aircraft (RPA). This work showed a number of zones at die-off sites: zones with shallow soils (1-15m depth) associated with no trees and canopy die-off, and a zone with deeper soils (15m+) associated with less die-off and a taller canopy and higher vegetation cover.
- A range of ecological responses to forest thinning have been examined at the Munro demonstration site, including canopy cover, coarse woody debris and the perennial understorey vegetation community.
- To examine the impacts of silviculture, rainfall, and forest type on microbial communities, soil samples were collected at 42 ForestCheck sites.
- To understand the impacts of climate change and fruit harvesting on fruit production of *Banksia grandis*, permanent plots have been established in three forest blocks and 2400+ adult trees have been measured.
- Established a study to examine the vulnerability of regrowth forests to high severity fire.

Management implications

- Understanding soil depth at multiple sites will help in understanding climate vulnerability across the forest, and help choose sites for proactive management intervention such as thinning.
- Quantifying the ecological responses from different thinning methods at the Munro thinning trial site, such as tonnes per hectare of coarse woody debris, will inform which thinning method is effective, and how that impacts fire hazard.
- Quantifying the impact of fruit harvesting in *Banksia grandis* can assist in managing fruit harvesting, such as directing harvesting towards or away from certain forest blocks.

Future directions

- Further examine the Munro and Hamilton thinning trials to understand the implications of different types of thinning for soil compaction, glyphosate residues, canopy structure, microclimate, and fuel loads.
- Understand the longer term community attitudes to forest thinning.
- Contribute to formalising a thinning demonstration site so that it is a self-guided tour, and work towards embedding it in a 'Forest Trail' of multiple demonstration sites across the southwest.



Investigating the causes of change in forest condition

SP 2019-048

K Ruthrof, 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

- Information from changing forest cover was incorporated into the end term review for the current Forest Management Plan (2014-2023).
- Further analysis regarding vegetation cover trends and landscape patterns has been undertaken.
- A field based investigation of how the remote sensing data on vegetation cover changes relates to on-ground forest stand and site characteristics, in the Collie region, has commenced.

Management implications

- Techniques used for mapping of vegetation cover, and understanding which ecosystem types and location in the landscape are associated with a declining vegetation cover, have been incorporated into forest management policy and planning, and contribute to mapping forest health and reporting for the next forest management plan.

Future directions

- Extend analysis capturing the last FMP period to encompass the past 30 years of canopy cover trajectory.

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 and system sensitivities to resolve potential ecohydrological management zones.
- Construct conceptual hydrological models and review the need and uncertainties associated with numerical models.

Progress

- Geochemical analyses of peat sampled from the Walyarta organic mound spring has been prepared for publication.
- Spring water level monitoring data have been compiled to describe the geochemistry of different spring systems in the Walyarta Conservation Park.
- In the Greater Brixton Street Wetlands hydrological and geophysical data were collected to investigate the role of the hydrology in vegetation patterns and condition.
- The Final Report for the Ashfield Flats Hydrological Study has been published and presented to government and community groups. Journal articles documenting the results are in preparation.
- A deep ground penetrating radar survey was conducted around Lake Cave to characterise cave pool organic carbon sources and to evaluate potential hydrological connections between Lake Cave at Cape Leeuwin and nearby Blue gum plantations.

Management implications

- Analysis of Walyarta mound springs organic matter indicates these low latitude (tropical) peat systems are more resilient in a drying climate, compared with peat wetlands in southwestern Australia. The main threat to the springs is a reduction in dry season groundwater discharge and spring flow.
- In the Greater Brixton Street Wetlands, water, sediment and soil chemistry are variable in space and time and indicate that many changes are potentially deleterious to vegetation and may be the result of changed land use.
- 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

- Complete journal paper on Walyarta organic mound spring geochemistry.
- Complete a journal article on benefits and threats associated with groundwater and surface water interactions in the Greater Brixton Street Wetlands.
- Participate in stakeholder engagement during the planning process and ongoing community consultation for Ashfield Flats Reserve and continue to publish research from that study.
- Complete journal articles on the carbon sources feeding three Leeuwin-Naturaliste caves and the hydrogeology in the vicinity of Lake Cave.

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, have 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 and 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

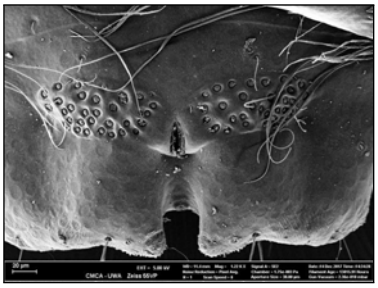
- The Toolibin Lake WatBal model has been updated with lake water level and salinity data collected over the current lake fill event that commenced in July 2021.
- Results from the Toolibin Lake groundwater model were presented to staff in the Wheatbelt Region and BCS.

Management implications

- Results from the Toolibin lake WatBal model were used to support a broad range of management decisions that include lake water and feral animal management.

Future directions

- Link the groundwater and Toolibin Lake WatBal models to increase confidence in modelling results.
- Complete hydrological models.
- Complete journal articles and science information sheets.



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 brine shrimp and associated data from recent DBCA survey projects were provided to a PhD student undertaking taxonomic research, resulting in the discovery of new taxa.
- New species of water mites were described by an external taxonomist from DBCA material, including a short-range endemic from a threatened ecological community in the northern Wheatbelt.
- Sampling moss beds on granite outcrops is revealing new species of aquatic oligochaetes belonging to the Gondwanan family Phreodrilidae, some likely to have very restricted distributions, and all restricted to this habitat.

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.
- Moss beds on granite outcrops contain unique invertebrate diversity not found in adjacent ngamma holes. This habitat can be damaged by recreational use including trailbikes.

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

- External modelling, interpretation and reporting commitments were completed.
- Outputs included a peat wetland management framework to reconcile conservation goals with options to manage wetland acidity.
- Analyses of peat organic matter from Poorginup Swamp are being prepared for publication as part of a global research collaboration (Global Peat Microbiome Project).
- Two journal articles outlining different approaches for investigating peat wetland resilience are being drafted.

Management implications

- Understanding responses of biodiversity values to peat wetlands activity will inform decisions on management treatments to reduce impacts on flora and fauna.
- Global research indicates peat wetlands in southwestern Australia will be challenging to manage under a drying climate as their high levels of carbohydrate makes them prone to mineralisation.

Future directions

- Investigate peat wetland acidity treatments and the nature and extent of hydrological and hydrogeochemical processes of the Muir-Byenup Ramsar site.
- Communicate findings through the completion of journal articles and a science information sheet.

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 and fire, 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 effects of management activities on terrestrial vertebrates in jarrah forest ecosystems.
- Provide information that helps improve ecologically sustainable management and biodiversity conservation in the jarrah forest.

Progress

- Vehicle based spotlight monitoring of mammals on three standardised transects was maintained with six repeat surveys per transect per year. The population of the critically endangered ngwayir (western ringtail possum) in the greater Kingston area remains very low, although this year showed the first increase in detection rate since 2017.
- A pedestrian-based spotlight survey within the Upper Warren was conducted in early 2022. A population of 7103 ngwayir (6052 – 8335 95% CI) across the 38,349 ha area surveyed was estimated using distance sampling methods and density surface modelling. The survey confirmed the very low densities of ngwayir

in the greater Kingston area and largely resolved the extent of the regional 'hotspot'. The incidence of severe fire over the last 20 years, landscape position, distance to surface water features and elevation, are among the factors that best explain the current distribution and abundance of ngwayir in the region. Two reports from this work have been published.

Management implications

- Identification of decline in 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 effects of management and environmental factors on terrestrial vertebrates and the factors responsible for changes in populations will inform ecologically sustainable forest management practices and the conservation of biodiversity.

Future directions

- Existing data will continue to be analysed and prepared for publication.
- A holistic and integrated regional assessment of priority fauna will be investigated.

Western Australian flora surveys

SP 2012-005

M Lyons, A Markey, M Langley, R Binks

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 the targeted survey of *Typhonium* in the Ord Valley.

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

- 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. Analysis is being planned by Spanish colleagues. Contribution to a worldwide phylogeny of *Frankenia* is ongoing.
- Survey of *Typhonium* sp. Kununurra in the Ord Valley was undertaken, providing information critical for conservation planning in the context of the Ord River Irrigation Area expansion. A supplementary genetic study on a subset of samples has been completed in conjunction with staff of the Australian Tropical Herbarium and reported to DPIRD. Lodgement of *Typhonium* material in the WA Herbarium has been completed.
- A project initiated in response to the Auditor General's review of salinity policy was undertaken. Populations of conservation significant flora and vegetation community plot data were overlayed on revised salinity mapping from CSIRO and DPIRD, to determine salinity threat to flora and vegetation communities. Reporting in is draft stage.
- A project to reanalyse the floristic community data for the Swan Coastal Plain commenced, in conjunction with regional and Species and Communities program staff. Existing plot datasets supplementing the original Swan Coastal Plain Survey and System 6 surveys has been compiled. Preparation of the data is underway, requiring a lengthy process of standardising taxonomy of entities across historical and more

recent data. Analysis will focus on examining this expanded dataset against the floristic communities types currently recognised for the region.
- Curation and lodgement of survey plant specimens is ongoing. Current priorities include Pilbara Biological Survey vascular aquatic plants and the extensive collections from plots sampled for GYPWORLD. Lodgement of priority listed taxa from recent survey work in the Ord Valley is progressing.

Management implications
- The *Typhonium* survey has provided scientific information on the distribution of this important species for the Ord-East Kimberley Development Project planning and approvals process.
- The analysis of salinity trends in relation to conservation significant flora and plant communities, coupled with an analysis of wetland salinity trends from the 40 years of data from the monitoring of south-west wetlands will inform DBCA's response to the Auditor General.
- Reanalyis of floristic data for the Swan Coastal Plain will provide a robust floristic classification for the vegetation of the region, and will enable a re-examination of the floristic community type currently listed for the plain. This information is central to the planning and approvals processes for assessing development and associated native vegetation clearing in the region.
- Specimen lodgement is a critical task, providing material for taxonomic research and distributional information for taxa.

Future directions
- In collaboration with European researchers undertake analysis of GYPWORLD plant community data and commence reporting.
- Complete reporting of analysis of salinity trends in reponse to Auditor General's report.
- Complete analysis and reporting of the updated analysis of floristic data for the Swan Coastal Plain.
- Maintain current impetus in the lodgement of voucher material.

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

SP 2011-020

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.
- A paper on modelling growth in karri and marri has been published in *Forest Ecology and Management*.
- Another manuscript on karri growth response and thinning is in review and a final manuscript investigating the effects of above and below ground competition in jarrah and karri forests is ready for submission.

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 wildlife habitat or resilience to disturbance. Thinning is 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. The extent of tree mortality in 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, J Sciano

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

- Resampled aquatic invertebrate communities in Pilbara river pools to determine impact of the invasive redclaw crayfish. Partially processed these samples.

- Completed identifications of aquatic invertebrates sampled from wetlands in Lake Carnegie environs.
- Completed identifications of aquatic invertebrates from samples collected in 2017 to understand aquatic diversity in the Goldfields Region. This will provide context for the Lake Carnegie survey.
- Completed identifications of aquatic invertebrates from wetlands supporting Western Swamp Tortoise to add to data on vegetated claypans of south-western Australia.
- Sampled several wetlands in the Wandoo Forest for Perth Hills District and processed samples for one of these.
- Published a paper in *Global Change Biology* on changes in alpha, beta and gamma diversity of aquatic invertebrates in relation to declining rainfall in the Wheatbelt region. This showed that species richness declined within individual wetlands (alpha diversity) and across the suite of wetlands (gamma diversity) sampled, as rainfall declined between 1998 and 2011. To examine resilience to climate-change, the same Wheatbelt wetlands were resampled during a relatively wet year in 2021, and these samples are being processed.

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.
- Better descriptions of invertebrate communities can assist understand the habitat needs of threatened aquatic species such as the Western Swamp Tortoise.
- Survey work is providing information to understand the threats posed by redclaw crayfish in the Pilbara and inform actions to minimise its spread.
- Ensuring that refugia, such as water supply reservoirs, are managed to also retain and enhance biodiversity values, is likely to retain regional biodiversity in wetlands.

Future directions

- 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.
- 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.

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

SP 2006-003

A Pinder, J Hyde, K Ruthrof, A Wills

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

- Soil and leaf litter samples from the fire chronosequence have been analysed to examine the potential for using eDNA to monitor invertebrate biodiversity.
- Vertebrate pitfall traps of all but 6 grids have been removed or made safe.
- A paper analysing the natural and anthropogenic influences on avian communities in the jarrah forest has been prepared using Forestcheck data.
- All data for birds, other vertebrate fauna, fungi and cryptogams has been curated and converted to a format suitable for archiving and upload to corporate repositories.
- Soil samples were collected from 41 of the original 48 sites to examine the potential of eDNA for vertebrate biodiversity monitoring. Samples were collected so that they can be used for invertebrate, microbial and fungal sampling in the future.

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 and the end of term report for the Forest Management Plan. 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 disturbance events such as bushfires and extreme droughts, and examining the impacts of a changing climate over the longer term.

Future directions

- Publish further analyses using data from first and second round of sampling and two more recently sampled jarrah forest ecosystems.
- Continue to investigate alternative biodiversity monitoring techniques with a focus on eDNA and ecoacoustics.
- Archive remaining Forestcheck project data in suitable repositories and ensure integrity of the grid sites.

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

SP 2000-003

J Kinal, 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, stream turbidity, rainfall, an automatic weather station and sap flow continued in Yarragil 4L, 4X, 6C, and Wuraming catchments in the Swan Region.
- Data from loggers were retrieved and analysed and long term local and regional data summarised for the FMP Mid-term review and for the Silviculture Review Panel.
- Eight sap flow sensors were installed as part of an experiment to assess tree water use in response to thinning in Yarragil 4X and 4L.
- Forest tracks in the catchments were cleared of fallen trees to maintain access to monitoring infrastructure.
- A research agreement was entered into with Alcoa who provided groundwater level data from a network of 2000 groundwater bores in the Northern Jarrah Forest and initial data analysis was completed.
- Characterisation of forest structure using remote sensing and linking this to ephemeral Jarrah Forest streamflow has commenced.
- A geophysics survey was trialed by department staff using a backpack portable Time Domain electromagnetic system at Yarragil 4X and 4L.

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 sap flow and 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, 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

- 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 accepted for publication by the journal *Ecology and Evolution.*

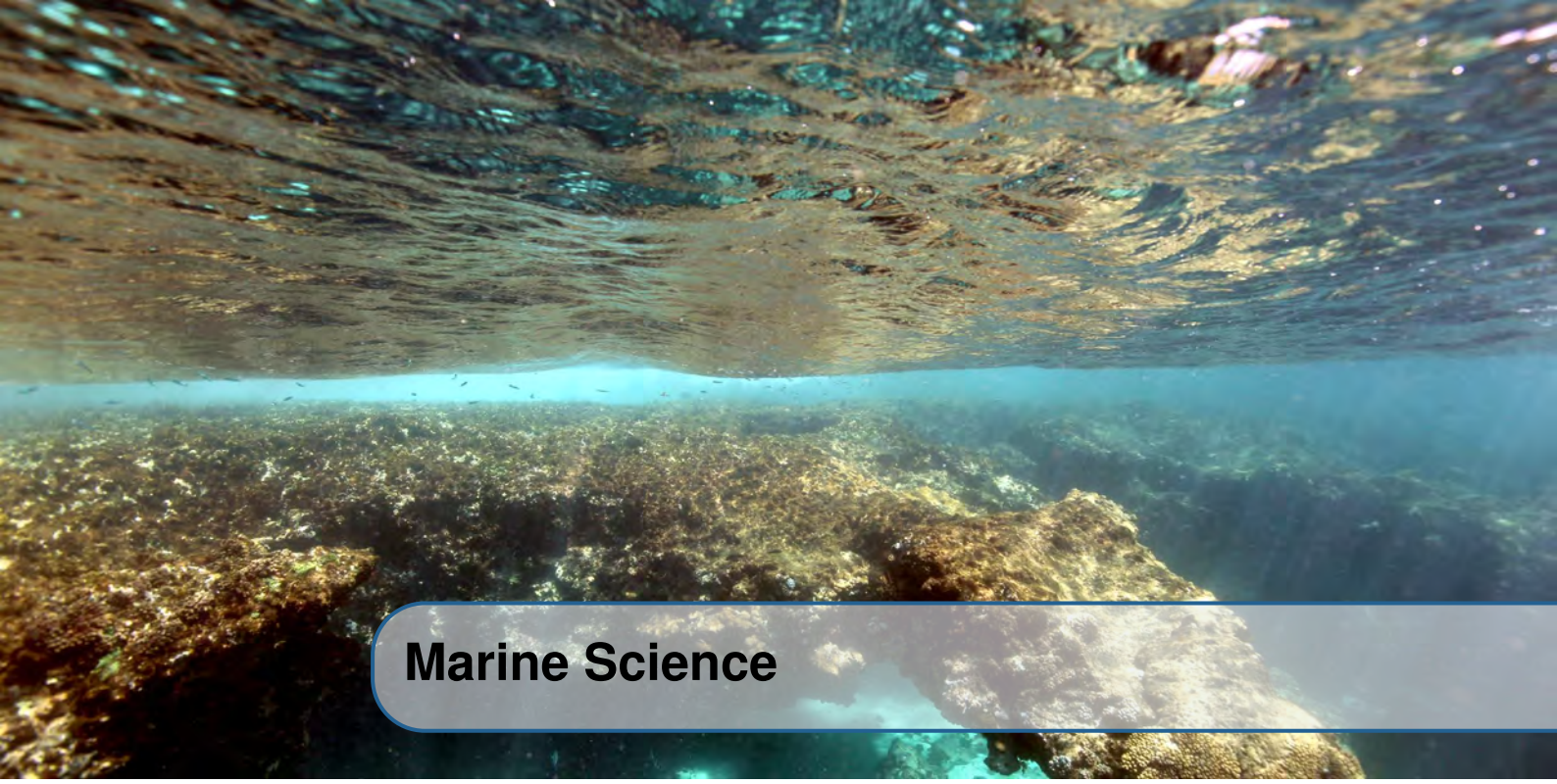
- Analysis of the small shrub *Mirbelia viminalis* shows genetic diversity similar to other widespread Pilbara species and genetic differentiation among populations, indicating some restrictions to gene flow as found for other Pilbara species of low stature. A manuscript is under review by the *Australian 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 currently under review in *Annals of Botany*.
- Analysis of genetic diversity in *Senna 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. A paper is in preparation.
- A synthesis manuscript is being prepared that summarises broad genetic patterns in eleven Pilbara species, focusing on seed collection zones and provenancing for mining restoration.

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 ranges in the Pilbara 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.

Future directions

- Finalise papers reporting the genetic results for Pilbara species *I. monophylla*, *P. labicheoides*, *M. viminalis* and *S. glutinosa* subsp. *glutinosa*.



Marine Science

Program Leader: Shaun Wilson 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 and management plans, ensuring that all activities are linked to departmental priorities and programs.

Benefits of marine parks for marine fishes in a changing climate

SP 2021-040

S Bell, J Goetze, T Holmes, W Robbins, C Ross, S Wilson

Context

To conserve WA's marine biodiversity, a network of marine parks has been established under the principles of being comprehensive, adequate and representative. These principles require knowledge of ecological assets over a statewide scale and are complicated by a changing environment. Finfish have been identified as a key ecological asset due to their high ecological and social values. Anthropogenic pressures are leading to shifts in the composition of fish assemblages, and it is unclear how well the current network of marine parks represents fish diversity. This project will combine DBCA finfish monitoring data with information collected by external collaborators to assess fish biodiversity inside and outside of WA marine parks over the last decade. This dataset will be used to describe statewide spatial and temporal patterns of finfish composition and distribution in relation to key pressures, to enable adaptive management and guide marine park planning.

Aims

- Collate a statewide finfish dataset with key collaborators to enable biodiversity assessments of fish inside and outside of marine parks, over the last decade.
- Develop conversion factors that will enable the synthesis of DBCA finfish data (diver operated video, DOV)

with legacy datasets (underwater visual census, UVC) and emerging methods (remotely operated vehicle, ROV).
- Compare the composition, biodiversity and productivity of fish assemblages among marine parks relative to non-reserved locations.
- Assess if the composition, biodiversity and productivity of finfish assemblages within marine parks has changed over time and if any changes correspond with climatic events or are due to fishing pressure.
- Determine if these changes persist through time and whether patterns of change differ among parks located along the WA coast.

Progress
- Remotely operated video data for assessing finish in the Northern Kimberley Marine Park that is a key data gap location, has been collected and a second trip is planned.
- DBCA data is in the process of being uploaded to GlobalArchive (https://globalarchive.org), a centralised repository that allows users to store data in a standardised and secure manner, makes meta-data discoverable, and encourages collaboration and synthesis of datasets within the community of practice.

Management implications
- Findings from this project will allow an assessment of how well the State's marine reserves represent biodiversity of fishes and associated ecological functions. This information can inform placement of new reserves and reconfiguration of existing reserves
- Temporal assessments will evaluate stability of marine fish diversity and functional values to determine if the current network of reserves will comprehensively and adequately represent fish assemblages in the future.

Future directions
- Ensure all data is cleaned, formatted and uploaded to GlobalArchive.
- Continue data collection in the Kimberley Marine Parks.
- Undertake statistical analysis and write manuscripts.

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 and retention data for interpreting spatial differences in productivity.
- Measure water quality parameters (total soluble solids, salinity, nutrients, Chlorophyll 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 these relate 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

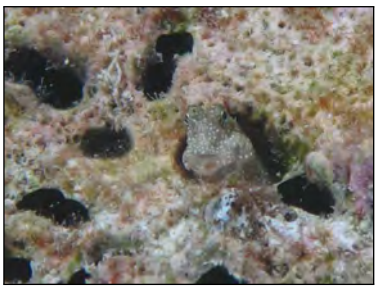
- Initial productivity measurements for mangroves were conducted.
- Seagrass productivity was measured at 8 sites in the Dampier Archipelago.
- Macroalgae productivity and invertebrate epifauna collections were conducted at 7 sites.
- 1500 stable isotope samples were processed in the laboratory. These analyses indicate that corals in Dampier Archipelago can adjust their feeding preferences depending on turbidity. Some corals do it more readily and may be better suited to adapt to environmental and human induced turbidity changes.
- More than 300 fish otoliths were processed to assess secondary production in fish.
- Abundance estimates of consumers (fish and invertebrates) have been conducted.
- Deployed oceanographic instruments continue to obtain data for development of fine scale hydrodynamic modelling.
- Sampling to evaluate water quality has continued and two additional sets of samples were sent for analysis.
- Second measurement of coral productivity using Structure from Motion photogrammetry has been completed.
- Coral survey during the heatwave in April 2022 found 10-80% of corals had bleached.
- Benthic and fish images were analysed.

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 to collect data to inform the development of productivity and hydrodynamic models, and analysis of fish, coral and invertebrate communities.
- Collect winter samples of macroalgae and invertebrate epifauna.
- Develop preliminary hydrodynamic model for the Dampier Archipelago.
- Analyse samples and data and begin writing scientific publications.
- Explore potential use of eDNA to understand productivity effects on biodiversity.
- Follow up surveys of corals to determine recovery from heat stress and bleaching.



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 with 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 been identified at the Western Australian Museum, and DNA from water and sediment samples has been extracted and identified.
- A manuscript describing and comparing fish assemblages from the different survey techniques is being prepared. Early results indicate that eDNA from water samples record more cryptobenthic fishes than other techniques.

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 be used to assess if management zones within the State's marine reserves adequately protect CRF in different marine habitats.

Future directions

- Complete and submit manuscript on comparing methods for surveying cryptobenthic fishes.
- 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, K Murray, T Holmes, B Huntley, S Bell

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 and 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

- The global database on seagrass growth and reproduction is currently under review for publication *Pangaea*, as well as the corresponding manuscript.
- Indicators of seagrass condition collated across 60 sites in six WA marine reserves are being analysed in order to assess the influence of environmental factors on long-term trends in seagrass condition.
- In response to another summer with La Nina conditions, seagrass data was collected for 20 *Amphibolis antarctica* sites across Shark Bay. Trends indicate that shoot density has continued to decline since March 2020.
- Preliminary data analysis of fish assemblages in Monkey Mia indicates that fish abundance, diversity and size class differ across seagrass meadows with different patch metrics and that both URUV and trawling methods are appropriate for capturing different parts of the assemblage.
- Updated mapping of seagrass extent in Monkey Mia in 2020 suggests some recovery since 2016, although this does not cover the whole Marine Park.

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 and identify appropriate indicators of stress.
- Assess how fragmentation of seagrass meadows can influence 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, 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 final ecological monitoring report for the Dampier Archipelago has been drafted and provides a synthesis of the baseline data collected in the Dampier Archipelago between May 2015 and June 2020. This data will provide a valuable baseline for long-term monitoring, or to assess the impact of a large-scale disturbance event.

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

This project has been completed.

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

SP 2014-021

K Waples, H Raudino

Context

Australian snubfin (*Orcaella heinsohni*), Australian humpback (*Sousa sahulensis*) and Indo-Pacific bottlenose (*Tursiops aduncus*) 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, 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 key factors 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 was published in a special issue of *Mammalian Biology*.
- Data analyses are complete and a manuscript will be submitted shortly on using density surface modelling and aerial survey data to better understand abundance and distribution of coastal dolphins at a regional scale in the Pilbara. Abundance estimates are in the low thousands for both Indo-pacific bottlenose dolphin and Australian humpback dolphin, with humpback dolphins apparently less abundant than bottlenose dolphins.

Management implications

- A baseline understanding of dolphin distribution and 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 information will be important to inform the Commonwealth review of the conservation status of the humpback dolphin under the EPBC Act.
- 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

- Publish the manuscript on dolphin abundance and distribution based on aerial survey data a for the Pilbara region.
- 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 component 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 paper on ranging patterns and site fidelity of snubfin dolphins in Yawuru Nagulagun Roebuck Bay Marine Park (YNRBMP) was published in *Frontiers in Marine Science*. Key findings that will inform management include confirmation that the population of snubfin dolphins that regularly use Roebuck Bay is resident and a subset of a broader population. High use areas have been identified, including the northern part of the bay and the Port of Broome.
- A public presentation on snubfin dolphin site fidelity and use of YNRBMP was made to the Broome community and stakeholders.
- A vessel-based dolphin survey (census) was undertaken in YNRBMP with regional staff and Yawuru joint managers. The survey confirmed that the population of snubfin dolphins that use YNRBMP has remained relatively stable.
- Two presentations were made to volunteers interested in the Dolphin Watch program and using the newly released marine fauna sighting app to record dolphin sightings as a citizen science initiative. Dolphin Watch volunteers also participated in one day of the dolphin census.
- The genetic analysis of tissue samples collected from snubfin dolphins in Prince Regent River was completed and a technical report written in partnership with DBCA regional staff and Dambeemangarddee Aboriginal Corporation. The analyses indicate snubfin dolphins from Prince Regent River are not genetically isolated from other populations in the Kimberley, although it is likely that gene flow is limited to potential migration of dolphins from Cygnet Bay to Prince Regent River. This population could be regarded as a distinct management unit and considered to be potentially vulnerable to anthropogenic pressures such as increased vessel traffic.

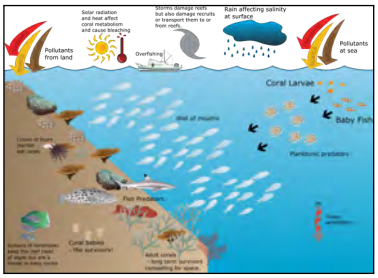
Management implications

- 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 YNRBMP..
- 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 Marine Fauna Sighting app and Finbook photo-identification guide will support ongoing monitoring of the snubfin dolphin population in YNRBMP. They will be used to address the key performance indicators related to maintaining abundance and diversity of these dolphin species in YNRBMP.
- A monitoring program for a 3 yearly census of dolphins in YNRBMP will inform ongoing management of these species using the marine park and surrounds.
- Understanding the population structure and genetic connectivity of coastal dolphin populations will inform conservation management of these species by identifying populations more vulnerable to anthropogenic impacts.

Future directions

- Publish the results of the genetic analyses of tissue samples collected from snubfin dolphins in Prince Regent River.
- Publish a new edition of the Yawuru Nagulagun Roebuck Bay Finbook.



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

- The results of this study show that the Kimberley has greater genetic variation than the Pilbara, including outlier loci. This highlights the Kimberley region as a location with greater ability to adapt to change.
- Preparation of a manuscript on reef fish connectivity is being coordinated with collaborators.

Management implications

- Information on population dynamics and connectivity has identified fish in the Kimberley region as having greater ability to adapt to change and may be managed accordingly as a more resilient population but also as a potential source population in the event of catastrophic disturbance in the Pilbara.

Future directions

- Complete and submit manuscripts on reef fish 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 2000 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

- A meta-analysis assessing the value of macroalgae associated with small-scale tropical reef fisheries was published in *Fish and Fisheries*. The study found that recreational fisheries in the Pilbara and Ningaloo are highly dependent on macroalgal habitats with >50% of the catch being fish that associate with macroalgae.
- Data from fish surveys over the past 10 years were used to examine if abundance of recruit and juvenile fish can predict abundance of adult spangled and yellow tail emperor. Initial modelling suggests juveniles reliably forecast abundance of fish 1-2 years of age, but not older fish.

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.
- Understanding how climatic processes affect both the supply of juveniles and quality of nursery habitat improves our understanding of temporal fluctuations in fish abundance and ability to predict future populations.
- Improving the capacity to predict future abundances of adult fishes, particularly those threatened by changes to habitat, climate and fishing pressure, will help to maintain important social values like recreational fishing

Future directions

- Complete data analyses of links between juvenile and adult fish abundance and write up findings for publication.
- Investigate the spatial and temporal dynamics of canopy forming macroalgae at Ningaloo to understand how important macroalgae are for capturing carbon.

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 manuscript describing the flatback turtle satellite tracks is in the final stages of preparation. For this study, information from over 300 turtles has been combined from multiple research partners to develop one of the worlds largest animal tracking data sets.
- Additional transmitters were applied to reproductively mature male turtles to fill knowledge gaps on mating areas.
- Movements of tracked turtles were displayed in real time on a website (www.seaturtle.org).

Management implications

- Spatial data of animals is essential to understand movements and habitat requirements of turtles. Data from this project has assisted identification of Biologically Important Areas (BIA) and "habitat critical to survival" including 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's and migratory pathways informs management on areas sensitive to human pressures to underpin any management decisions.

Future directions

- Finalise analyses of datasets for manuscript preparation
- Continue to use a multi-discipline approach of flipper tags, satellite tags, genetics and stable isotopes to understand movements and distribution.

Marine monitoring program

SP 2012-008

T Holmes, W Robbins, C Ross, I Leal, S Strydom, K Murray, S Wilson, S Bell, K Crook, L Arrowsmith, H Raudino, K Carter, J Goetze

Context

A statewide system of marine protected areas has been established and regularly updated 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 and 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, the Conservation and Parks Commission, 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 collaborators for fish, coral, seagrass, macroalgae, mangroves, macro-invertebrates, little penguins, shorebirds, intertidal invertebrates, sea lions, 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 Rowley Shoals, Walpole and Nornalup Inlets, Marmion and Shoalwater Islands marine parks.
- Five scientific papers incorporating departmental monitoring data or examining developments in monitoring methodologies and indicators were published in *Diversity*, *Global Change Biology*, *Estuarine Coastal and Shelf Science*, *Conservation Biology*, and *Environmental DNA*.
- Significant scientific advice was provided as a part of the ongoing planning process for Marmion and Buccaneer Archipelago marine parks, through community engagement forums associated with the south coast Plan for our Parks process and to external research and management agencies (AIMS, DPIRD, RIA, Minderoo Foundation, Resilient Reefs and the state-wide coral bleaching network).
- Significant development was undertaken for 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 statewide framework.

Future directions

- Transition all of marine monitoring data to publicly visible online reporting platform to replace need for static hard-copy reports.
- Continue the implementation and periodic review of ecological value monitoring across the marine reserve system, including planning and prioritising of monitoring activities in the proposed South Coast, Marmion and Exmouth Gulf marine reserves.
- Reprioritisation 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

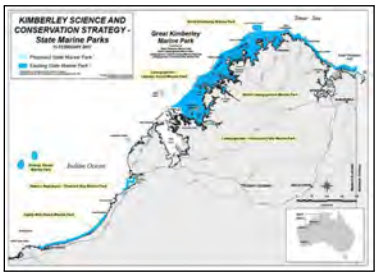
- Nesting turtle monitoring projects were continued at Delambre and Thevenard Islands, Eco Beach and Cape Domett.
- Major studies were completed on estimating turtles age to maturity and total age.
- Foxes were removed for the fourth year at a major Pilbara flatback turtle rookery at Mundabullangana Station.
- Indigenous engagement activities continued at several sites including employment at Delambre Island, community visits at Thevenard Island and a continuing partnership with Woalitji Foundation.
- Seven presentations were given at the 40th Annual Sea Turtle Symposium held in Perth and the NWSFTCP program received an award from the International Sea Turtle Society for outstanding achievement.

Management implications

- Sea turtle monitoring requires long term data sets. The foundations are established for a roust monitoring program for the North West Shelf genetic stock of turtles to inform conservation and management decisions.
- The flatback turtles foraging project at Roebuck Bay provides insight into biology and ecology of resident flatbacks and provides access to turtles for health studies. It has provided a spatial context to habitat use that can be used by joint managers (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.
- Partnerships with Indigenous groups have been an important part of the program. This 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 a way of transferring information.

Future directions

- Complete a synthesis report for the work of the NWSFTCP so far.
- Develop the next strategic plan
- Complete a manuscript of flatback turtle movements
- Continue to monitor key flatback nesting beaches including Delambre and Thevenard Islands, Port Hedland, Eco Beach and Cape Domett.
- 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 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 paper published in *Ocean and Coastal Management* identified remaining priority knowledge gaps for the Kimberley from the perspective of scientists, natural resource managers and indigenous healthy country mangers, highlighting the synergies across these groups.

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 and the 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.
- Continued support for research initiatives that bring together western and indigneous science and participants for shared purposes.

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

SP 2009-013

I Leal, 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 for 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

- Collaborated in an Edith Cowan University (ECU) student camp at WNIMP. Third year undergraduate students studying Coastal and Marine Management with Professor Paul Lavery collected data on bivalve, gastropod and polychaete communities.
- Invertebrate samples have been processed to generate data for analysis.

Management implications

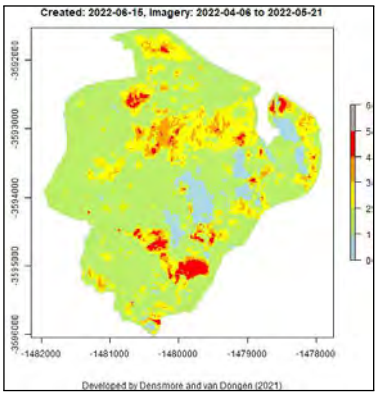
- Benthic invertebrates are a KPI for this marine reserve. Understanding the relationship between invertebrates and finfish informs management of how changes to invertebrate communities can influence another KPI community within the reserve.
- Knowledge of spatial and temporal patterns of invertebrate 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.
- Analyse multiple 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 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

- Severity maps were produced and verified for all spring and autumn prescribed burns that occurred within the Swan, Southwest and Warren regions in 2021-22.
- Work is underway to automate the severity mapping approach for all future burns within these regions.
- A technical guide to creating fire severity maps for the southwest has been drafted and submitted to the Burn Severity and Monitoring Working Group for approval.
- A manuscript describing OzCBI (the field-truthing method) and the modelling process has been submitted to *Australian Forestry*.
- Aerial ignition patterns, weather, fuel characteristics and severity data have been compiled for 17 spring burns to analyse causal relationships.
- The role of prior severity class on the development of fuel hazard (per Vesta Mk 2), has been assessed for the Warren Region.
- Historical severity maps have been produced to investigate the role of severity in affecting woylie capture rates within the Upper Warren Catchment.
- Historical severity maps for fires adjacent to select wetlands across the lower southwest have been supplied on request to the Commonwealth, to inform an application to list *Empodismia* wetlands as a threatened ecological community.

Management implications

- Improved understanding of how severity classes relate to habitat retention and future fire risk will inform adaptive management of fire, priority species and ecological communities, and contribute to refinement of the prescribed fire planning process, including development of objectives that are measurable, achievable and relevant to particular land management values.
- Routine production of standardised severity maps 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.
- Analysis of historical fire severity and the relationship between aerial ignition patterns and fire severity will support identification of key drivers of fire outcomes across vegetation types and regions and an informed comparison of the effectiveness of the overall fire management program.

Future directions

- This project will be complete with finalisation of automation processes.

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

- Paper was published on vegetation structure and fuel dynamics of Banksia woodlands in *Forest Ecology and Management*.
- Weed management was 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 underway for pre-fire to 6 years postfire are in preparation of publication.
- Refined allometric relationships for grass fuel loads were developed.
- First short rotation (7 year) burn treatment was completed for Kings Park, with assistance from Kings Park bushland staff, Swan Region and DFES.
- Results were presented at local community urban management workshop, and site visits were held with BGPA, Bold Park Guides, and local council / DFES to demonstrate outcomes.

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.
- Burning without weed management results in increased grass weed cover and poorer recovery of native species.
- Post-burn weed management is effective in maintaining low levels of weed cover at pre burn levels (or lower) and beneficial for native community regeneration.

Future directions

- Ongoing implementation of weed treatments and survey schedule.
- Analysis of vegetation response data to be undertaken as a burn x weed treatment for understanding vegetation structure and weeds and native species responses.
- Continue second experimental burn phase with short rotation burn treatments in Bold Park including pre-burn survey.
- Continue post-fire (1st and 2nd rotation treatments) monitoring of Kings Park site.

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

- Six burns were undertaken at McCorkhill site. Two were burnt under summer conditions (November) and four under autumn conditions (April).
- Soil, fresh jarrah leaves and jarrah leaf litter samples were collected from both sites to assess whether fire regime affects the phosphorous cycle and subsequent litter flammability. Nutrient analysis was undertaken by the ChemCentre, and results are currently being analysed.
- Review and consolidation of historical datasets has commenced to identify opportunities for analysis and subsequent publication.
- Prior publications related to this project have been identified and collated.

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 review of historical data to inform future project direction, potential for further analyses and publication of current available data.
- Analyse soil nutrient data to establish Phosphorus availability and absorption at sites.
- Undertake floristic surveys following prescribed burn treatments at McCorkhill and Perup plots.
- Maintain the integrity of the study sites for ongoing monitoring in the longer term. Including continuing current burn regimes (next burns 2024-2026).
- Investigate potential for establishing new burning regime in "burnt once only" plots (2 per site) and 2 "spare" plots at the McCorkhill site.

North Kimberley Landscape Conservation Initiative: monitoring and evaluation

SP 2012-027

I Radford

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

- Monitoring at both Wunaamin Miliwundi and Prince Regent National Parks in the north Kimberley indicate that northern quolls have survived cane toad invasion starting 2019. Despite no quolls being recorded in 2021 at Bells Gorge, 3 quolls were trapped in 2022. Single quolls were captured at Mt Hart in 2021 and 2022.
- Fire and cattle management at Wunaamin Miliwundi has allowed accumulation of optimal long unburnt and undisturbed savanna vegetation, which has led to increases among threatened mammals including golden backed tree rats, pale field rats and western chestnut mice. These species are otherwise declining across most of northern Australia.
- This program has provided feedback on where fire regimes have not achieved benefits to threatened mammals, which has been used by fire managers to fine-tune prescribed burning.
- Two journal papers were published in *Frontiers in Ecology and Evolution* and a third was published in *Molecular Ecology*. The data contributed to meta-analyses on trends among threatened mammals nationally.

Management implications

- Analysis of the monitoring data shows that increasing patchy early dry season prescribed burning benefits most threatened species.
- The fire mosaic attribute most closely aligned with high diversity and abundance of threatened mammals is percentage of long unburnt vegetation. This indicates that long unburnt patches are an important target for prescribed burning in the region.
- 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 groups threatened by cattle.
- Feral cats are strongly negatively associated with threatened mammal abundance and richness. In this context, it is important to maintain vegetation cover through fire and cattle management to reduce cat hunting effectiveness.

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.
- Undertake analysis of change in vegetation condition under prescribed management regimes.

Fire regimes and impacts in transitional woodlands and shrublands

SP 2010-011

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 is 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

- On-ground vegetation structure measurements of tree allometry at 274 sites were linked to remotely piloted aircraft (RPA) and airborne LiDAR data demonstrating that woodland age classes can be reliably distinguished based on their 3D canopy structure.
- Combining high-resolution RPA and medium resolution airborne LiDAR to coarse-resolution GEDI satellite LiDAR covering the whole region, supported identification of vegetation structural features that scale robustly across platforms for development of a draft spatial model of woodland age-class across the whole GWW.
- Juvenile period data from the *E. salubris* chronosequence formed part of a south-western Australian-wide analysis estimating juvenile period in slow-maturing serotinous obligate seeders from site productivity predictors. Climate and gross primary productivity were strong predictors of juvenile period, allowing the development of models of juvenile period over space and time under both recent environmental conditions and those projected to occur in the future. This work has been published in *Plant Ecology*.
- Plant trait data from the *E. salubris* chronosequence was provided to a national collaboration cataloguing plant traits (AusTraits), forming a part of the publication in *Scientific Data,* capturing 448 traits across 28,640 taxa with ~1M trait by taxa combinations.
- Plant fire response data from the *E. salubris* chronosequence formed part of a national synthesis of plant fire-response traits published in the *Australian Journal of Botany*. A phylogenetic reconstruction of the evolution of fire-response traits showed that resprouting mapped as an ancestral trait, with subsequent independent evolution of post-fire seeding in multiple lineages. The proportion of resprouters and reseeders in an ecosystem was associated with ecosystem productivity and fire regime characteristics.

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 understanding ecological responses to fire.
- 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.
- Development of spatial and temporal models of juvenile period in slow-maturing serotinous obligate seeders across the whole of south-western Australia allows identification of where: (i) historic fire intervals may have have led to immaturity risk impacts, assisting in delineation of areas and taxa for which targeted conservation interventions may be most valuable; and (ii) the risks of climate change-driven decreases in fire intervals are greatest and where fire management to support persistence of fire refugia is most important.
- A spatial map of multi-century GWW woodland age classes provides the basis for departmental and Ngadju Conservation Aboriginal Corporation fire managers to plan fire mitigation and suppression activities to minimise loss of mature woodlands in bushfires.

Future directions

- Finalise journal publications on estimates of time since the fire of long-unburnt gimlet woodlands and changes in carbon stocks with time since fire.
- Finialise spatially explicit models of woodland age-class based on integration of on-ground and remotely-sensed data.
- Develop a carbon accounting method in GWW eucalypt woodlands for carbon fluxes with fire.

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 manuscript describing the effects of mosaics and vegetation on epigaeic invertebrate richness and trophic structure has been drafted.
- A draft manuscript describing the effects of mosaics on vegetation has been prepared.

- A manuscript describing interaction between rainfall and fire intensity effects on fungi fruiting body diversity has been drafted.
- An overview manuscript on effects of mosaic fire versus wildfire on plant, fungi and epigaeic macroinvertebrate biodiversity has been drafted.
- A manuscript on beetle richness responses to time since fire has been drafted and is approved for publication.
- A paper describing the theory of fire-induced mosaics, how to describe and characterise mosaics, and operational challenges in creating fire mosaics, was published in the *International Journal of Wildland Fire*.

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, overview paper covering the biodiversity outcomes of mosaic burning, and beetle richness with time since fire.

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 postgraduate 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

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 seed viability testing of over 200 accessions of existing seed collections of 24 species banked for up to 40 years to examine seed longevity in storage.
- Collected seeds of 30 new species from the Kimberley and initiated experiments to determine seed storage behaviour and longevity.
- Completed a study quantifying seasonal dynamics of seed hydration status in soil seed banks to inform risks of seed mortality during fire.
- Completed a study to optimise seed flaming as a seed enhancement treatment for 19 species used for mine site rehabilitation in the Pilbara.
- Installed a field trial at a mine rehabilitation site within Banksia woodland testing extruded seed pellets comprising activated carbon for four native species to determine the protection that pellets provide to seeds from herbicide application.
- Completed a study on the dormancy break and germination requirements of 8 species of Rutaceae from south-west WA to inform seed-based propagation and restoration.
- Filed provisional patent applications for two mechanised seeding devices to protect intellectual property whilst the technologies are further developed and evaluated for broad-acre restoration.

Management implications

- Research on the longevity of stored seeds informs viability monitoring schedules to improve the curation of banked seeds and contributes to developing seed banking procedures for long- and short-lived seeds.
- Development of seed flaming techniques has matured to commercial uptake by industry and the flaming of seeds is now incorporated into the seed supply chain for mine site rehabilitation in the Pilbara.

Future directions

- Contribute to leading a strategic review of seed collections made over the past 20 years across the Australian Seed Bank Partnership to identify their representativeness, functionality, and value to conservation and to inform future collection and research priorities for the Partnership.
- Develop a Utilisation Plan with mining sector partners to identify potential pathways for commercial uptake of direct seeding machinery for mine site rehabilitation across Australia.
- Continue to focus on the development of reliable seed propagation methods for species in demand for restoration, including a renewed focus on species of *Hibbertia*.

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, through collaboration

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 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

- A review of 10 year old post-pine plantation restoration data for Banksia woodland systems commenced to understand success and knowledge gaps in returning biodiversity after pine removal.
- Continued to monitor chlorotic decline syndrome within the jarrah trees of Kings Park. This data is supporting baseline observations before mitigation actions are undertaken in Kings Park during 2023 onwards.
- Extended the collaborative program with DPIRD to understand biodiversity values of Kimberley grassland grazing systems. Exclosure plots were established to support regeneration of priority native grasses and allow for experimental manipulation of the site to increase selected grass species.
- Informed topsoil salvage of rare banded iron formation species within the goldfields region by assisting in identifying topsoil collection zones and collection techniques to maximise its usage for future rehabilitation programs.
- Completed stage 1 of the *Tetratheca erubscens* translocation research project that included (1) developing technologies and methods to support the translocation and restoration of *T. erubescens* and (2) improving understanding of plant growth and function within restored/translocated populations to determine the long-term sustainability of translocated populations compared with natural populations, through a partnership with Mineral Resources Limited. Commenced habitat modelling for *Aluta quadrata* in collaboration with Rio Tinto.

Management implications

- Monitoring of previous restoration trials is being used to inform future restoration and research strategies for improving biodiversity outcomes in post-pine systems within the Gnangara mound area.
- Providing baseline physiological information of jarrah trees currently impacted by chlorotic decline will enable quantifiable impacts of changing irrigation infrastructure and regimes on tree health.
- Improved knowledge of natural seedbanks, and seed germination biology will improve the success of plant establishment in the restoration of both mining and rangeland systems.
- Providing findings from rare species distribution models and outcomes from experimental translocations informs decision making around rare species conservation and management within the mining sector.

Future directions

- Continue to develop an understanding of drivers of rare species functioning and distributions to inform conservation and restoration strategies.
- Undertake analyses to determine knowledge gaps in returning biodiverse ecosystems to post-pine landscapes.
- Continue to 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

- Provenance trials established with 32,000 seeds from 40 populations of *Eucalyptus todtiana* and *Banksia attenuata* at 8 sites across the Swan Coastal Plain.
- Seed germination and glasshouse trials completed with *E. todtiana* and *B. attenuata* to demonstrate provenance effects of temperature, moisture and drought on germination and seedling survival.
- Pollinator exclusion experiments on multiple banksias reveal the relative effectiveness of honeypossums, birds and insects as pollinators.
- Ecological genetic assessment of restored populations of the bird-pollinated *Lambertia multiflora* shows equivalent parameters to natural populations, and demonstrates a measure of restored functionality.
- Population genomic assessment of seagrass in Shark Bay has identified the world's largest clonal organism, a polyploid descendent of a diploid progenitor.
- Range-wide population genetic analysis of the seagrass *Posidonia australis* has identified spatial structure driven by historical, biogeographic and contemporary processes.

Management implications

- Provenance trials continue to show that diverse local provenance seed provides resilience to current and future climates for restored plant communities of Banksia woodlands.
- Complete early failure of provenance trials in some post-mining sites have highlighted the critical importance of substrate in restoration.
- Restitution of bird-pollinator services in restored plant communities suggest a resilience in these plant-pollinator relationships that may come from historically naturally fragmented landscapes.
- Polyploidy, clonality and sterility in Shark Bay seagrass meadows were probably key to its establishment and resilience to stress, and highlights its use for restoration over its diploid progenitor.
- Range-wide population genetic structure in *Posidonia australis* has identified biologically relevant clusters of relevance to IMCRA regions.

Future directions

- Assess and publish results of large-scale provenance trials, glasshouse trials, and seed germination trials for key species from Banksia woodlands.
- Assess and publish results of reciprocal transplant trials with polyploid and diploid seagrass in Shark Bay.
- Conduct experimental molecular and ecological field studies of pollination by birds and mammals on banksias.

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

- The second phase of the *Caladenia busselliana* translocation was undertaken (210 plants, total 40 plants at the translocation site) and monitoring was undertaken throughout the first growing season for the translocation. Monitored survival, growth and reproductive success for an augmentation planting of 140 *Caladenia busselliana* plants in the second year post-release to the wild.
- A further 200 *C. busselliana* and 900 *Caladenia viridescens* were propagated and successfully transferred to the glasshouse.
- Collections focussing on the seven threatened orchid species of the Midwest region were made, with capture of seed and fungal material from all known populations (totalling 57 seed and 170 fungal accessions to the *ex situ* collection).
- Surveys at each Midwest species population were conducted to provide up to date numbers on population sizes and new populations.
- All fungal isolates and seed lots collected from the Midwest were screened for germination and fungal efficacy.
- Pollinator surveys continued for *C. busselliana, C. viridescens* and *Caladenia lodgeana* to help inform future translocations.
- Surveys across the extent of *C. lodgeana, C. viridescens* and *C. busselliana* provided updated numbers on population size and new plants.

Management implications

- Growing *ex situ* collections of *C. busselliana, C. viridescens* and *C. lodgeana* provide essential conservation support for these species with critically low wild plant numbers or single populations. The provision of plant

material to undertake pollinator research and site selection for translocations is critical to the program.
- 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 and populations of threatened orchid species provides vital demographic and location data to better manage populations of these threatened orchids.
- Development of germination protocols for threatened orchid species provides conservation support in the form of *ex situ* living collections and advances the possibility of translocations as a conservation tool.

Future directions
- 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* sites.
- 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

E Bunn, B Funnekotter

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.
- Novel cryoprotective agents were assessed for thermal characteristics and toxicity to plant germplasm for cryostorage.
- The *Banksia montana* culture lines were maintained as a living collection in the tissue culture laboratory.
- *Eugenia* and *Syzygium* species were initiated into tissue culture, for development of cryopreservation protocols for species potentially impacted by Myrtle Rust.
- Initiation of *Barringtonia* spp. were initiated into tissue culture for protocol development of recalcitrant seeded species.
- A novel pH indicator mixture was developed for monitoring performance of tissue culture medium across multiple species.

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 protocols for Kimberley monsoon rainforest species that may possess recalcitrant seeds and/or may be threatened by Myrtle Rust in the future.
- 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 breed-for-release 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 when it was found in poor feather condition when captured during a translocation program.
- No eggs were laid during 2021.

- Upgrades to the aviaries were made to improve access to natural UV light, and two additional aviaries were constructed to provide for a reduced density of males in close proximity to breeding pairs.

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 of the colony.

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

CF 2018-119

C Holland, E Polla

Context

Keeping charismatic megafauna 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 has progressed onto his 4th distractor scent and is continuing to score 100% success in the trials.
- The cow elephant involved in the study has progressed to five scent stations and one target scent. She is continuing with the trials with a high success rate.

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, E Polla

Context

Animals survival depends on good and timely solutions to the problems being experienced. 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, are long-lived and have 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

- The cognitive repeat behaviour trials have been completed and the 'Mark' cue is currently being attached to selected behaviours.
- Training continues with good results and memory recall.

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 publish results.

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

SP 2018-115

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

- A methodology for data collection was developed that was suitable for behavioural observations for all nocturnal house animals. Observations on the dibbler's behaviour revealed an increase in out of sight behaviour in response to increased zoo visitor density.
- Behavioural observations of orangutan mother and offspring pairs with a focus on use of enrichment items was completed. Observations were also made of mother and offspring pairs in the two pairs that have offspring approaching the normal age of dispersal away from their mothers.
- Observations were made throughout the African Savannah precinct to gather information on the behaviour and location of animals and their visibility from specific visitor viewing areas.
- Observations were made within the Australian Bushwalk precinct to determine what factors influence the use of different areas of the exhibit by the resident macropods. Preliminary analysis indicates that the density of zoo visitors influences the animals' behaviour with a greater number of animals utilising deeper retreat areas when the visitor numbers were highest.
- Observations of the binturong pair and how they used exhibit space and furniture led to the addition of another nest box. Preliminary data analysis revealed that the adult binturong now spend less time interacting with each other, while the female has successfully given birth to two offspring in the new nest box.

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

Context

There are two species of *Anstisia* (formerly *Geocrinia*) frogs, white-bellied frogs (*Anstisia alba)* and orange-bellied frogs (*A. vitellina)*, that have a restricted distribution in south-west Western Australia and are listed as critically endangered and vulnerable, respectively. 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 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 to maintain or increase the current extent and viability of populations of these species.

Progress

- A captive breeding colony of *A. alba* and *A. 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.
- Both species of *Anstisia* were bred successfully in captivity in the same year for the first time in 2021 - 30 *A. alba* and 28 *A. vitellina* were bred in captivity.
- 107 *A. alba* and 40 *A. vitellina* juveniles were each released into sites in conservation estate east of Margaret River.

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 subpopulation, and bolstering the genetics of isolated populations.
- Successful captive breeding of both species of frog in captivity in the same year for the first time offers a real prospect that reintroductions could potentially be facilitated using both captive bred animals and eggs collected from the wild.

Future directions

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

Western swamp tortoise breed for release program

SP 2018-101

P Mawson

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 been established at Adelaide Zoo and Monarto Zoo (South Australia) to reduce the risks associated with keeping half the global captive population of western swamp tortoises in a single facility.

Aims

- Produce a minimum of 30 hatchling tortoises (> 30 days of age) each year for release into wild sites.

Progress

- Seventy-three swamp juvenile tortoises were released into two swamps east of Augusta as part of a planned conservation introduction.
- A total of 102 eggs were produced in the captive breeding colony, 71 of which hatched.
- A DNA sample was provided to the the UWA-based DNA Zoo Australia research group to construct the whole genome for this species.

- An analysis of historical mortalities of western swamp tortoises held in the captive breeding facility indicated that hatchlings derived from eggs requiring manual hatching were more likely to die within 30 days of hatching and that hatchlings derived from small eggs (<6 g) were also more likely to die. Eggs produced by breeding females <20 years of age were less likely to hatch. The majority of mortality occurred in tortoises <6 months of age.
- Post-mortem examinations revealed that respiratory pathology was the most commonly reported finding followed by hepatobiliary and gastrointestinal pathologies with disease mainly associated with opportunistic infection in immunologically naïve hatchlings.

Management implications

- Developing eDNA technologies may facilitate better and more reliable surveys of actual 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, T Friend

Context

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

- Thirty-six juvenile dibblers were released onto Dirk Hartog Island National Park. This was the third release of this species onto the island.
- Fifty pouch young were produced from matings and are developing normally.

Management implications

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

Future directions

- Provide additional dibblers for release onto Dirk Hartog Island National Park for one further year.

Numbat breed for release program

SP 2018-098

P Mawson, 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 National Park, Mount Gibson Sanctuary in Western Australia, Yookamurra Sanctuary and Secret Rocks Mallee Refuge (South Australia), and Scotia Sanctuary and Mallee Cliffs National Park (New South Wales).

Aims

- Produce yearling numbats in sufficient quantity to support proposed reintroductions to wild sites.

Progress

- Produced five yearling numbats for release into the a fenced enclosure in Mallee Cliffs National Park, NSW.
- Three adult numbats, surplus to the requirements of the breeding program, were released into a fenced enclosure in Secret Rocks Mallee Refuge, South Australia.
- Two female numbats were brought into the program from Dryandra National Park to expand the genetic integrity of the breeding program.
- Produced 14 pouch young, with 13 young developing normally.

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 to meet demand from approved translocation programs.

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 Carnaby's cockatoo nestlings 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 168 (114 as pullus, 4 as adults and 50 rehabilitated) Carnaby's cockatoos, along with 5 Baudin's cockatoos (all rehabilitated) and 35 forest red-tailed black cockatoos (all rehabilitated).
- 1195 recovery records and resightings (photo identification or scanning of microchips) were made of Carnaby's cockatoos and one for Baudin's cockatoo. Only three of those records involved birds that had died.
- A research paper describing habitat use by forest red-tailed black cockatoos in urban landscapes was published in *Avian Conservation and Ecology*.
- A research paper describing the need for regular maintenance of natural and artificial nest hollows used by Carnaby's cockatoos was published in *Pacific Conservation Biology*.
- Analyses of banding data for Carnaby's cockatoo to determine a more accurate annual survival estimate 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 757 leg-banded rehabilitated cockatoos (418 Carnaby's, 53 Baudin's and 286 forest red-tailed black cockatoos). The total number of cockatoos banded (all species and all ages) is now 2087 providing data for understanding breeding dynamics of the population. The rehabilitation techniques and release protocols currently in use provide very high survival rates, as supported by the high number of cockatoos which contributes to the conservation of these three species.

Future directions

- This project will be complete with finalisation of the cost-benefits publication.

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

- Acoustic receivers were retrieved from an acoustic receiver array that was established in the Swan Canning estuary in 2016. Data on the movement of 120 tagged black bream were downloaded and movements

are being analysed relative to historic physico-chemical data derived using the Swan Canning Estuarine Response model.
- Acoustic receivers were redeployed and re-destributed for the purpose of tracking juvenile bullsharks.
- Non-selective gillnetting and targeted rod and line fishing commenced, with two juvenile bull sharks tagged to date. The dorsal fin of each shark was fitted with a InnovaseaV9 acoustic tag attached to a rototag. These are expected to transmit a signal every 90 seconds for approximately two years, with the location of the shark recorded by the array when it is within range.
- Project summaries for side scan, acoustic sonar and split-beam transducer work were completed.

Management implications
- The application of acoustic receiver technology combined with water quality estimates derived from model outputs will help improve understandings of how fish populations respond to changes conditions.
- The movement of bull sharks, within the Swan Canning Riverpark remains a key gap in our understanding of the ecosystem. The provision of better data about the movement of this species will improve our understanding of the residency time, distribution, habitats used and responses to changes in environmental conditions within the system.

Future directions
- Continue the analyses of bream movement relative to water quality.
- Undertake further tagging activity of bullsharks during the pupping season.
- Supplement the existing array with additional receivers through the lower Swan Canning basin.

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. Five tributaries have been impounded for water supply purposes. With a growing urban population, demands for fresh water are increasing and finding the balance between the public water supply system and ecological 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 and duration of flow to adequately protect them. When ecological water requirements are determined and water provision is set, it is appropriate to monitor to ensure values are maintained and expected outcomes are being achieved. The latter includes consideration of how in-stream barriers and other threatening processes 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.
- Assess in-river structures that might obstruct movement of riverine biota, determine potential impacts and recommend options for management.
- Investigate novel approaches to identification and management of freshwater dependent biomes within the Swan Canning system.

Progress

- Water provisions were monitored to ensure the prescribed water allocation to the lower Helena River was applied appropriately for maximum ecological benefit.
- A further 20 potential barriers in the Canning River were assessed to determine obstruction to fish movement. Criteria to categorise the severity of impact to fish passage were developed and will be applied to all barriers in the database.
- eDNA methods for assessment of freshwater faunal communities detected invasive cichlids in areas of the Canning River that were not previously detected by traditional sampling methods.

Management implications

- Management of in-river barriers may involve removal or modification to improve native fish movement through the Canning River but will require consultation will adjacent landowners and local authorities. Some barriers may need to be maintained to reduce the movement of invasive species and protect upstream native fish populations.
- Information obtained from monitoring fish movement and identification of incursions identified through eDNA surveys of the Canning River will provide an evidence base to manage invasive aquatic species expanding in range and to address new threats.
- Data and knowledge compiled as part of this work is contributing to the development of the Canning Waterways Restoration Plan.

Future directions

- Finalise the transfer of the barriers database into a GIS based framework that supports decision making and provides a tool for management.
- Based on environmental water studies, develop recommendations for water provisions for the lower Helena River.

Swan Canning Water Quality Monitoring

SP 2020-027

S Hoeksema, J Watsham, P Howie, J Cosgrove, P Novak, S Muller, J Gregory, S Thompson, J Baker, K Antahputri, A Saeed, K Trayler, S Robinson

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 is used to 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, 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.
- Water quality reports and phytoplankton information were updated weekly on the Eyes on the Swan Canning Riverpark web page.
- The annual data reports for the estuary and catchment were produced and made available on the Departmental website.
- Planning for an online dashboard featuring site maps and data has been completed, and data provisioning, scoping steps and a front end prototype have been developed.
- A technical report supporting the 5-year review of the River Protection Strategy is in development.
- A review of monitoring approaches has commenced.
- Historical monitoring data collected through this project has been explored to improve understandings of the dynamics of the Kent St Weir pool on Canning River.

Management implications

- Routine water quality monitoring data has be used to develop baseline water quality triggers for development projects within the Riverpark's Development Control Area, and to augment environmental monitoring.
- Elevated levels of some harmful algal species were detected, although there was no single bloom incident triggered.
- Historical monitoring data collected through this project is helping to improve understandings of the dynamics of the Kent St Weir pool on Canning River, and improve management approaches for this important freshwater environment.
- The online dashboard will replace public facing annual data reports and present monitoring data to the public in a more timely and interactive manner.

Future directions

- Finalise the review of monitoring approaches to look for efficiencies in phytoplankton sampling and through the use of real-time monitoring technologies.
- Complete phase 1 of the web-based dashboard and interactive portal to present water quality data.
- Finalise the production of a technical report supporting the 5-year review of the River Protection Strategy.

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 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, is pending release and a subsequent journal article is in development.
- A report determining the concentration and composition of contaminants in western school prawn in the Swan Canning Estuary to provide guidance for human consumption guidance and baseline data for this species, has been completed.
- A report investigating change in sediment contamination in the Swan Canning Estuary has been completed.
- Sampling to determine the effectiveness of the Ellen Brook constructed wetland in removing and storing PFAS from surface water, has been completed.

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 the information has informed initiation of management activities to mitigate PFAS runoff.
- 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

- Complete report on the effectiveness of the Ellen Brook constructed wetland to remove PFAS from surface water.
- Preparation of manuscripts on PFAS project.

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 advise management and operations when required.
- Investigate and provide advice to management on contaminant spills.
- Provide information and advice to support river management and planning.

Progress

- A number of small blooms were detected and additional response samples were taken to investigate these. No alerts were triggered.
- Inter-agency incident response team meetings were held to prepare for and close out the *Alexandium* bloom season. *Alexandrium* did not exceed trigger levels in the 2021-22 season. Warning signs were erected as a precaution and FAQs updated.
- A small fish kill of 35 fish was detected in the Canning Estuary in March after a significant flow event and low oxygen was thought responsible.
- Advice provided regarding a wide range of development proposals, blooms and policy.
- The impact of the 2021 Wooroloo bushfire on Avon River pools within Walyunga National Park was investigated. The fire caused an influx of ash, sediments and other contaminants into pools and increased turbidity and sedimentation. The longevity of impacts was complicated by a concurrent Avon flood event. No evidence of firefighting products was found.

Management implications

- Advice on waterways management guidelines and policy, bridge developments and Metronet has provided support for assessment and contributes to management of waterways.
- Scientific information from incidents has contributed to new incident response frameworks for fish kills and algal blooms that have been agreed between DBCA, DWER and DPIRD.
- The Wooroloo fire impacts on pools were reported to an incident management team to inform future management of fire response and to minimise impacts.

Future directions

- Response guidelines for harmful algal blooms to be revisited.
- Respond to river incidents and involve key stakeholders and other management agencies where necessary.
- Continue to review environmental management plans, contaminants data, construction management plans, and provide advice, as required, to Rivers and Estuary Branch statutory assessments unit.

Seagrass monitoring and evaluation

SP 2018-039

J Cosgrove, P Howie, J Baker, J Watsham, K Trayler

Context

Seagrasses are a highly valued component of estuary ecosystems as they improve water quality by reducing sediment resuspension, removing nutrients, providing habitat and as 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

- Seagrass sampling was conducted in the Swan and Canning Estuaries. In general, seagrass presence was slightly higher in 2021-22 compared to the previous season.
- Average seagrass percent cover was higher than last year at all sites and this was most evident at the Canning site (most upstream) in mid to late summer.
- High rainfall and riverine flow through winter and early spring of 2021 brought significant nutrient load into the lower Swan and Canning Estuaries, resulting in increased cover of macroalgae between November and January, compared with previous years.
- A preliminary trial of remotely operated vehicle technology for benthic habitat assessment identified seagrass habitat in the shallows around Heirisson Island and at Point Fraser. This is the furthest upstream seagrass has been directly observed in the Swan Estuary.
- Monitoring data indicates seagrass cover was resilient to high macroalgal cover and strong freshwater flows in 2021 and high temperatures of summer 2022.

Management implications

- Seagrass metrics and key drivers of condition provide indicators of river health and maintenance of water way condition. They are being incorporated into a 5-year report on the waterway and have been used to support reporting on the River Protection Strategy.

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

J Cosgrove, K Trayler, S Thompson, S Hoeksema

Context

Parts of the Swan and Canning Rivers are affected by algal blooms, with the species causing 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

- Investigate harmful algal blooms and understand factors influencing their presence and toxicity.

- Test the products suitable for controlling algae in laboratory and field settings.
- Understand the risks associated with blooms and bloom control products.
- Refine tools that contribute to understanding algal blooms.

Progress

- Historic water quality datasets were analysed using multivariate approaches to investigate patterns in *Alexandrium* abundance relative to physico-chemical conditions.
- *Alexandrium minutum* bloom development relative to water temperature and salinity, and the implications of those blooms for public health and fisheries management, were assessed and approaches to harmful algal bloom control, and particularly the use of hydrogen peroxide, were considered.
- Culture material was sourced to support a project aimed at better characterising toxin profiles and genetics of *A. minutum,* and investigate control options.
- Where harmful algal species were detected in the waterway, investigation of blooms across spatial and temporal scales was undertaken to build understandings of conditions that influence these events.

Management implications

- *A. minutum* has the potential to severely affect fisheries, human health and ecosystem function. Significant *Alexandrium* blooms were not observed during the summer 2021-21 and 2021-22 seasons suggesting a change in conditions that may have implications for management and mitigation.
- Continued routine water quality monitoring is recognised as important in detection of harmful algal blooms and can allow provision of algal material to associated research projects and/or collection of toxin samples.

Future directions

- Data from across 2019-22 will be analysed to investigate potential environmental triggers or suppressors for successful *Alexandrium* bloom formation.

Investigating fish communities as an indicator of estuarine condition

SP 2018-033

K Trayler, J Baker, J Watsham

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 (2007-12) 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

- A report documenting the 2021 fish community index results was completed.
- Fish communities were sampled at 48 sites in summer and autumn. Species abundances in each sample were used to derive values for core metrics used in calculation of index scores for each zone.

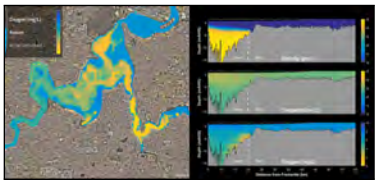
- Preliminary results in for the 2022 season show a positive improvement in fish community index scores that are believed to be related to strong freshwater flows in winter 2021. Across the entire estuary, the ecological condition of both nearshore and offshore waters in 2022 was assessed as 'good' based on their fish communities. Combined, the nearshore and offshore index scores for 2022 are the highest ever recorded since regular annual monitoring began in 2012.
- Compared with other areas, the Canning Estuary continues to score poorly.

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.

Future directions

- A report documenting the results of the 2022 sampling will be completed.
- Fish community datasets will be compared with physico-chemical datasets derived from the Swan Canning Estuarine response model to better understand patterns and discern factors influencing poor scores.



Model frameworks for estuarine reporting

SP 2018-027

K Trayler, S Hoeksema, J Watsham

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 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

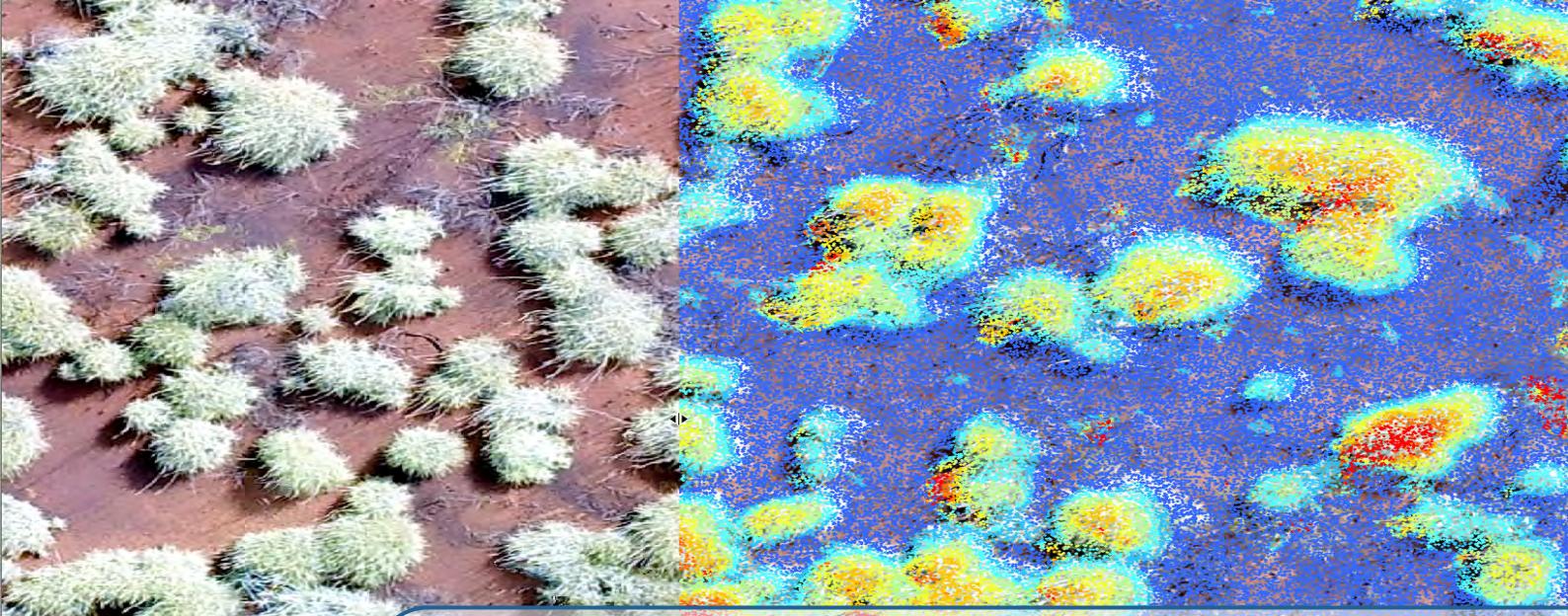
- The Swan Canning Estuarine Response Model (SCERM44) was coupled with a catchment model to predict the impact of climate and land use change on nutrient loads and hydrological flows to 2050.
- The model was also used to hindcast water quality datasets from 2010-2020 for the purpose of comparison to existing biological datasets.
- The Swan Canning Estuary Virtual Observatory was reviewed and re-established on-line.

Management implications

- Model outputs will inform development of a revised Swan Canning Water Quality Improvement Plan, providing information to support planning approaches to nutrient management in the landscape.

Future directions

- Further progress the analyses of hindcast model outputs relative to biological datasets.
- Revisit the Swan Canning Estuary Virtual Observatory framework to confirm validation of display outputs.



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

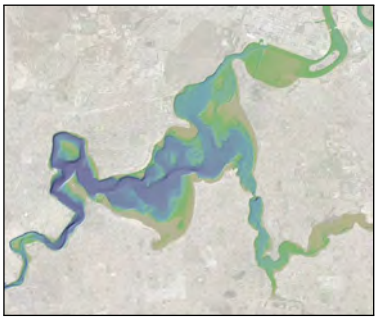
- Collected transect data, multispectral remote piloted aircraft imagery and remote piloted aircraft LiDAR from Boolardy Station, ex. Thundelarra and ex. Burnerbinmah, with the assistance of trainee rangers from Kalbarri National Park.
- Obtained and processed 150,000 ha of airborne LiDAR covering the 'Badimia' block, with a 5 m canopy height model and vegetation cover density maps produced.
- Presented a project update to the DBCA Geraldton regional office.
- Produced a draft manuscript examining growth rates, mortality and recruitment of dominant woody shrubs in the Western Australian Rangelands Monitoring System (WARMS) database.

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

- Publish first paper from WARMS analysis examining growth rates, mortality and recruitment of dominant woody shrubs.
- Prepare a second manuscript from WARMS data examining changes in shrub community compositions in relation to changes in ecological condition of sites.
- Develop a method to map rangeland vegetation cover and structure from a fusion of Sentinel 1 radar satellite, Sentinel 2 optical satellite imagery and Global Ecosystem Dynamics Investigation space-borne LiDAR.



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 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

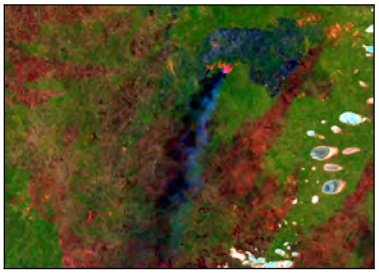
- Application of processes to make spatial data discoverable and accessible as DBCA moves data storage to a cloud environment.
- LiDAR data sets purchased by other state agencies were obtained and included for corporate use.
- Bathymetry data loggers installed on three Kimberley vessels have started to contribute data to a crowd sourcing bathymetry program run by Geoscience Australia's AusSeabed program.
- A review of data management protocols was undertaken and new protocols implemented.
- 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 provide information for management decisions and 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 the application of spatial modelling of soils, vegetation and habitats for management.
- Bathymetry data from regional patrols can now contribute to AusSeabed that 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.

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, J Ruscalleda Alvarez

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 include 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, including incident mapping and prediction and 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

- Developed information on fire size in relation to the time of year burnt in the Western Desert, in collaboration with the 10 Deserts Project (a part of the Indigenous Desert Alliance).
- 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.
- Supported the operational use of airborne thermal cameras to detect hotspots for burn security.
- Initialised investigation into remote piloted aircraft (RPA) based LiDAR for fuel accumulation modelling and fire behaviour response.
- Supported regional and district fire managers in 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 derive fire history based statistics.
- Provided data to Fire Management Services Branch to inform fire recovery, fire chronology and the new satellite technology/availability.
- Spinifex satellite fuel cover model updated with new Pilbara field data and delivered to the Pilbara region.
- Options for monitoring vegetation change in landscapes of the Great Victoria Desert were developed.
- A comprehensive update of the fire history information across the entirety of the Great Western Woodlands for the period of 2010 to 2020 was undertaken by Landsat image analysis.

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 aircraft-based thermal imagery hotspots to on-ground staff improves the security of burns.
- Development of a new cost-effective method for ground staff to assess burn security by detecting boundary hotspots from a RPA can be more efficient in more remote areas or when visibility is limited from an aircraft.
- Using RPA-based LiDAR for fuel height and density measurement will lead to a more accurate model of fuel accumulation for better management of fuel levels in the forest and safer bushfire management.
- Satellite derived spinifex fuel cover maps enable regional fire activities to be more targeted, efficient and safe in their fuel reduction activities.
- Identifying differences in the size of fire in desert landscapes informs fire managers about reducing the impact of large fires in the hot season by burning during the cool season.
- Fire history information in the Great Western Woodlands will be used to identify locations vulnerable to fire regime change and guide burn planning to protect these vegetation communities.

Future directions

- Continued development and automation of fire scar detection methodology.
- Investigation and development of new data sources including new satellite data and aerial capture.

- Continue testing and finalise fire severity model in south west forests.
- Implementation and development of spatial analysis of fire patterns and fuel loads.
- Investigate the viability of utilising remote piloted aircraft based thermal imaging for operational use by detecting near boundary hot-spots after prescribed burns.

Spatial analysis and modelling

SP 2018-073

J Kinloch, K Zdunic, G Loewenthal, B Huntley, 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

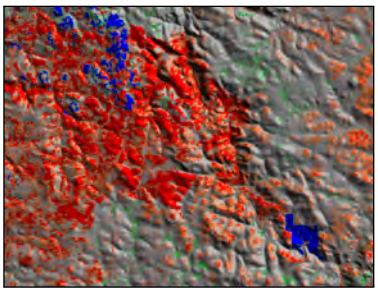
- The 2021 terrestrial lands report was produced.
- A Maxent habitat suitability model was developed for the yellow-spotted monitor (*Varanus panoptes)* for an area in the west Kimberley to north-west Pilbara. This monitor is a target species for cane toad taste aversion training. The spatial products were published on ArcGIS online to enable access to other cane toad project partners including traditional owner groups.
- Completed multi-criteria analysis of the ecological value of wetlands in the South west region.
- Further developed fire regime spatial metrics for several Kimberley DBCA-managed lands using remotely sensed fire history data over 2000-20.
- Published a paper in *Nature Communications*, investigating the role wildfires in tropical savannas play in enhancing marine phytoplankton production.
- Contributed to the spatial analysis for a paper, published in *Plant Ecology*, that identifies risk to plant populations of short or long fire intervals.
- Spatial variables developed for the North West Shelf flatback turtle rookeries and at-sea distribution models.
- Developed a software solution for data parsing oxygenation metrics for Rivers and Estuaries Branch.
- An R Shiny app framework was developed for exploration of genetics data associated with an upcoming paper for *Animal Science*.
- Developed and delivered an R software package (ScatMatch) to aid identification of individual animals from genotype data.
- Supported regional conservation planning processes with spatial analysis, including fauna and threat matrix compilation for the south coast region.

Management implications

- The department uses vegetation and protected areas statistics to report against aspects of the CAR (comprehensive, adequate, representative) principles.
- Spatial information on where significant habitat of the yellow-spotted monitor is likely to occur will be used to optimise the location of cane toad taste aversion training.
- Species distribution models provide information on the likelihood of habitat for a species being present and thus are critical for determining species conservation and management priorities and actions.
- Information on the conservation values and threats present in each conservation management unit, contributes to the identification of management priorities during the DBCA's Regional conservation planning process.
- Prescribed burning is used to mitigate the threat of wildfires in WA's tropical savannas and fire metrics contribute to the assessment of the effectiveness of the burn program against ecologically derived fire pattern targets. In the south-west of WA, varying tolerable fire intervals of different plant species need to be considered during prescribed burn planning.
- R software solutions have provided robust and easy to use tools to significantly simplify data analysis for animal scientists and aid in the formulation of quality inputs for complex environmental modelling for the Rivers and Estuaries Branch.
- R Shiny interface allows for unique visualisation of data used in a publication and assists with science communication to the public.

Future directions

- Further develop landscape scale spatial metrics that assess conservation values and threats. Develop models for the yellow spotted monitor in other locations along the cane toad front.
- Document and publish application of the 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.
- Develop further functionality for the ScatMatch software to allow for alternative data inputs.



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, and also includes optical imagery from handheld and airborne platforms [manned aircraft and remotely piloted aircraft (RPA)] 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. Remote sensing monitoring 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 assessing the threats to biodiversity.

Aims

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

Progress

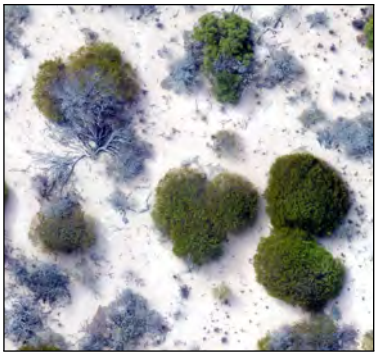
- Mangrove monitoring using Sentinel-2 10 m satellite imagery was developed for the Eighty Mile Beach, Yawuru Nagulagun/Roebuck Bay and Ningaloo Marine Parks.
- Statistics and maps were provided to aid selection of monitoring sites in banksia and wandoo woodland.
- Millstream Chichester National Park riparian vegetation monitoring continued.
- High resolution seagrass extent maps were produced for the years 2010, 2013, 2016 and 2020 in Monkey Mia using Worldview-2 and Sentinel-2 satellite imagery.
- 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 to determine bittern habitat.
- Model development to relate remote piloted imagery of vegetation cover in the Fitzgerald River National Park and Sentinel-2 satellite imagery was undertaken to determine changes in vegetation cover.
- Classification of remote piloted aircraft (RPA) imagery was undertaken over monitoring sites on the Fortescue Marsh. Developed landscape function analysis (LFA) metrics based on classified imagery and evaluated these against ground assessed LFA.
- A method was developed to identify potential sooty mould affected fig trees on Barrow Island using 10 cm aerial photography.
- Remote sensing inputs to the Forest Management Plan 2014-2023 end of term reporting for KPIs 1, 2 and 3 were delivered.

Management implications

- Mangrove monitoring information provides quantitative locational changes of mangrove canopy informing management action and is applied in Conservation and Parks Commission reporting.
- Wetland inundation and hydroperiod analysis provides information to understand the status and conservation significance of wetlands especially those remotely located.
- Evaluation of wetland characteristics is informing land managers about the locations of suitable habitat for threatened species.
- The statistics provided to the Forest Management Plan allow for objective, broad scale assessments of change that can be used to identify areas where declines in vegetation cover are occurring.
- 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 informing management actions.
- Monitoring of changes in vegetation cover and landscape function will assist in determining the effectiveness of feral herbivore control measures and other conservation actions on the Fortescue Marsh.

Future directions

- 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 exposed intertidal seagrass methods to Sentinel 2 imagery from 2017 to 2021 at Roebuck Bay/Yawuru for annual reporting.
- Develop bittern wetland habitat modelling application in Benger Swamp.
- Further develop monitoring methods and establish additional monitoring sites on the Fortescue Marsh and capture imagery of sites with a real-time kinematic remote piloted aircraft.



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

Progress

- Vegetation cover change was analysed with 42 percent of the island experiencing a significant increase since destocking.
- Data from transects that extend across a gradient of density of buffel grass [collected in 2015 and 2021] were examined. Preliminary results show variation in buffel grass change and detectability.
- A paper regarding the use of remote piloted aircraft data to monitor changes at mammal exclusion plots was published in *Remote Sensing*.
- Preliminary modelling of banded and rufous hare wallaby habitat was carried out. The modelling used locations from scat surveys for training and testing and produced a basic habitat map.

Management implications

- Results from the program demonstrate the ecological benefits of the eradication of introduced species and provide evidence that, with the improvement in vegetation condition, the mammal reintroduction program has a high likelihood of success.
- The data collected and further study of the fauna exclusion plots will aid in measuring the impacts of the reintroduced fauna.

Future directions

- Update vegetation monitoring and sand dune area movement using Landsat imagery and carry out field validation of vegetation change.
- Complete assessment of changes to buffel grass extent over the period 2015 to 2022 and further investigate buffel grass detectability.
- Complete modelling of banded and rufous hare wallaby habitat with additional data to be collected by the fauna team.

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 and 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 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

H Bucktin, M Coote, F Felton

Context

Wetland conservation activities are conducted to improve the identification, protection, knowledge and management of wetlands on the conservation estate and off-reserve across Western Australia. The department partners with the Australian Government in implementing responsibilities under the Ramsar Convention on Wetlands to coordinate the protection and management of the listed sites in Western Australia and assist 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.

Aims

- Coordinate partnership responsibilities with the Australian Government for the implementation of the Ramsar Convention in Western Australia.
- Assist in the 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 protection of wetlands within the State's conservation reserve network and other high ecological value wetlands.
- Implement the off-reserve program for 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

- New wetland mapping data sets have been developed for the Swan Coastal Plain (SCP), Moora-West, Dandaragan and parts of the South-West in collaboration with the Department of Water and Environmental Regulation. The SCP data set has undergone extensive internal review across collaborating agencies and external review from research institutions and non-government scientists.
- Climate change response strategies are being considered in the development of adaptation plans for the Muir-Byenup 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 Ramsar Information Sheets have commenced for six Ramsar sites and finalised for three other sites in WA.
- Four requests to modify the 'Geomorphic Wetlands Swan Coastal Plain' dataset were processed.
- Technical advice was provided to departmental staff, other State and Commonwealth agencies, landowners and their consultants, for 42 land use planning issues.
- The 'Healthy Wetland Habitats' to assist landholders with Voluntary Management Agreements to manage their wetlands with conservation values.

Management implications

- The production of information sheets, mapping and condition reports for Ramsar wetlands facilitates their ongoing management, and is required by 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 strategy to respond to major impacts of climate change.
- Management and land use planning advice assists 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 and to inform impact assessment and conservation decisions. Pursue option to convert current geomorphic wetland mapping datasets to Australian National Aquatic Ecosystem (ANAE) Classification Framework to align with national framework.
- Review documentation for the 12 sites listed under the International Ramsar Convention on Wetlands. Report to the Commonwealth Government on the status of each Ramsar site, any management actions and potential changes in ecological character.
- 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, M Hunter, J Chick, K Grogan, S Woodman, 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 in status of ecological communities, ensures that the most recent ecological information is available to stakeholders. The team facilitates the Threatened Ecological Communities Scientific Committee (TECSC) and implements the provisions of the *Biodiversity Conservation Act 2016* (BC Act) that relate to TECs. The group also coordinates recovery programs, including developing interim recovery plans and supporting recovery teams, to guide conservation activities for TECs and PECs.

Aims

- Implement the provisions of the BC Act that relate to TECs.
- Undertake assessments of conservation status based on all available data and prepare nominations for TECs and PECs for consideration by the TECSC.
- 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.

Progress

- At 30 June 2022, 65 extant ecological communities were listed under the Western Australian Environmentally Sensitive Areas list (20 critically endangered, 17 endangered and 28 vulnerable), and four were listed as collapsed. Another 390 ecological communities were on the PEC list.
- Two meetings of the TECSC were held to provide comments on draft assessment reports of the threat rank for 65 extant and three collapsed ecological communities in preparation for consideration for listing under the BC Act.
- The six week public consultation process for nominations to list of the 65 extant ecological communities under the BC Act was initiated. Letters were sent to land owners, holders of mineral tenements, managers of indigenous protected areas, and pastoral leases where a TEC is recorded and emails were sent to external stakeholders including government departments, inviting comment on the 65 listing nominations.
- New occurrence information was added and edits to existing spatial information on the TEC database were completed for 548 occurrences of 37 TEC and PEC occurrences distributed across the state.
- On-ground survey was undertaken for 61 occurrences of TECs and PECs throughout the state to support conservation decision making. A total of 650ha of vegetation supporting one TEC and three PECs on private land was surveyed for potential consideration for inclusion in the reserve system.
- Advice was provided in relation to 56 clearing permit application, and land use planning, mining and development proposals to improve conservation outcomes for 19 TECs and 18 PECs across the State.
- Current TEC and PEC locational data were provided in response to 547 requests from a range of stakeholders to help ensure that up to date information was available for proposal documents. Specialist TEC or PEC advice was also provided with many of these requests.
- Draft survey and identification methods were compiled for 65 TECs and released for public comment for three months on the department's website.
- Data were compiled from 141 quadrats for inclusion in a review of the Swan Coastal Plain floristic community types.
- Monitoring data and other information about 12 TECs and three PECs was utilised to assess the sensitivity and exposure of ecosystems to multiple fire-related threats for a publication in *Global Ecology and Biogeography*.
- 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.

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 support improved advice for environmental impact assessments, land use planning, and conservation management.
- TEC and PEC data and advice support determinations of priority areas for reservation.
- Listing of TECs under the BC Act supports increased legislative protection.
- Inclusion of ecological communities on the PEC 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.

Future directions

- Complete the process for listing 65 nominated TECs under the BC Act.
- Prepare nominations for consideration by the TECSC for other high priority ecological communities.
- Pursue improvements in TEC and PEC data, and data migration into the new corporate database.
- Continue to provide data and advice for the protection, conservation and management of TECs and PECs.
- 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 LFW.
- Integrate science knowledge into technical biodiversity management advice.
- Improve conservation management on lands not managed primarily for nature conservation.

Progress

- Forty six landowners applied for registration with LFW during 2021-22. A total of 2002 properties are currently registered, supporting 1,048,742 hectares of bushland managed for conservation.
- 24 property assessments were undertaken for LFW by NRM partners, and 20 by the departmental coordinator during the year. 33 properties were added to the program as members and 11 were deemed unsuitable.
- 16 new covenants (15 conditional and one voluntary) were registered, and the Nature Conservation Covenant program is currently negotiating an additional six voluntary and eight conditional covenants.

Through the program, covenants have been established on 396 titles covering 30,457 hectares, including habitat for threatened species and ecological communities, a Ramsar-listed wetland and registered Aboriginal heritage sites.
- Advice was provided to landowners, local government and departmental planning staff on land use planning matters relating to covenants.
- There were 10 changes of ownership of covenanted land and new landholders were welcomed into the Nature 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 as IUCN Management Category IV areas.

Future directions
- 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

T Llorens, C Bourke, J Donaldson, K Griffiths, R Rees, S Williamson, A Cooke

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
- 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 biodiversity 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

- As at 30 June 2022, 429 flora species were listed as threatened species under the *Biodiversity Conservation Act 2016* (BC Act) (160 critically endangered, 140 endangered and 129 vulnerable), and 15 were listed as extinct species. There were 3410 species on the department's priority flora list.
- Conservation status assessments resulted in 72 additions to the priority flora list, change in category of 9 taxa, and delisting of 5 taxa after survey and/or taxonomic review clarified their conservation status.
- Four nominations for threatened flora were received and are currently under review for addition to the threatened flora list. A further 13 listed species are under review for changes to listing status.
- Public consultation was undertaken for 22 threatened flora nominations prior to assessment of nominations by the TSSC.
- 21 flora nominations were provided to the Threatened Species Scientific Committee (TSSC) for their consideration.
- Continued to review the status of 125 threatened flora species that are currently listed under the BC Act using superseded criteria. So far, reviews against the current IUCN Red List v3.1 criteria have been prepared for 69 species and the TSSC has endorsed nominations for two of these species to be .
- Conservation status was reviewed for taxa newly described in 16 draft *Nuytsia* manuscripts.
- 2287 new records were added to the TPFL database, of which 458 were records of new populations.
- 650 data search requests for threatened and priority flora were processed (39 from DBCA staff, 77 from other government departments, 486 from consultants or the mining sector, and 48 from other organisations).
- 201 threatened flora authorisations were issued. Of these, 71 were issued for herbarium specimen collections for identification purposes, 20 for scientific or research purposes and 110 for land management and operational purposes.
- Five translocation proposals were approved (2 internal and 3 DBCA external partnerships).
- Impact assessment advice was provided in relation to 46 clearing permit applications, 20 mining or other development projects and 11 land use planning proposals with the potential to affect threatened and priority flora.
- Advice was provided on flora license applications for priority flora, and on issues relating to the management of the Western Australian flora industry.
- Drafts of new policy guidelines, templates and associated documents to govern translocations of conservation-significant species were produced.
- Support was provided to the Goldfields region threatened flora recovery team meeting.
- Participated in expert elicitations and provided advice to support the Regional Conservation Planning process for every DBCA region.
- Participated in the national working group for implementing the MoU on a Common Assessment Method and single operational list of threatened species.
- Continued liaison 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 67 flora species.
- Nineteen draft conservation advice documents prepared by DAWE were reviewed and updated.
- Provided support to coordinate two volunteer-led projects to survey poorly-known priority flora so that the conservation status can be assessed. The Adopt an Orchid volunteer program surveyed or monitored 18 threatened and 37 priority orchid taxa in the Midwest, Swan, South West, Warren, South Coast and Wheatbelt regions, with 279 populations monitored and 59 new populations discovered. The Wildflower Society of WA's Rare Flora Search project surveyed seven priority flora species in the Midwest, Wheatbelt, South Coast, Swan and South West regions.

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 decisions.
- 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, regional conservation planning, 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 data to the new Threatened Species and Communities database and ensure high quality data is maintained and shared.
- Finalise translocation guidance documents.

Fauna conservation and recovery

CF 2018-040

M Dziminski, T Johnston, C Kemp, B Palmer, J Renwick, B Richards, A Mutton, A Robey

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, including developing recovery plans, supporting recovery teams, administering strategic translocation planning and other conservation activities, as well as leading management plans for non-threatened species. The team administers the department's Animal Ethics Committee (AEC) to manage requirements for ethical consideration of animals in departmental research and management activities.

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 30 June 2022, 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

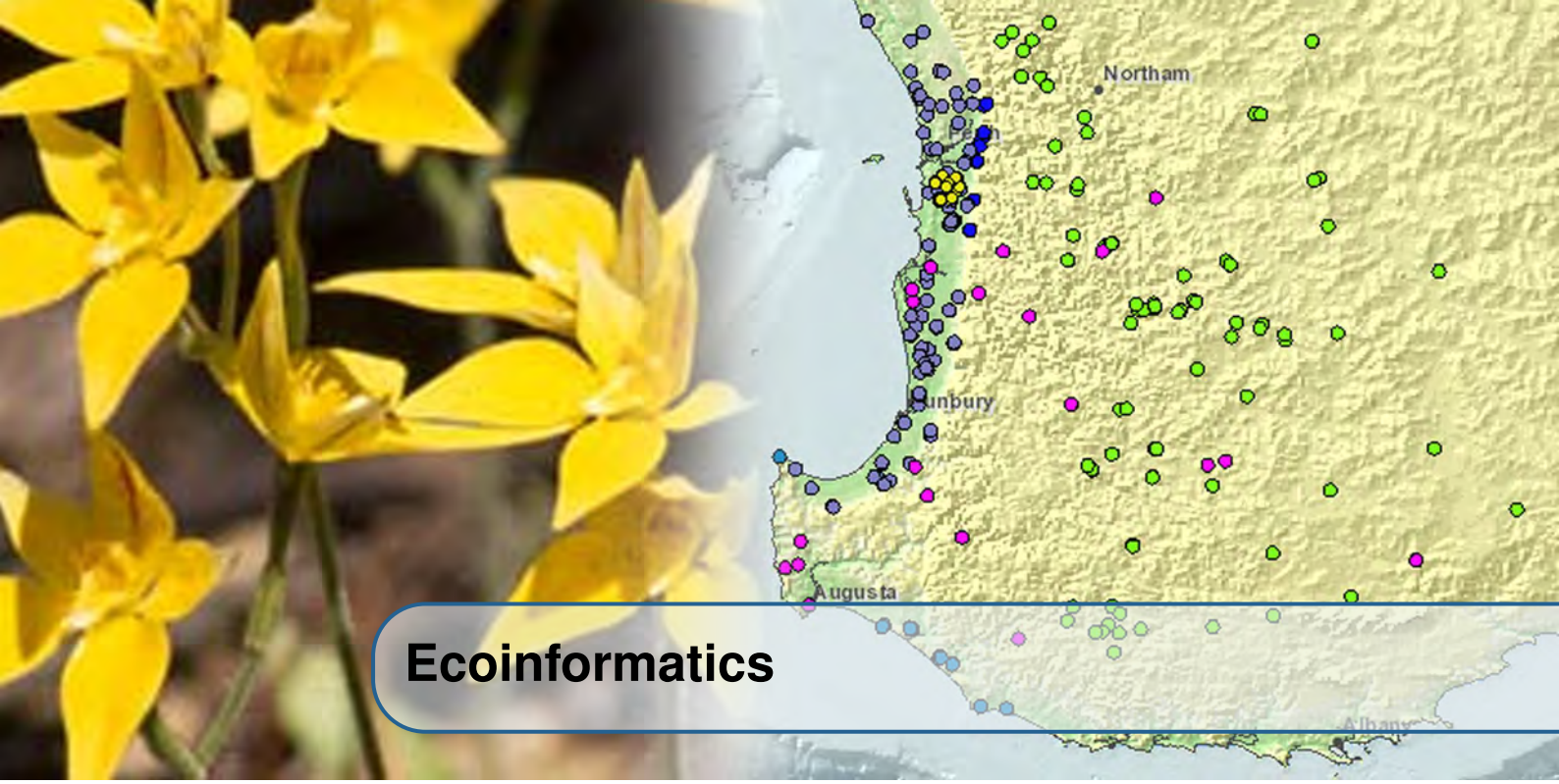
as specially protected species (seven conservation dependent, seven other specially protected and 74 migratory species). There were 219 species on the department's priority fauna list.
- A total of 305 new records of sightings, captures or evidence of threatened and priority fauna occurrences were added to the Threatened and Priority Fauna database.
- Two hundred and forty 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.
- 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.
- The AEC met six times, conducted a total of 330 assessments, approved 22 new projects and approved the renewal of 48 projects. There were 126 active AEC approved 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 activities and outcomes.
- 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.
- 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 BC Act requirements related to native fauna, and ensure processes and guidelines are in place as required.



Ecoinformatics

Program Leader: Ben P Richardson 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 external 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

B Richardson, 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 invaluable 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

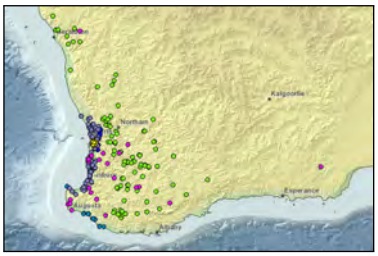
- Data held in BioSys was maintained.
- Documentation for BioSys was updated.

Management implications

- Reporting, research and analysis will be more efficient and effective 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

- Ongoing requirement for a biological survey 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 conserving biodiversity at the scale of the conservation estate in Western Australia, 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 the State's 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

- Access to *NatureMap* by internal staff was maintained.
- Searches of *NatureMap* data were provided by staff as required to meet requests from external users.
- *NatureMap* was maintained until December 2021 when external access was no longer able to be provided.

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* is being incorporated into the Biodiversity Information Office data system.

External Partnerships

Partners	Project Title	External Funding	Departmental Involvement
Atlas Iron, Fortescue Metals Group, Iron Ore Holdings, Roy Hill, Main Roads Western Australia	Ecology and management of the northern quoll in the Pilbara	$195,000	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

Partners	Project Title	External Funding	Departmental Involvement
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	S Whiting, S Fossette-Halot, T Tucker
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
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, 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, R 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

Partners	Project Title	External Funding	Departmental Involvement
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 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
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	$475,000	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

Partners	Project Title	External Funding	Departmental Involvement
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
BirdLife Western Australia	Conservation of the threatened Australasian bittern in south-western Australia	Nil	A Burbidge, A Pinder, S Comer, A Clarke, A Barrett, C Taylor, K Williams
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
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

Partners	Project Title	External Funding	Departmental Involvement
CSIRO, Ngadju Conservation Aboriginal Corporation, University of Bristol	Mapping of mature woodlands in Ngadju lands for fire management	$265,000	C Gosper, K Zdunic, G Page
CSIRO, The University of Western Australia	Marine turtle stable isotopes	Nil	T Tucker, S Whiting
CSIRO, Woodside	Great Western Woodlands carbon methodology	$315,000	C Gosper, K Zdunic
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
Conceptual population model and knowledge gaps for little penguin colonies in Western Australia	Conceptual population model and knowledge gaps for little penguin colonies in Western Australia	$18,000	T Holmes, I Leal, S Wilson
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, 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
Department of Fire and Emergency Services, Bushfire Front	Karri forest fuel dynamics	Nil	V Densmore, A Wills, S Samson, J Hollis
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	$2000	B Huntley
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	$30,000	A Pinder, S Easton, A Barrett, K Quinlan, G Barrett, R Glowicki, M Brotherson

Partners	Project Title	External Funding	Departmental Involvement
Ecological Horizons, Fortescue Metals Group, Roy Hill	Testing the efficiency and efficacy of Felixer feral cat grooming traps	$85,000	L Gibson
Edith Cowan University, Australian Museum Research Institute	Diversity of infaunal polychaete assemblages in Walpole and Nornalup Inlets Marine Park	Nil	I Leal, S Wilson
Edith Cowan University, University of Western Australia, Australian National University, Department of Primary Industries and Regional Development	Australian sea lions in the Perth metropolitan area: abundance, movement and habitat use.	$264,803	K Waples, H Raudino
Edith Cowan University	WAMSI-Westport seagrass project	$1,200,000	S Strydom
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
Fremantle Ports	Fremantle Marine Quality Monitoring Program	$30,659	S Hoeksema, K Trayler
Genomics for Australian Plants (Bioplatforms Australia, et al.)	Phylogenomics of the Western Australian flora	-	B Anderson
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
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
Hannah Cliff and Gareth Catt, Indigenous Desert Alliance	Impact of prescribed fire on desert fire regimes	Nil	V Densmore, J Chapman

Partners	Project Title	External Funding	Departmental Involvement
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
Landscape SA and SARDI	Prioritising onground actions for the endangered Australian sea lion	$32,600	K Waples, H Raudino
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	Radio Frequency Identification devices as a new method to estimate Little Penguins population size: Penguin Island as case-study	Nil	I Leal, T Holmes

Partners	Project Title	External Funding	Departmental Involvement
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
Murdoch University	Genetic studies of Pilbara EPBC Act listed threatened vertebrate fauna	$235,000	D Pearson, M Cowan
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

Partners	Project Title	External Funding	Departmental Involvement
Office of Environment and Heritage (NSW)	Evaluating BioSys within the Office of Environment and Heritage (NSW) data environment	$150,000	J Tonti-Filippini
OpenDataKit	OpenDataKit (ODK)	In-kind staff resources	
Research Agreement	Characterising organic carbon sources supporting cave pool communities in the Leeuwin Naturaliste Ridge	$10,000	M Venarsky, G McGrath
Rio Tinto, BHP	Seed collection zones for the Pilbara	$450,000	M Byrne, R Binks
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
Shire of Mundaring	Wildlife corridor mapping	Nil	K Zdunic
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
Threatened Species Initiative (plants)	Threatened Species Initiative (plants)	N/A	A Crawford, L Monks, R Binks, M Byrne
University of Adelaide, Uppsalla University, Australian Genomed Research Facility, National Research Council Italy	Understanding adaptation to improve conservation of Australian flora	$605,188	M Byrne
University of Adelaide	Aquatic microinvertebrate identification and systematics	$5000	A Pinder, K Quinlan, D Cale
University of Aukland, Macquarie University, University of Western Australia	Mirnong Maat (whale journeys) – Southern Right Whale research project	Nil	K Waples, H Raudino, S Bell
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

Partners	Project Title	External Funding	Departmental Involvement
University of New South Wales, Western Sydney University, Royal Botanic Gardens and Domain Trust etc	AusTraits: a national database on the traits of Australia's complete flora	$500,000	C Gosper
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

DBCA Officer	Student	Academic	Project Title	Duration	Page
D Algar	S Comer (PhD)	Dr D Roberts (The University of Western Australia), Dr P Speldewinde (The University of Western Australia)	Ecology of the feral cat in coastal heaths of the south coast of Western Australia	2014 – 2021	156
R Binks	G Carey (MSc)	Dr W Webb (University of Western Australia), A Lullfitz (University of Western Australia), Prof S Hopper (The University of Western Australia)	Phylogeographic analysis for Kalloora conservation management in the South-Western Australian Floristic Region	2022 – 2023	156
B Funnekotter, E Bunn	L Whelehan (PhD)	Prof R Mancera (Curtin University)	Characterisation of mitochondrial function in the cryopreservation of threatened flora	2019 – 2022	157
B Funnekotter, E Bunn	M Lukic (PhD)	Prof R Mancera (Curtin University)	Role of redox homeostasis in recovery from cryopreservation in *Arabidopsis thaliana*	2020 – 2023	157
B Funnekotter, E Bunn	L Hou (MSc)	Prof R Mancera (Curtin University)	Development of cryopreservation for the recalcitrant seeded Australian plants *Syzygium australe* and *S. paniculatum*	2020 – 2020	158

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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	158
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	158
M Byrne	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	159
M Byrne	L Monks (PhD)	Dr R Standish (The University of Western Australia)	Factors affecting the success of threatened flora translocations	2016 – 2020	159
J Cosgrove	S Kwambai (PhD)	Dr D Laird (Murdoch University), A/Prof N Moheimani (Murdoch University), A/Prof A Lymbery (Murdoch University)	*Alexandrium* spp. in Western Australia: characterisation, toxin mobility and control options	2021 – 2024	160
J Cosgrove	M Jung (PhD)	Dr M Fraser (The University of Western Australia), Dr B Martin (The University of Western Australia), Prof. G Kendrick (University of Western Australia)	Tracking seagrass condition: development and application of novel molecular biomarkers	2020 – 2023	160
A Burbidge, S Cowen	A Gibson Vega (PhD)	Associate Prof. A Ridley (University of Western Australia), Dr J Kennington (The University of Western Australia)	Genetic characterisation and behavioural ecology of the western grasswren (*Amytornis textilis*)	2019 – 2022	161
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	161
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	162

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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	162
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	162
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	163
S Fossette-Halot	M Gammon (PhD)	A/Prof N Mitchell (The University of Western Australia)	Predicting the vulnerability of flatback turtle rookeries to a changing climate	2018 – 2022	163
L Gibson	M Cowan (PhD)	A/Prof D Nimmo (Charles Sturt University), A/Prof S Setterfield (University of Western Australia)	The influence of mining on the movement ecology and behaviour of the endangered northern quoll (*Dasyurus hallucatus*)	2022 – 2025	164
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	164
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	165
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	165
C Lohr	C Wang (BSc Honours)	Dr A Koenders (Edith Cowan University)	Non-invasive collection of genetic samples from brushtail possums (*Trichosurus vulpecula*) in the arid zone	2021 – 2021	166
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	166

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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	166
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	167
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	167
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	168
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	168
G McGrath	K Staples (PhD)	Dr P Neville (Edith Cowan University / Department of Health)	Modelling mosquito development at Ashfield Flats	2020 – 2022	169
G McGrath	R Clohessy (BSc Honours)	Prof J Awange (Curtin University)	Evaluating satellite remote sensing of wetland water levels	2021 – 2022	169
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	169
D Merritt	S Henningsen (PhD)	T Erickson (The University of Western Australia)	Ecophysiology of seed dormancy of *Hibbertia*	2022 – 2025	170
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	170

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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	171
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	171
P Novak	T Crutchett (PhD)	R Hovey (UWA)	Microplastic distribution, sources, ingestion and health impacts in urban estuarine environments	2021 – 2024	171
P Novak	M Williams (PhD)	A/prof J McIlwain (Curtin University)	Plastic pollution in urban drains	2022 – 2022	172
P Novak	A Gillies (PhD)	A/Prof N Callow (University of Western Australia)	Canning River water quality and macrophyte investigation	2022 – 2022	172
K Ottewell	R de Visser (BSc Honours)	Dr R Catullo (University of Western Australia), Dr M Hall (Bush Heritage Australia)	Landscape genetics of red-tailed phascogales in south-west WA	2022 – 2022	173
K Ottewell	K Rick (PhD)	A/Prof N Mitchell (University of Western Australia)	Understanding patterns of phenotypic and genetic divergence in island mammals to improve conservation outcomes	2020 – 2023	173
A Pinder	K Webzell (PhD)	Dr J Chaplin (Murdoch University)	Can feathers be used to understand Australasian bittern populations?	2021 – 2021	173
A Pinder	A Islam (PhD)	Dr J Chaplin (Murdoch University)	Taxonomy and evolutionary history of *Parartemia* brine shrimp from Australian salt lakes	2020 – 2023	174
A Pinder	M Rahman (PhD)	Dr J Chaplin (Murdoch University)	Taxonomy and evolutionary history of *Australocypris* giant ostracods from Australian salt lakes	2019 – 2022	174
A Pinder	A Lawrie (PhD)	Dr J Chaplin (Murdoch University)	Taxonomy, ecology and evolutionary history of the salt lake gastropod *Coxiella*	2019 – 2022	175
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	175
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	176

DBCA Officer	Student	Academic	Project Title	Duration	Page
H Raudino, K Waples	J Tucker (BSc Honours)	Dr C Salgado Kent (Edith Cowan University)	Extending aerial surveys beyond target marine mammal species: an application of strip transect methodology to humpback whale abundance estimation in Exmouth Gulf, WA	2022 – 2023	176
C Ross	E Haskin (MSc)	Dr J Prince (University of Western Australia), Dr M O'Leary (University of Western Australia)	Coral recruitment at Ningaloo, Montebello Islands and Onslow	2021 – 2022	177
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	177
J Stevens	J Rus-calleda 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	178
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	178
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	179
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	179

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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	180
V Densmore, B Miller, R Van Dongen	A Deshayes (Undergraduate project)	Dr M Andrew (Murdoch University)	Relating fire severity field measurements to remote sensing for the Great Western Woodlands	2021 – 2022	180
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	181
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	181
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	181
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	182
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	182

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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	183
S Wilson	R Harris (MSc)	Dr C Fulton (Australian National University)	How does environmental disturbance effect macroalgal assemblages at Ningaloo	2019 – 2021	183
K Trayler, J Hyde, G McGrath	S Thompson (MSc)	Dr A Hopkins (Edith Cowan University), Dr A Koenders (Edith Cowan University)	Chasing Flamingos - Tracking synthetic eDNA in a river network using passive sampling methods	2022 – 2024	183

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 of this PhD project is to improve the understanding of feral cat ecology to increase the effectiveness of feral cat control programs in south coast ecosystems. The thesis will be submitted in 2022.

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 invasive predator management for Bush Heritage's Fitz-Stirling feral cat control project and will provide recommendations for increasing the efficacy of baiting programs in coastal reserves. Prey availability studies have been completed, with the suitability of remote sensing data to predict optimal baiting periods for south coastal investigated. In addition, dietary preferences of feral cats have been studied across the region using conventional diet analysis and stable isotope techniques.

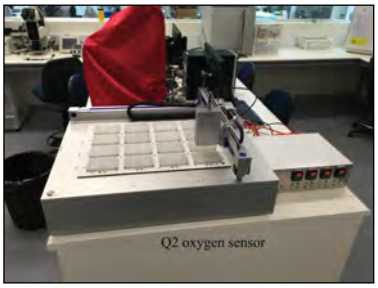
Phylogeographic analysis for Kalloora conservation management in the South-Western Australian Floristic Region

STP 2022-021

Scientist(s): R Binks
Student: G Carey (MSc)
Academic(s): Dr W Webb (University of Western Australia), A Lullfitz (University of Western Australia), Prof S Hopper (The University of Western Australia)

This project is working with the Wadandi people of the Busselton/Margaret River region to understand the cultural significance and traditional use of the Kalloora (Emu Plum, *Podocarpus drouynianus*) in southwestern Australia. This project also includes a genetic study to assess the health and population dynamics of the species that will inform its future management and long-term preservation.

The research proposal for this project has been approved and engagement with the Wadandi peoples has been undertaken to share in their knowledge of Kalloora and see the species on country. Wadandi representatives have undertaken a tour of the genetics laboratory, herbarium and seed centre to see where the samples for the project will be processed. Fieldwork to collect leaf samples and herbarium vouchers for the genetic analysis of 22 populations has been completed. DNA has been extracted and sequencing is underway.



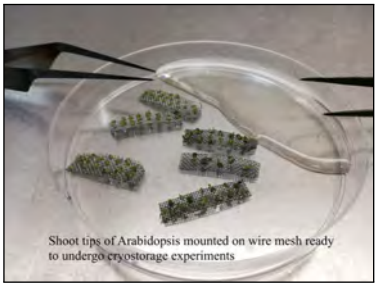
Characterisation of mitochondrial function in the cryopreservation of threatened flora

STP 2020-066

Scientist(s): B Funnekotter, E 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.

Respirometry measurements of shoot tips during cryopreservation using Q2 oxygen sensing technology has been completed and accepted for publication. Continuation of trials measuring oxygen consumption of Daucus carota cells on the Seahorse XF analyser remain to be completed. Further experiments on the viability of the Seahorse method using respiratory inhibitors to determine specific parameters of mitochondrial function are planned. The study species will be used to optimise methods for application to threatened species of native WA plants from the Kings Park tissue culture collection.



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

STP 2020-064

Scientist(s): B Funnekotter, E 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 with reduced antioxidant contents. 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* has been developed using vitamin C- and GSH-deficient mutant plants (vtc2-1, vtc2-4, pad2-1 and cad2), to assess changes in transcriptome using RNA-seq. Visualisation of roGFP via confocal microscopy to confirms redox changes in both the wild type and mutant plants after cryopreservation and assessment of antioxidant content during cryopreservation is being progressed.

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

STP 2020-063

Scientist(s): B Funnekotter, E Bunn
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 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 damage. The experimental work has been completed and thesis preparation is underway.

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.

A paper has been published on protocols for acoustic surveys for night parrots. A manuscript on implications for management, and guidelines for appropriate management actions, has been submitted for publication in *Biodiversity and Conservation*. This project is now complete.

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 assisted colonisation 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. Early results indicated suitable food availability as a key component. The aims are to 1) develop novel environmental DNA methods to understand diet in new habitats; 2) document foraging behaviour in relation to water temperatures and prey availability; 3) link metabolic processes and food intake to predict long-term growth rates and reproduction in new environments. This 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. 73 juvenile tortoises were released in August 2021 as part of a third assisted colonisation trial. Monitoring showed the juvenile tortoises gained an average 5.6% of their initial body mass over the hydroperiod before moving into aestivation for the summer and autumn months. Analysis indicates there is a positive relationship between tortoise activity levels and carapace temperature. Environmental DNA (eDNA) methods are being tested as a monitoring tool. A review on the use of environmental DNA in reptile conservation was published in *Ecology and Evolution*.

Mating systems, reproductive output and progeny fitness of translocated plant populations compared to wild populations

STP 2017-027

Scientist(s): M Byrne
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.

Analysis has been completed for genetic diversity, mating system analysis, reproductive output and progeny performance data for *Acacia rhetinocarpa* and methods and results drafted. A journal article on genetic diversity, mating systems, reproductive output and pollination analysis (for one translocated *B. brownii* population and four wild populations) has been submitted to *Australian Journal of Botany*. Methods and results have been drafted for a third paper on comparison of *B. brownii* progeny fitness traits from a translocated population with those from wild populations. An introduction and discussion for the *Acacia* study and *Banksia* progeny study are currently being drafted.

Factors affecting the success of threatened flora translocations

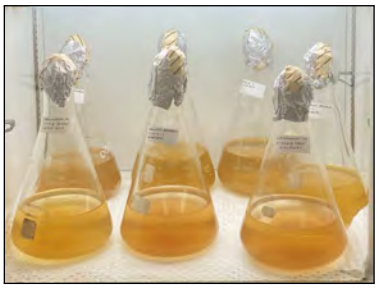
STP 2017-026

Scientist(s): M Byrne
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 complete, 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 whether translocated populations have comparable

demographic characteristics (plant height, volume, seed set and seed viability) 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 has been accepted for publication in *Australian Journal of Botany*.



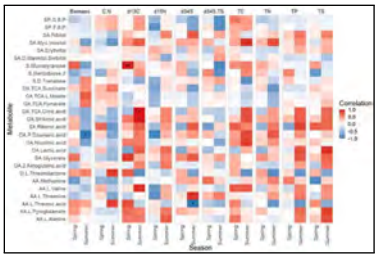
Alexandrium spp. in Western Australia: characterisation, toxin mobility and control options

STP 2022-044

Scientist(s): J Cosgrove
Student: S Kwambai (PhD)
Academic(s): Dr D Laird (Murdoch University), A/Prof N Moheimani (Murdoch University), A/Prof A Lymbery (Murdoch University)

Globally, harmful algal blooms represent a major and growing threat due to their undesirable ecological, economic and health impacts. *Alexandrium* species produce toxins that can be concentrated within filter feeding shellfish and other biota. Consumption of seafood containing high levels of these toxins can cause potentially fatal Paralytic Shellfish Poisoning (PSP). In 2019 and 2020, two significant blooms of *Alexandrium minutum* occurred in the Swan Canning Riverpark impacting both recreational and commercial fisheries and triggering this research project to examine toxicity and control.

To date, cultures of 2 different strains of *A. minutum* have been established, one from South Australia and one from Bunbury, WA. A local strain will be collected opportunistically and cultured when a bloom recurs. Development of toxin analysis protocols is underway, and culture material has been used to conduct a laboratory-based assessment of kaolinite clay (with and without addition of poly-alum chloride) as a control option.



Tracking seagrass condition: development and application of novel molecular biomarkers

STP 2020-005

Scientist(s): J Cosgrove
Student: M Jung (PhD)
Academic(s): Dr M Fraser (The University of Western Australia), Dr B Martin (The University of Western Australia), Prof. G Kendrick (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.

Metabolomic studies of *H. ovalis* have been conducted in both field and controlled laboratory environments in order to identify potential 'early warning bioindicators' of nutrient loading, sediment sulfides and other stressors. Findings of the field component have be submitted to the journal *Ecological Indicators*. Thesis writing is currently underway.

Genetic characterisation and behavioural ecology of the western grasswren (*Amytornis textilis*)

STP 2021-043

Scientist(s): A Burbidge, S Cowen
Student: A Gibson Vega (PhD)
Academic(s): Associate Prof. A Ridley (University of Western Australia), Dr J Kennington (The University of Western Australia)

The western grasswren (*Amytornis textilis*) is restricted to Shark Bay in Western Australia and is listed as Priority Four. The species formerly occurred on Dirk Hartog Island but became extinct due to non-native herbivores and feral cats. The Dirk Hartog Island National Park Ecological Restoration Project seeks to reintroduce a suite of locally extinct fauna to the island, including the grasswren. However, the western grasswren is probably the most poorly studied of all these species and little is known about its genetics or behaviour. The aim of this project is to investigate the population genetics and behavioural ecology of this cryptic bird species. This will require intensive studies of colour-banded birds, as well as obtaining tissue samples from a sufficient number of birds to undertake robust genetic analyses. This work will culminate in the development of a population viability analysis which will directly inform the translocation strategy for Dirk Hartog Island.

A final year of fieldwork was undertaken in spring of 2021 at Hamelin Station Reserve to collect breeding data, collect blood samples and gather further audio data. Blood samples were sequenced and a new SNP dataset was created which contains all western grasswren blood samples collected between 2019 to 2021. The breeding and SNP data was integrated into a population viability analysis, which aims to provide guidance on the translocation of western grasswren from mainland Shark Bay to Dirk Hartog Island. Currently, a manuscript detailing the population genetics of the western grasswren is in review in Ibis, and the manuscript detailing the breeding biology and social organisation of the western grasswren is in review in *Emu – Austral Ornithology*. The manuscript investigating the presence and effects of song dialects in western grasswren is in progress.

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 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 naturally occurring 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).

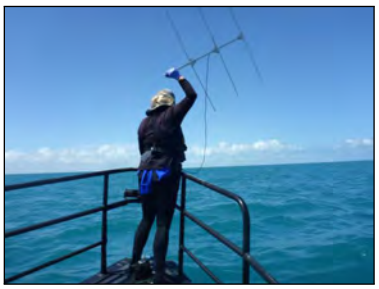
Results of this work found that all three Shark Bay mouse populations have relatively low genetic diversity and differentiation between populations, with marginally more variability present in the original source on Bernier Island. The PVA suggested that the optimal ratio of founders was 80 from Northwest 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. 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.



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 are used to analyse the turtles' fine-scale vertical and horizontal movements at a foraging ground.

All fieldwork has now been completed. A second paper describing flatback diving behaviour at a foraging ground has been accepted for publication in *Royal Society Open Science*. Two oral presentations have been given at international conferences. A third paper is about to be submitted to *Applied Ecology* that looks at fine scale spatio-temporal behavioural patterns of these foraging turtles to inform dynamic spatial management of this species in Roebuck Bay Marine Park. Tide and season have been found to strongly impact the turtles'

behaviour in the bay. Detailed maps are being produced to help management.

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 examines predator-prey interactions between ghost crabs and hatchling sea turtles on the Ningaloo coast to better conserve threatened turtle species and manage a native predator. It provides critical information regarding the potential impact of native ghost crabs on turtle eggs and hatchling survival. Results are helping assess the vulnerability of different nesting sites and determine if there is a need for human intervention.

A third fieldwork season has been completed for work on both loggerhead and flatback turtles. Ghost crab feeding assays have been performed at the Minderoo Exmouth Research Laboratory. Results were presented at the International Sea Turtle Symposium. A first draft of a paper on predation rates of eggs and hatchlings of loggerhead turtles has been completed. Laboratory work comparing predation rates of ghost crabs on eggs and hatchlings of loggerhead and flatback turtles has been completed.

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)

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.

All field work is now completed and the project is in the analysis and reporting phase. Two papers have been published including a comprehensive review of the literature and one on the metabolic thresholds of flatbacks turtles. A third has been submitted on the vulnerability of sea turtles nesting to erosion and inundation. The two remaining chapters are being finalised for thesis submission. These two chapters include hindcast and forecast climate change modelling to help understand turtle population changes. A presentation was made at the 40th International Sea Turtle Symposium and this project has produced an innovative collaboration with the UWA School of Engineering combining biological concepts and engineering models.

The influence of mining on the movement ecology and behaviour of the endangered northern quoll (*Dasyurus hallucatus*)

STP 2022-002

Scientist(s): L Gibson
Student: M Cowan (PhD)
Academic(s): A/Prof D Nimmo (Charles Sturt University), A/Prof S Setterfield (University of Western Australia)

The northern quoll (*Dasyurus hallucatus*) is a nocturnal mesopredator threatened by habitat loss due to mining in the Pilbara region of Western Australia, and the impacts of mining on the movement and behaviour of northern quolls are poorly known. This project seeks to fill this knowledge gap and identify the movement and behaviour of northern quolls living in mining landscapes.

Ten individuals from two separate field seasons have been tracked in mining landscapes using GPS technology. The next step will be to undertake GPS tracking at a natural reference site with no mining to compare the movement of northern quolls between the two areas. Quantifying predator abundances around mine camps compared to ecologically similar natural areas is currently being completed. The first chapter is currently in review and investigates the habitat use of northern quolls using historical datasets.

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. The 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 found a decrease in reproductive periods and growth rates, but increased absolute fecundity and lifespans for range-shifting rabbitfish species at the leading edge of expansion, likely increasing their ability to persist in marginal environments. In addition, there were higher levels of kelp consumption and detritous production in range expanding species than temperate counterparts in marginal environments, increasing local kelp consumption. Functional diversity increased in fish communities where range expansion had occurred, increasing novel herbivory functions and grazing intensity on seagrass and macroalgae. This study has shown the long-term persistence of tropicalised fish communities and altered benthic habitats in a formerly kelp dominated community, following the 2011 heatwave event. This has a number of social and ecological implications that may require modifications to management strategies into the future. The project resulted in the publication of four journal articles in *Proceedings of the Royal Society Part B*, *Functional Ecology*, *Journal of Ecology*, *Journal of Animal Ecology*.

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.

DNA extractions, and PCR analysis and sequencing of samples collected from ten sites between dams and weirs, are complete. The Masters dissertation has been submitted for this project and a paper is being prepared, using some additional sequencing data for the reference library. The study demonstrated that eDNA can detect a wide range of fish taxa and that the less labour-intensive passive sampling is also successful in freshwater systems. The project also highlighted significant gaps in the reference database for Western Australian freshwater species. Work is underway to expand the reference library for freshwater macrofauna in south-western Australia.

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 aimed 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, were tested in post-mining rehabilitation field sites, as well as glasshouse growth trials where environmental parameters were modified. In addition, physical, chemical and biological properties of soils from these multiple source sites were assessed and compared to the performance of seeds sourced from these sites.

The project is complete and key findings included glasshouse studies that showed seedlings sourced from wetter regions showed higher growth and 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 analyses 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 have been interpreted to better inform seed sourcing strategies under changing environmental conditions.

Non-invasive collection of genetic samples from brushtail possums (*Trichosurus vulpecula*) in the arid zone

STP 2021-041

Scientist(s): C Lohr
Student: C Wang (BSc Honours)
Academic(s): Dr A Koenders (Edith Cowan University)

The status of local populations of a species must be assessed prior to further supplementary translocations. Brushtail possums were reintroduced to the Matuwa Indigenous Protected Area in 2007 under the assumption that the local population was extinct. Concerns were raised about potential bottlenecking of sub-populations of the translocated possums in 2017. This project investigated whether viable genetic material could be collected from brushtail possums in the arid zone via baited tracking tunnels; whether there is ongoing evidence of inbreeding or genetic bottlenecking in the brushtail possum population on Matuwa; and whether the phylogenetics of brushtail possums in the arid zone can be assessed through fecal or hair DNA collected through non-invasive techniques.

Unfortunately, viable DNA could not be extracted from either tracking tunnels or relatively fresh possum scats collected near trees. DNA was extracted from 2/20 preserved possum skins held by the WA Museum, one from Cranbrook and a second from Bendering. Structure analysis of DNA taken from translocated possums suggests considerable genetic admixture between founder populations has occurred. Principal components analysis suggests that the population at Matuwa is significantly different to animals from Cranbrook.

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 boodie (*Bettongia lesueur*), and the mala (*Lagorchestes hirsutus*), are restricted to a few predator-free offshore islands and enclosures across Australia. Both species were reintroduced to an enclosure on the Matuwa Indigenous Protected Area. Little is known about the ability of these species to co-exist in a fenced environment.

This research found that the population of mala is slowly increasing and inter-specific competition between the species is minimal. One paper on resource competition has been published in *Ecological Management and Restoration*, and a second paper containing a protocol for estimating the abundance of mala via genetic fingerprinting has been submitted to *Wildlife Research*.

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.

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 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).

Writing up has commenced with chapters on research design and diet nutritional analysis completed.

Evaluation of the welfare and reproductive biology of captive tigers using non-invasive conservation physiology techniques

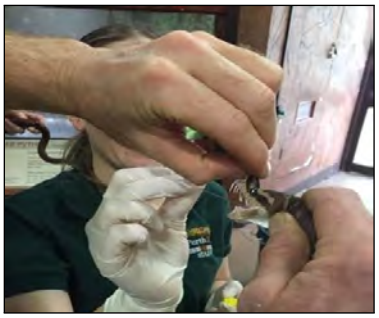
STP 2018-117

Scientist(s): P Mawson
Student: J Scherpenhuizen (PhD)
Academic(s): Dr R Friere (Charles Sturt University)

Sumatran tigers (*Panthera tigris sumatraeare*) are 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 aimed to develop and refine non-invasive assessment methods of tiger welfare and determine their effectiveness. To determine the factors most influential to captive tiger welfare there is a need to develop better tools with which to measure their welfare. A variety of enzyme immunoassays (EIAs) were used to quantify faecal glucocorticoid metabolites (FGMs) as biomarkers of physiological stress.

An EIA for tiger FGMs that was both highly sensitive and robust, allowing for the accurate analysis of FGMs in tiger faeces even after short term exposure to the elements, was used for longitudinal analysis. Faecal samples (1–2 per week) were collected from seven Sumatran tigers in three zoos around Australia for over a year. Australian temperate climates influenced Sumatran tiger FGMs as the seasons changed, with seasons most similar to that of the tropical, less changeable, Sumatran climate predicting the lowest FGM concentrations. Of particular importance was the amount of precipitation, with rainier seasons correlating with lower FGM concentrations. Furthermore, cold weather appeared to be more likely to coincide with a physiological stress

response in tigers. An observational study at a facility that housed 12 tigers (the single largest collection in Australia at the time) showed that the greatest predictor of low pacing prevalence was the presence of olfactory cues from conspecifics, followed by the presence of a pool, with the effects being greater for larger pools than smaller ones. Additionally, tigers in oestrus and those exposed to the scent of a tiger in oestrus further increased their patrolling, but when in smaller and less complex enclosures it also caused an increase in pacing. The results lead to several management suggestions regarding the ways in which water and olfactory enrichment could be used to improve captive tiger welfare.



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 project is investigating the prevalence of arenavirus, bornavirus, nidovirus/coronavirus, sunshinevirus and ferlavirus in both captive and wild populations of snakes.

All laboratory analyses are complete and the thesis has been produced.

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 on jarrah growth response and a third paper on modelling growth in karri and marri have been published in *Forest Ecology and Management*. Another manuscript on karri growth response and thinning is in review and a final manuscript investigating into the effects of above and below ground competition in jarrah and karri forests is ready for submission.

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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 and active management of mosquitoes by State and local government occurs in the Reserve. 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 composition 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 mosquito development. Modelling of mosquito populations at Ashfield Flats is incorporating sea-level rise projections and other IPCC scenarios. A paper documenting the model that has now been coupled to a mosquito development model is in preparation.

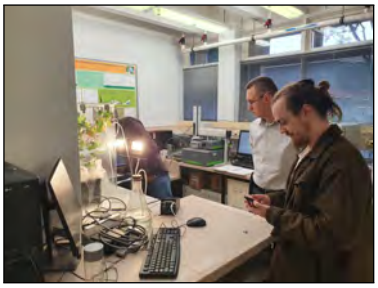
Evaluating satellite remote sensing of wetland water levels

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.

Satellite data from GRACE and GRACE FO were correlated with water level data collected at several wetlands in South west WA and Australasian bittern wetlands and a paper describing these regional correlations is in preparation.



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 resilience 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.

A multidisciplinary laboratory experiment was completed to assess 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. The data from the chamber experiment have now been curated for use with a new model to estimate the water ages. Initial testing of the model indicated modifications were required in order to more accurately reproduce observations. Model testing is underway, as is the preparation of a journal article to report on the model and the experiment.

Ecophysiology of seed dormancy of *Hibbertia*

STP 2022-009

Scientist(s): D Merritt
Student: S Henningsen (PhD)
Academic(s): T Erickson (The University of Western Australia)

Seeds of *Hibbertia* possess complex dormancy and germination requirements. Reliable methods of propagation are yet to be established for most species. Within the jarrah forest of south-west WA, *Hibbertia* are common, and the inability to propagate their seeds precludes their use in mine site rehabilitation. This project will focus on the germination ecology of *Hibbertia* seeds through field trials studying the intra- and inter-specific variation in seed dormancy and germination timing of a range of *Hibbertia* species differing in collection year and location. Through linked laboratory studies, seed pre-treatments applicable to nursery settings will be developed to allow for the large-scale production of *Hibbertia* seedlings for planting in mine site rehabilitation.

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. 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 will assess resprouting capacity and soil seedbank dynamics across a chronosequence of ages between three and 27 years since restoration.

Responses to small scale burns conducted across the restoration chronosequence have been monitored at both ~6 months and 1 year post fire in the restoration chronosequence. A variety of factors including size, restoration age and soil compaction, was found to influence resprouting success. Regeneration capacity following fire exists across the chronosequence, with different rseponses in older compared to younger restoration. Exploration of soil seedbank dynamics following smoke treatment revealed strong potential for regeneration, with annuals associated with younger restoration and perennials with older restoration.

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.

Fire has a very complex effect on the soil fungi community in Banksia woodland and results indicate that ecosystem function is maintained throughout a chronosequence of time since fire. Herbicides, seem to alter the soil fungal community, and further investigation is being undertaken.

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 have been completed. One review paper (on fire season effect mechanisms) and one experimental paper (on fire seasonal germination and emergence patterns) have been published. Papers on population structure and reproductive patterns are in late draft.

Microplastic distribution, sources, ingestion and health impacts in urban estuarine environments

STP 2022-006

Scientist(s): P Novak
Student: T Crutchett (PhD)
Academic(s): R Hovey (UWA)

This project builds on the work completed under the Swan Canning plastic investigation by determining the presence of microplastics (plastics <1 mm) in surface water and beaches of the estuary, developing a method to identify the polymers of these tiny plastics and investigating the presence of microplastics in the digestive systems of fish and determine the potential harm caused by these materials.

An extensive review of the literature has been undertaken and a pilot trail completed to test and refine water and beach sampling methods. Three, quarterly sampling events at 38 beach sites and four estuary regions have been completed. Analytical methods for plastic fragment identification are being developed in collaboration with the ChemCentre to analyse the plastic fragments that have been collected.

Plastic pollution in urban drains

STP 2022-005

Scientist(s): P Novak
Student: M Williams (PhD)
Academic(s): A/prof J McIlwain (Curtin University)

The DBCA Swan Canning Plastic project highlighted some major differences in the plastic accumulation in beaches within the Swan and Canning Estuaries. This work aims to determine if there are differences in the plastic washing down three major drainages in each estuary catchment. In addition, this work will determine the types of plastic commonly washing down the drains into the estuary, providing vital knowledge for the Plastic Free River Program to identify priority catchments for remediation work.

Six catchments sites have been identified and field work undertaken to ground truth sites. The sampling equipment has been obtained and a method trial has been undertaken.

Canning River water quality and macrophyte investigation

STP 2022-004

Scientist(s): P Novak
Student: A Gillies (PhD)
Academic(s): A/Prof N Callow (University of Western Australia)

Submerged macrophytes play a fundamental role in the functioning of freshwater lakes and rivers providing food, refugia, shade and influencing physico-chemical conditions. A submerged macrophyte community has been a important part of the Canning River Kent Street Weir Pool (KSW) for decades, although, recent observations suggest it has disappeared from the weir pool. This project aims to determine the changes in water quality in the weir pool over the last 20 years, determine the historical extent of submerged macrophytes in the the weir and investigate reasons for their changes in abundance.

Preliminary GIS work to review historical photos to establish past distribution of submerged macrophytes in the KSW was completed. Macrophytes were surveyed at five sites along a 5 km stretch of the river. Light penetration was also investigated. The influence of light and water quality on changes in abundance and impact on macrophyte growth are being explored.

Landscape genetics of red-tailed phascogales in south-west WA

STP 2022-037

Scientist(s): K Ottewell
Student: R de Visser (BSc Honours)
Academic(s): Dr R Catullo (University of Western Australia), Dr M Hall (Bush Heritage Australia)

The red-tailed phascogale, *Phascogale calura*, is listed as conservation-dependent. Due to their highly fragmented and restricted habitat in south-west Western Australia, understanding their genetic structure and diversity is crucial to informed conservation action. This study aims to 1) assess genetic structure across remaining wild reserve populations, 2) assess genetic diversity within reserves, 3) determine the genetic outcome of a previous mixed wild-to-wild translocation to Kojonup reserve, and 4) estimate effective wild global population size.

DArTseq analysis was undertaken for 208 red-tailed phascogale samples. An isolation by distance model best explained the genetic structure, with some evidence of fine scale structure of two northern reserves. Autosomal heterozygosity indicated that diversity is spread uniformly across reserves, and no populations showed signs of inbreeding or strong genetic drift. Although Kojonup has retained the diversity of the wider species, the source populations were unevenly represented. Global effective population size was estimated at 100 individuals in 2021.

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): A/Prof N Mitchell (University of Western Australia)

This project will focus on quantifying phenotypic and genetic divergence amongst island and mainland populations of several threatened mammals including the burrowing bettong (*Bettongia lesueur*), golden bandicoot (*Isoodon auratus*) and the dibbler (*Parantechinus apicalis*) 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.

Genomic analyses have been completed for the golden bandicoot and a draft manuscript is in preparation. Morphological measurements of museum specimens of dibbler and the burrowing bettong have been completed and a morphological assessment is underway.

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 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 aimed to investigate the potential for extracting and analysing DNA from shed feathers.

Protocols were developed to extract DNA from a number of feathers collected in recent years by DBCA and Birdlife Australia. Bittern DNA has been obtained from some feathers but the sample size and rate of success has been low. Extractions were more successful (all four feathers) for feathers shed by a bird while being fitted with a satellite tracking device. Amplification and sequencing of CO1 DNA confirmed the DNA came from that species. It is unclear whether this increased success is due to the freshness of the feathers or improved handling and storage. Further research into new shed feathers with optimal storage and handling techniques would be needed to determine this, but results suggest that feathers could potentially provide insights into population size and movements of this species. Given the poor results from the older feathers, a second component to this project was undertaken, examining population genetics of a species of *Coxiella* snails. This was completed and showed populations of *Coxiella striatula* inhabiting near coastal salt lakes around the south-west of WA were dominated by two haplotypes and suggested a recent genetic bottleneck.

Taxonomy and evolutionary history of *Parartemia* brine shrimp from Australian salt lakes

STP 2020-013

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

Australia has many salt lakes that support a diverse range of invertebrates. Crustaceans are particularly dominant and many species, genera, and even some families are endemic to these environments. The brine shrimp genus *Parartemia* is a good example, being one of the most diverse, common, and salt-tolerant groups of invertebrates that only occurs in Australian salt lakes. This research focuses on this endemic brine shrimp genus, with three main aims: 1) to use mitochondrial DNA data and, if necessary, also nuclear data, to assess the validity of the current morpho-taxonomy, 2) use molecular data to understand the evolutionary history of *Parartemia*, and 3) investigate the population genetic structure of *P. longicaudata* considering its conservation importance.

A paper reviewing *Parartemia* literature has been developed. One hundred and two populations of *Parartemia* from Western Australia have been collected so far and these have been identified based on the current morpho-taxonomy. A total of 102 16S (~ 477 bp), 206 COI (658 bp), and 47 28S (~ 868 bp) sequences have been generated which comprised a total of 88 16S, 141 COI, and 25 28S haplotypes. All these sequences represented 16 previously described morpho-species (out of 18) and 2 new species. The first draft of the molecular taxonomy article has been developed. These data are being used to determine the evolutionary history of the species, and a draft is underway for another article. An additional 200 COI (658 bp) sequences of *P. longicaudata* have been generated for the population genetic structure and phylogeographic study, data analysis is ongoing for this chapter.

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 of giant ostracod ecology and biology was submitted to Marine and Freshwater Research. Data for the second chapter on the taxonomy of Mytilocypridinae giant ostracods have been analysed, and a draft of the associated article completed. Analyses of the phylogeography and evolutionary history of *Australocypris* ostracods are complete and drafting this chapter has commenced. Most experiments for experimental analysis of hatching conditions are complete and analyses are underway, and sediment/egg samples have been collected for a final experiment.

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 taxonomic assessment of *Coxiella* has been completed which identified a total of 14 species, with six considered to be new species indicating that the diversity of this group has been underestimated. The taxonomic study also included a South-African genus *Tomichia* to test the hypothesis that these genera were once a Gondwanan assemblage. The genetic analyses found that *Coxiella* and *Tomichia* formed a monophyletic clade relative to outgroup taxa suggesting an ancient relationship between these genera. Physiological experiments on the salinity tolerances of 6 *Coxiella* species were also undertaken. The results suggested that although all *Coxiella* species can persist across a wide range of salinities (~5 – 70 mS/cm) some species are much more tolerant of higher salinities than others. *Coxiella* n. sp 2 in particular was able to tolerate salinities of ~ 135 mS/cm without displaying significant levels of mortality, suggesting that this species may be one of the most salt tolerant gastropods globally.

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.

This field work and analyses are complex and the research revealed that sympatric finches have different temporal-spatial waterhole visitation patterns implications for inter-specific accuracy of census data. Gouldian finches were found to increase their broad-scale movements between activity nodes while halving their residence time at nodes consistent with reduced density of seed resources into the late dry season. Sympatric finches also diverged in their feeding and movement niches during the late dry season. Gouldian finches moved more and remained strictly granivorous, while masked and long-tailed finches diversified diet to include more invertebrates and non-grass seeds and remained sedentary. As postulated from previous research, Gouldian finches preferred foraging in early prescribed burnt savanna indicating preference for low intensity mosaics rather than wildfire dominated regimes.

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 and 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 builds dens closer to the ground in dead trees and hollow logs, and forages at ground level. This makes them 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.

Arboreal mammals in savannas have differing tree hollow preferences based on camera trap and radio tracking data, with the brush-tailed rabbit-rats preferring smaller hollows in standing dead timber and closer to the ground. Brush-tailed possums and black-footed tree-rats prefer large hollows high in the canopy, and savanna gliders have much broader hollow tolerance. Arboreal species overlapped in their use of hollows, with multiple individuals and species sharing them with birds and arboreal predators including tree snakes and goannas. Despite this, on densely forested Melville Island, ground layer factors including presence of feral cats, shrub and fruiting plant density were the dominant influences on arboreal mammal abundance rather than hollow density or related arboreal habitat. Perhaps unlike mainland savannas, tree hollows on Melville are at higher densities and are therefore less limiting on arboreal species abundance.

The project has been completed and five papers published, including one this year in *Frontiers in Ecology and Evolution*.

Extending aerial surveys beyond target marine mammal species: an application of strip transect methodology to humpback whale abundance estimation in Exmouth Gulf, WA

STP 2022-031

Scientist(s): H Raudino, K Waples
Student: J Tucker (BSc Honours)
Academic(s): Dr C Salgado Kent (Edith Cowan University)

Aerial survey is a standard technique used in wildlife management to estimate population abundance and

detect trends. It is particularly useful for species with large ranges and broad distribution patterns, such as marine mammals, as the technique allows relatively large areas to be covered over short periods of time. While aerial surveys are typically designed for specific target species, additional species are often recorded as surveys are generally infrequent due to expense and logistical constraints. Analyses to estimate abundance of non-target species recorded during surveys can have limitations as information recorded for these species may be constrained or incomplete. In this study, analysis of aerial survey data collected in Exmouth Gulf, Western Australia, will be extended beyond the target species (dolphins) and applied to humpback whale (*Megaptera novaeangliae*) abundance estimation. While the survey was designed for distance sampling abundance estimation of dolphins, a strip transect approach was taken for humpback whales, and a maximum strip width was not defined. This study will evaluate various strip width estimates derived from the detection functions of comparable cues and a field based trial. An absolute abundance estimate for humpback whales will be calculated using strip-transect based methods, with corrections for availability and perception bias. The methods used here will be evaluated through comparison of these estimates with those derived from photographs taken during the survey, which have a known strip width. The relative density distribution of the species within the area will also be mapped and evaluated. The results of this study will update current knowledge on the abundance and distribution of key marine mammals with a focus on humpback whales in Exmouth Gulf, to inform ongoing monitoring and management of this 'conservation dependant' population.

The research proposal for this project has been approved and processing of image and aerial survey data relevant to humpback whales has begun.

Coral recruitment at Ningaloo, Montebello Islands and Onslow

STP 2021-006

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

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. Coral recruitment data was collected biannually from 2014-2018 at Onslow and from 2019-2021 at both Ningaloo and the Montebello Islands Marine Parks.

The main findings of this study were that coral recruitment varied spatially and seasonally, recruitment was positively correlated with coral cover at some but not all locations, and that the composition of recruits was not reflective of the adult coral community composition. The findings are being prepared for publication.

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; although

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.

All experimental work has been completed including research to (1) understand germination thresholds of semi-arid restoration priority species (2) investigate how preconditioning seedlings to water stress influences tolerance to subsequent drought in restoration substrates and (3) understand how propagule type, substrate and water availability influence establishment in restoration environments. Analysis and writing is underway.

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 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 continued to explore hyperspectral reflectance (measured with a field spectrometer) as a predictor of plant water status, plant water content, pigment content and maximum potential quantum efficiency of Photosystem II, as well as leaf temperature (measured through thermal imagery) to predict stomatal conductance. Initially this work was completed in controlled environment facilities and then applied to Banksia woodland restoration sites where five functionally distinct plant species were monitored over 15 months. All experiments are completed and analysis and writing are underway.

Soil-microbial-plant signals and effects on plant eco-physiological performance for mine site restoration

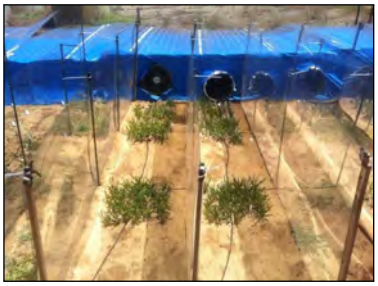
STP 2018-145

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 and plant tolerance against abiotic stress such as drought induced by microbial phytohormone and enzyme signals. 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.

The results of the project demonstrated rather limited beneficial effects of the selected microbial inoculants on the tested native plant species and highlights that further research is required before advocating the use of

commercial microbial inoculant in post-mining ecological restoration. The work also provided an approach to evaluate the use of commercial microbial inoculants through method development and experimental approaches that will be useful for future research.



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, is 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.

This study investigated canopy flow in native Australian vegetation and post-mine restoration systems. These wind flow dynamics were then used to monitor the impact of wind on *Banksia attenuata* seedling growth and physiology, providing a significant insight into the role of wind as an abiotic factor in arid and semi-arid ecosystems.

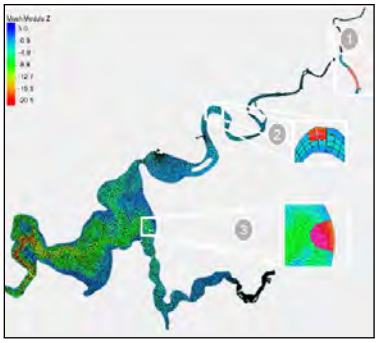
Dolphin health - toxicogenomics and pathology investigations

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 (SCR), a collaborative project with Murdoch University was established for post-mortem investigations 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 from Shark Bay (Western Gulf) and another estuarine population from the 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.

Liver and blubber samples of deceased dolphins collected from the SCR and Shark Bay have been analysed for key contaminants, including perfluorinated chemicals and persistent organic pollutants, and these data are being analysed. Analyses of blubber samples taken from skin biopsies are pending lab availability.



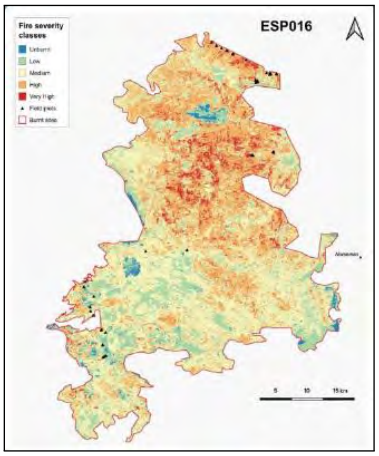
Identification of controls on the metabolism of the Swan Canning Estuary using numerical modelling and high-frequency data

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. 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.

An estuarine information portal was established, which integrated routine monitoring, high-frequency sensor data, and 3D coupled modelling, to provide insights into estuarine metabolism and oxygen dynamics. Data revealed signs of CO_2 oversaturation, highlighting the role of carbonate buffering in high pH environments. The SCERM model helped partition the contribution of advection to oxygen dynamics in the estuary as per the oxygen budget calculation. This research contributed to a deeper understanding of estuarine metabolism and oxygen dynamics using an integrative approach.



Relating fire severity field measurements to remote sensing for the Great Western Woodlands

STP 2022-017

Scientist(s): V Densmore, B Miller, R Van Dongen
Student: A Deshayes (Undergraduate project)
Academic(s): Dr M Andrew (Murdoch University)

This project sought to establish relationships between satellite and field-based measurements of fire severity, focusing on three large bushfires that burned part of the Great Western Woodlands during December 2019-January 2020. The study utilised data from 113 field sites that were collected approximately one week and again thirteen months after the fires to capture the initial and more extended impacts, as well as early recovery post-fire. The field data spanned three broad vegetation structures including heath, woodland and mallee, which resembled regrowth woodland. The field severity metrics analysed in this study included estimated pre- and post-fire functional cover at three strata (bare surface cover, crown scorch at two strata), canopy death and resprouting live trees. Satellite spectral indices included the differenced normalised burn ratio (NBR), normalised difference vegetation index (NDVI), relativised burn ratio (RBR) and i35 / Land Monitor. The strongest relationship was demonstrated between the overall field severity score and NBR, particularly for heath and woodland vegetation types. Field measures of severity were regressed against the spectral indices as a single regression and faceted by vegetation type. Significant differences between vegetation types were found for ground, shrub and canopy cover, while bare surface cover showed differences over time. Initial canopy scorch did not appear to predict the degree of later canopy death or resprouting on live trees a year later. All analyses were conducted using R. Severity maps for the three fires and a report outlining the study context, methodology and results have been finalised.

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 Nagulagun/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 sources over a thirteen-year period was undertaken to assess snubfin dolphin range patterns, site fidelity, and social structure in Roebuck Bay at individual and population levels. 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 and the Port of Broome. The findings were published in *Frontiers in Science.*

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 to use these methods to assess the potential extent of 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 evidence of loss of anti-predator traits has been identified in havened woylies. Two behavioural assays have been developed, one for cage trapping and another for feeding stations. These assays will now be used to compare anti-predator responses in havened and non-havened woylie populations across WA.

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 3 mm above ground and angled traps set 1 m and 2 m above ground) at 12 locations within

Julimar State Forest. Cameras were deployed for 6 weeks. Image processing and data analysis are underway to determine the best configuration 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 the species' 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 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. Modelling of predator responses to fox baiting intensity, prey abundance and rainfall has been undertaken, and the results of this have been submitted to Wildlife Research. State-space models have been used to predict spatial and temporal variation in abundance across the Upper Warren, and then used in structural equation models and scenario analysis to identify drivers of population change, including baiting intensity, fire history and severity, timber harvesting and primary productivity. An additional project has also begun to use multi-species abundance modelling and optimisation analyses to identify optimal fire regimes and fox baiting intensities in the Upper Warren.

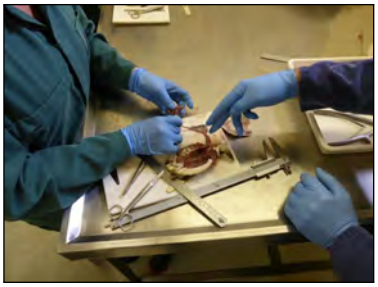
The population and spatial ecology of the numbat in the Upper Warren

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 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 and 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.



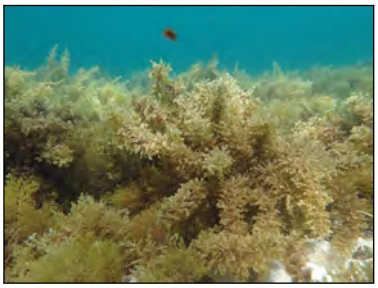
The health status of marine turtles in northern and western Australia

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.

The outcomes of this project included the first health assessment of sea turtles in Western Australia, including blood chemistry and reference baselines for nesting and in-water flatback turtles. Processes for pathology and pathology descriptions for flatback turtles were developed and personnel across the state were trained. Knowledge transfer to stakeholders included support for the banning of mass balloon releases in WA. A novel disease related to a multiple species mortality event in Broome (fish kill) was identified, as were a new parasite and haemoparasites in flatback turtles. A paper has been published in the journal *Diseases of Aquatic Organisms*, three draft manuscripts are in preparation.



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 paper describing spatial variation in macroalgal assemblages has been published in *Marine Biology*. The study shows that both sediment and abundance of urchins (Tripneustes gratilla), influence the community composition and physical structure of macroalgal assemblages at Ningaloo.

Chasing Flamingos - Tracking synthetic eDNA in a river network using passive sampling methods

STP 2022-003

Scientist(s): K Trayler, J Hyde, G McGrath
Student: S Thompson (MSc)
Academic(s): Dr A Hopkins (Edith Cowan University), Dr A Koenders (Edith Cowan University)

Biodiversity assessment methods using DNA sampled from the environment are evolving rapidly and becoming

widely used. Application to freshwater environments in Western Australia has been limited. This project aims to develop passive eDNA sampling methods for biodiversity assessments of river systems that will ultimately build capability within DBCA for large-scale application using methods for which limited expertise or training is required. The research will incorporate two components: 1) an experiment to trace artificial DNA through a river network using passive sampling methods; and 2) the application of passive eDNA sampling methods to a river network seasonally to produce a full biodiversity assessment of the aquatic fauna community, with inferences on the distribution of key species detected in the system.

Publications and Reports

Ahrens CW, Challis A, Byrne M, Leigh L, Nicotra AB, Tissue D. et al. (2021). Repeated extreme heatwaves result in higher leaf thermal tolerances and greater safety margins. New Phytologist **232** 1212-1225

Allendorf FW, Funk WC, Aitken SN, Byrne M, Luikart G (2022). Conservation and the genomics of populations.746 p. Oxford University Press, Oxford, England

Anderson B, Binks R, Butcher R, Byrne M, Hislop M, Macfarlane T et al. [Rye B, Shepherd K] (2021). Helping to resolve difficult taxonomic complexes of conservation importance in Western Australia with ddRAD population genomics. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 14-15

Anderson B, Binks R, Macfarlane T, Shepherd K (2021). Using genomic data to help resolve difficult taxonomic complexes of conservation importance in Western Australia. In *Biodiverse Futures: Systematics in A Changing World, 12-16 July 2021, Virtual: Annual Conference of the Australasian Systematic Botany Society* pp. 53

Anderson H, Richards B, Ross W, Palmer R (2022). Feral cat (*Felis catus*) predation confirmed for Rothschild's rock-wallaby (*Petrogale rothschildi*) in the Pilbara. *Australian Mammalogy* **44** 169-172

Anderson N (2021). When two disturbances collide: a look at jarrah forest after drought and wildfire. *For People & Plants* **116** 24-26

Anderson N, Tangney R, Miller R, Fontaine J (2021). Seasonal fluctuations in live foliar moisture delineate fire seasons in Mediterranean-type Banksia woodlands. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 25-26

Aplin KP, Cowan MA, Doughty P (2022). Synonymy of two west coast *Lerista* (Reptilia: Scincidae) species. *Records of the Western Australian Museum* **37** 22-25

Arif S, Graham NAJ, Wilson S, MacNeil MA (2022). Causal drivers of climate-mediated coral reef regime shifts. *Ecosphere* **13**: e3956

Atkinson ST, Cale D, Pinder A, Chambers JM, Halse SA, Robson BJ (2021). Substantial long-term loss of alpha and gamma diversity of lake invertebrates in a landscape exposed to a drying climate. *Global Change Biology* **27** 6263-6279

Ayre B, Krauss S, Phillips R (2021). The impact of introduced honeybees (*Apis mellifera*) on native plant reproduction. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 38-39

Bai L, Maslin B, Xia N (2021). *Senegalia propinqua* (Leguminosae: Mimosoideae), a new species from the Yuanjiang dry-hot valley in south-central Yunnan Province, China. *Phytotaxa* **522** 38-46

Bain D, Clarke RH, Oliver D, Bramwell MD, MacGregor C, Lindenmayer DB et al. [Burbidge AH] (2021). Southern eastern bristlebird *Dasyornis brachypterus brachypterus* Latham, 1801. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 584-587. CSIRO Publishing, Melbourne

Bain K, Wayne A, Virgo M (2021). A bait efficacy trial for the management of feral cats (*Felis catus*) in karri forest areas after timber harvesting activities: a report for the Forest Products Commission, Manjimup. 34 p. Python Ecological Services, Walpole, W.A

Baker GB, Candy S, Robinson S, Friend JA, Holdsworth M, Jensz K et al. [Page M, Algar D] (2021). Effectiveness of dogs for detecting feral cat scats in wheatbelt reserves of Western Australia. *Wildlife Research* **48** 690-700

Baker J, Cosgrove J (2021). Annual Swan Canning estuarine data report 2019-20. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 102 p.

Baker JD, Hoeksema SD (2022). Swan Canning Catchment data report January-December 2019: technical report. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 305 p.

Barnes M, Desmond A, Carter R, Newell J, Davis R, Clarke RH et al. [Burbidge AH] (2021). Houtman Abrolhos painted buttonquail *Turnix varius scintillans* Gould, 1845. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 311-313. CSIRO Publishing, Melbourne

Barnes M, Subroy V, Monks L, Crawford A, Coates D, Pandit R et al. [Davis B, Gosper C, Yates C] (2021). Prioritising translocations for effective conservation of a highly threatened flora. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 61

Bates BC, Dowdy AJ, McCaw L (2021). A Bayesian approach to exploring the influence of climate variability modes on fire weather conditions and lightning-ignited wildfires. *Climate Dynamics* **57** 1207-1225

Bearham D, Strzelecki J, McLaughlin J, Bryce M, Fromont J, Hara A et al. [Huisman JM] (2022). Habitats and benthic biodiversity across a tropical estuarine-marine gradient in the eastern Kimberley region of Australia. *Regional Studies in Marine Science* **49**: 102039

Beca G, Palmer B, Valentine L, Erickson T, Hobbs R (2021). More than just diggers: quenda and woylie disperse viable seed: science for saving species, research findings factsheet, project 4.1.7. 4 p. National Environmental Science Programme, Threatened Species Recovery Hub, Canberra

Beca G, Palmer B, Valentine LE, Erickson TE, Hobbs RJ (2021). Gut-passage time and viability of seeds consumed by Australian marsupials. *Australian Mammalogy* **43** 363-367

Benkwitt CE, Carr P, Wilson SK, Graham NAJ (2022). Seabird diversity and biomass enhance cross-ecosystem nutrient subsidies. *Proceedings of the Royal Society B* **289**: 20220195

Bergmann R, Donovan R, Davison E, James S, Lebel T, Barrett M et al. [Shepherd K] (2021). An investigation into the presence of amatoxins and phallotoxins in Western Australian mushrooms. In *Western Australian Forensic Science Forum 2021: 1/10/2021, Maylands* pp. 19-20

Bhandari SK, Veneklaas EJ, McCaw L, Mazanec R, Renton M (2021). Investigating the effect of neighbour competition on individual tree growth in thinned and unthinned eucalypt forest. *Forest Ecology and Management* **499**: 119637

Binks RM, Heslewood M, Wilson PG, Byrne M (2022). Phylogenomic analysis confirms polyphyly of *Leptospermum* and delineates five major clades that warrant generic recognition. *Taxon* **71** 348-359

Black AB, Burbidge AH, Garnett ST (2021). Dirk Hartog western grasswren *Amytornis textilis carteri* Mathews, 1917. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 562-563. CSIRO Publishing, Melbourne

Black AB, Burbidge AH, Garnett ST (2021). Large-tailed western grasswren *Amytornis textilis macrourus* Gould, 1847. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 564-565. CSIRO Publishing, Melbourne

Black AB, Burbidge AH, Garnett ST (2021). Murchison western grasswren *Amytornis textilis giganturus* Milligan, 1901. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 563-564. CSIRO Publishing, Melbourne

Black AB, McGregor SR, Burbidge AH, Garnett ST (2021). Cape Range rufous grasswren *Amytornis striatus parvus* Black, 2020. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 546-548. CSIRO Publishing, Melbourne

Bonnin L, Mouillot D, Boussarie G, Robbins WD, Kiszka JJ, Dagorn L et al. (2021). Recent expansion of marine protected areas matches with home range of grey reef sharks. *Scientific Reports* **11**: 14221

Bosch NE, Monk J, Goetze J, Wilson S, Babcock RC, Barrett N et al. [Holmes TH] (2022). Effects of human footprint and biophysical factors on the body-size structure of fished marine species. *Conservation Biology* **36** 1-13

Bougher N (2022). A wealth of new fungi in Kings Park and Bold Park. *Landscope* **37(3)** 48-52

Bougher NL (2021). Observations of successive crops of an individual *Myxarium nucleatum* (a jelly fungus) in Western Australia. *Western Australian Naturalist* **32** 101-103

Brace A, Ruthrof K, Fontaine J, Miller B, Hopkins A (2021). Temporal changes in soil microbial community compositions of a threatened ecological community post disturbance. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 209

Bradley HS, Tomlinson S, Craig MD, Cross AT, Bateman B (2022). Mitigation translocation as a management tool. *Conservation Biology* **36**: e13667

Brown A (2021). *Orchids of the south-west*. 72 p. Dept. of Biodiversity, Conservation and Attractions, Kensington, W.A. (Bush books)

Brown VS, Erickson TE, Merritt DJ, Madsen MD, Hobbs RJ, Ritchie AL (2021). A global review of seed enhancement technology use to inform improved applications in restoration. *Science of the Total Environment* **798**: 149096

Browne NK, Cuttler M, Moon K, Morgan K, Ross CL, Castro-Sanguino C et al. [Evans RD] (2021). Predicting responses of geo-ecological carbonate reef systems to climate change: a conceptual model and review. *Oceanography and Marine Biology: an Annual Review* **59** 229-370

Bunn E, Turner SR (2021). Case study 9.3: Translocation of micropropagated *Eremophila resinosa*. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 294-295. Australian Network for Plant Conservation, Canberra

Bunn E, Turner SR (2021). Case study 9.4: Somatic embryogenesis for mass production of native species. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 298-300. Australian Network for Plant Conservation, Canberra

Burbidge A (2022). Book review: For the love of birds. Australian bird photography by Georgina Steytler. *Western Australian Bird Notes* **181** p. 15

Burbidge A, Comer S, Ford S, Berryman A, Thomas A, Blythman M et al. (2022). Overcoming the challenges of recovery for kyloring. In *Abstract Book: Australasian Ornithological Conference, 8-10 February, Auckland 2022* pp. 50

Burbidge A, Dolman G, Ottewell K, Johnstone R, Burbidge M (2021). Genetic and morphological relationships of fieldwrens (*Calamanthus*): implications for conservation status and management. *Emu: Austral Ornithology* **121** 75-89

Burbidge AH, Blythman M, Garnett ST (2021). Dirk Hartog southern emu-wren *Stipiturus malachurus hartogi* Carter, 1916. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 518-520. CSIRO Publishing, Melbourne

Burbidge AH, Comer S, Garnett ST (2021). Western heath whipbird *Psophodes nigrogularis nigrogularis* Gould, 1844. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 719-722. CSIRO Publishing, Melbourne

Burbidge AH, Cowen S, Garnett ST (2021). Dorre rufous fieldwren *Calamanthus campestris dorrie* Mathews, 1912. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 665-667. CSIRO Publishing, Melbourne

Burbidge AH, Cowen S, Garnett ST (2021). Shark Bay purple-backed fairy-wren *Malurus lamberti bernieri* Ogilvie-Grant, 1909. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 507-509. CSIRO Publishing, Melbourne

Burbidge AH, Ford SS, Blythman M, Garnett ST (2021). Dirk Hartog rufous fieldwren *Calamanthus campestris hartogi* Carter, 1916. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 667-669. CSIRO Publishing, Melbourne

Burbidge AH, Ford SS, Garnett ST (2021). Barrow Island white-winged fairy-wren *Malurus leucopterus edouardi* Campbell, 1901. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 512-513. CSIRO Publishing, Melbourne

Burbidge AH, Ford SS, Garnett ST (2021). Dirk Hartog white-winged fairy-wren *Malurus leucopterus leucopterus* Dumont de Sainte

Croix, 1824. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 514-515. CSIRO Publishing, Melbourne

Burbidge AH, Garnett ST (2021). Western rufous bristlebird *Dasyornis broadbenti litoralis* Milligan, 1902. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 594-595. CSIRO Publishing, Melbourne

Burrows N, Stephens C, Wills A, Densmore V (2021). Fire mosaics in south-west Australian forest landscapes. *International Journal of Wildland Fire* **30** 933-945

Butcher R (2021). *Tephrosia sabulosa* (Fabaceae: Millettieae), a new species from Australia's sandhill deserts. *Nuytsia* **32** 109-119

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

Byrne M (2022). Science for the west. *Science For Saving Species* **19** 19

Cabrera FP, Huisman JM, Spalding HL, Kosaki RK, Sherwood AR (2022). Diversity of Kallymeniaceae (Gigartinales, Rhodophyta) associated with Hawaiian mesophotic reefs. *European Journal of Phycology* **57** 68-78

Cale D (2021). Wheatbelt wetland biodiversity monitoring: fauna monitoring at Lake Ronnerup 1999-2012. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 25 p.

Carpenter F, Dziminski M, Greatwich B, McPhail R, Gibson L (2021). Conservation and management of the bilby in Western Australia: partnerships with traditional owner rangers. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* p. 76. Conference Organising Committee, Perth

Carpenter F, Dziminski M, Greatwich B, McPhail R, Gibson L (2021). Conservation and management of the bilby in Western Australia: partnerships with traditional owner rangers. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 77

Carter L, Mankad A, Campbell S, Ruscoe W, Oh KP, Brown PR et al. [Byrne M] (2022). Conditions for investment in genetic biocontrol of pest vertebrates in Australia. *Frontiers in Agronomy* **3**: 806569

Carter R, Davis R, Burbidge A, Lohr C (2022). Catch me if you can: tracking down the Abrolhos painted button-quail. *Australian Birdlife* **11** 34-35, 37

Carter R, Davis R, Burbidge A, Lohr C (2022). Conservation ecology of the Abrolhos painted button-quail: averting another bird extinction. In *Abstract Book: Australasian Ornithological Conference, 8-10 February, Auckland 2022* pp. 26

Chabanne D, Raudino H, Ottewell K, McArthur S, D'Cruz E, Barrow D et al. [Waples K] (2021). Are you from my mob (mummagul)? Genetic connectivity of Australian snubfin dolphins (*Orcaella heinsohni*) between Prince Regent River and other Western Australian sites. Kensington, W.A. 25 p.

Chabanne D, Raudino H, Ottewell K, McArthur S, D'Cruz E, Barrow D et al. [Waples K] (2021). Are you from my mob (mummagul)? Genetic connectivity of snubfin dolphins in the Kimberley. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 14

Chambers B, Maxwell MA, Sullivan D, Wayne AF (2022). New technology to target feral cats in the south-west forests. *Bushland News* **122** 16

Coates D (2021). Evaluating persistence in threatened plant translocations: genetic diversity and mating systems as measures of success: science for saving species, research findings factsheet, project 4.3. 6 p. National Environmental Science Programme, Threatened Species Recovery Hub, Canberra

Coates D, Dillon R, Barrett S (2021). Case study 4.1: Patterns of genetic variation, ex situ seed collections and translocations of *Banksia brownii* (feather leaved banksia), Proteaceae. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 101-102. Australian Network for Plant Conservation, Canberra

Cochrane A, Barrett S (2022). Plant regeneration from seeds in the southern Mediterranean regions under a changing climate. In *Plant Regeneration from Seeds: A Global Warming Perspective* (eds C Baskin, J. Baskin) pp. 115-129. Academic, London

Cochrane A, Crawford AD, Errington G, Cuneo P, Viler M, Wood JA et al. (2021). Seed and vegetative material collection. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 85-117. Australian Network for Plant Conservation, Canberra

Collett S, Radford I, Crewe T, Campbell H (2021). Impacts of early prescribed burning on granivorous finch site utilisation. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 29-30

Comer S, Burbidge A, Berryman A, Thomas A, Blythman M, Stokes H et al. (2021). A new chapter for kyloring. *Landscope* **37(1)** 18-22

Comer S, Burbidge A, Stokes H (2021). Second chance. *Australian Birdlife* **10(3)** 18-21, 23

Comer S, Burbidge AH, Danks A, Garnett ST (2021). Noisy scrubbird *Atrichornis clamosus* Gould, 1844. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 480-483. CSIRO Publishing, Melbourne

Comer S, Burbidge AH, Danks A, Garnett ST (2021). Western bristlebird *Dasyornis longirostris* Gould, 1841. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 591-594. CSIRO Publishing, Melbourne

Comer S, Burbidge AH, Garnett ST (2021). Western ground parrot *Pezoporus wallicus flaviventris* North, 1911. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 437-440. CSIRO Publishing, Melbourne

Comer S, Ford S, Thomas A, Berryman A, Blythman M, Burbidge A (2021). December update on the first ever wild to wild translocation of western ground parrots! *Friends of the Western Ground Parrot Newsletter* **92** p. 2-3

Comer S, Ford S, Thomas A, Berryman A, Stokes H, Blythman M et al. [Burbidge A] (2021). An update on the first ever wild to wild translocation of western ground parrots! *Friends of the Western Ground Parrot Newsletter* **91** p. 2-4

Comer S, Thomas A, Berryman A, Stokes H, Blythman M, Utber D et al. [Burbidge A] (2022). Kyloring: an exciting autumn (djeran), winter (makuru). *Friends of the Western Ground Parrot Newsletter* **93** p. 2-5

Commander L, Quarmby A, Cochrane A, Ruiz-Talonia L, Craigie S, Crawford A (2021). Seed quality testing. In *Florabank Guidelines: Best Practice Guidelines for Native Seed Collection and Use* Second Edition pp. 10.1-10.27. Australian Network for Plant Conservation, Canberra

Cowan E (2021). Soil seedbank dynamics following smoke treatment in a restoration chronosequence. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 67

Cowan E, Standish R, Miller B, Enright N, Fontaine J (2021). Soil seedbank development in a 23-year restoration chronosequence following smoke treatment. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 104-105

Cowan M, Moore H, Jolly C, Dunlop J, Hernandez-Santin L, Wysong, M et al. [Gibson L] (2021). The space use of a native mesopredator is influenced by sex and habitat type. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 18

Cowen S, Branch K, Rayner K, Sims C (2021). Artificial refuges assist with monitoring short-term success of reintroductions of two threatened rodents. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 19

Cowen S, McArthur S, Ottewell K (2021). Developing faecal monitoring techniques to evaluate translocation success of trap-shy mammal species. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 37-38

Cowen S, Rayner K, Sims C (2021). Dirk Hartog Island National Park Ecological Restoration Project. Stage two, year three, translocation and monitoring report. Department of Biodiversity, Conservation and Attractions, Woodvale, W.A. 44 p.

Cowen S, Sims C, Ottewell K, Garretson S, Rayner K, Angus J, Gibson L (2021). Restoring biodiversity: a multi-faceted approach to a multi-species fauna reconstruction on Dirk Hartog Island. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 62

Cowen S, Smith M, McArthur S, Rayner K, Jackson C, Anderson G et al. [Ottewell K] (2021). Novel microsatellites and investigation of faecal DNA as a non-invasive population monitoring tool for the banded hare-wallaby (*Lagostrophus fasciatus*). *Australian Journal of Zoology* **69** 55-66

Cowen SJ, Comer S, Wetherall JD, Groth DM (2021). Translocations and their effect on population genetics in an endangered and cryptic songbird, the noisy scrub-bird *Atrichornis clamosus*. *Emu: Austral Ornithology* **121** 33-44

Crawford A (2021). Western Australian Seed Centre, Kensington. In *Australian Seed Bank Partnership Annual Report 2019-20* p. 22-23. Australian Seed Bank Partnership, Canberra

Crawford A, Binks R (2021). The prostrate flame pea, *Chorizema humile*. p. 1-2. Conference Organising Committee, Canberra

Crawford A, Cochrane A, Breman E, Harrison PA, Quarmby A, Driver M (2021). Seed collection. In *Florabank Guidelines: Best Practice Guidelines for Native Seed Collection and Use* Second Edition pp. 6.1-6.25. Australian Network for Plant Conservation, Canberra

Crawford A, Kelly A, Cochrane A (2021). Achievements of 25 years of conservation seed banking in Western Australia. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 73

Crawford A, Phoebe T, Joyce K, Quarman T, Funnell C, Kaur S et al. (2021). The Woodlupine seed project. *Bushland News* **119** p. 23-25

Crawford AD, Monks L (2021). Case study 4.2: Seed collection sizes required for translocation success: allow for losses! In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 103-104. Conference Organising Committee, Canberra

Crawford AD, Monks L, Shade A, Wood JA, Errington G, Stevens A et al. [Coates D] (2021). Maintenance, utilisation and information storage. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 449-476. Australian Network for Plant Conservation, Canberra

Crayn D, Simpson L, Lum M, Barrett M, Gustaffson J, Murphy D et al. [Shepherd K, Byrne M, Coffey S, MacDonald B, Macfarlane T] (2021). GAP phylogenomics: the Australian Angiosperm Tree of Life project: progress and future directions. In *Biodiverse Futures: Systematics in A Changing World, 12-16 July 2021, Virtual: Annual Conference of the Australasian Systematic Botany Society* pp. 51-52

Cruz MG, Cheney NP, Gould JS, McCaw WL, Kilinc M, Sullivan AL (2022). An empirical-based model for predicting the forward spread rate of wildfires in eucalypt forests. *International Journal of Wildland Fire* **31** 81-95

Curtis AL, Grierson PF, Batley J, Naaykens J, Fowler RM, Severn-Ellis A et al. [Thiele KR] (2022). Resolution of the *Eremophila tietkensii* (Scrophulariaceae) species complex based on congruence between morphological and molecular pattern analyses. *Australian Systematic Botany* **35** 1-18

D'Cruz A, Kent CS, Waples K, Brown AM, Marley SA, Thiele D et al. [Raudino HC] (2022). Ranging patterns and site fidelity of snubfin dolphins in Yawuru Nagulagun/Roebuck Bay, Western Australia. *Frontiers in Marine Science* **8**: 758435

Dadzie F, Moles AT, Erickson TE, Muñoz-Rojas M (2021). Harnessing soil microbial communities to improve restoration success in arid ecosystems. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 212-213

Dalziell E (2021). Case study 6.2: Non-orthodox seed storage behaviour of Australian Nymphaea. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 168-170. Australian Network for Plant Conservation, Canberra

Dalziell E, Merritt D, Funnekotter B, Bunn E (2021). Ex situ collections hold the key. *For People & Plants* Special Issue 12-13

Dalziell E, Merritt D, Hay F, Tomlinson S, Crawford A, Withers P (2021). Predicting seed lifespan for the improved curation of conservation seed banks. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 90

Dalziell E, Monks L, Crawford A (2022). Using ex situ collections of Australian native species: translocation and other end uses. 1 video. Australian Network for Plant Conservation, Canberra

Dalziell E, Tomlinson S, Merritt D, Lewandrowski W, Turner S, Withers P (2021). Resting metabolic rates in seeds: relationships with mass, phylogeny and climate. In *Australasian Seed Science Conference, 6th-10th September 2021 Australian Seedbank Partnership* pp. 26

Dalziell EL, Merritt DJ, Hay FR, Tomlinson S, Crawford A, Withers PC (2021). Predicting seed lifespan for the improved curation of conservation seed banks. In *13th Triennial Meeting of the International Society for Seed Science, 9-13th August 2021: Programme and Abstract Book* pp. 96

Davie H, Dziminski MA, Carpenter FM, Morris F, Meadham J, Mulcahey L et al. (2021). Managing feral predators and fire to ensure the persistence of wild bilbies at Warralong in the Pilbara. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 45

Davis B (2021). Jewels of the bushland. *For People & Plants* Special Issue 18-19

Davis B, Lim W-H, Lambers H, Dixon KW, Read DJ (2022). Inorganic phosphorus nutrition in green-leaved terrestrial orchid seedlings. *Annals of Botany* **129** 669-678

Davis B, Shade A (2021). A new home for wild spiders. *For People & Plants* **115** 34-37

Davis RW, Hammer TA (2022). *Swainsona picta* (Fabaceae), a new species from the Yalgoo bioregion, Western Australia. *Swainsona* **36** 71-73

Davis RW, Palmer J, Hammer TA (2021). *Gomphrena axillaris* and *G. longistyla* (Amaranthaceae), new species of *Gomphrena* from central and northern Australia. *Swainsona* **35** 59-64

Davis RW, Wege JA (2021). *Isotropis petrensis* (Fabaceae: Mirbelieae), a new species from arid Western Australia. *Nuytsia* **32** 99-102

Davison EM, Giustiniano D, Bougher NL, McGurk LE, Watkin ELJ (2021). Additions to *Amanita* (Amanitaceae, Agaricales) section *Arenariae* from south-western Australia. *Australian Systematic Botany* **34** 541-569

de Prato L, Ansari O, Hardy GE St J, Howieson J, O'Hara G, Ruthrof KX (2022). Morpho-physiology and cannabinoid concentrations of hemp (*Cannabis sativa* L.) are affected by potassium fertilizers and microbes under tropical conditions. *Industrial Crops and Products* **182**: 114907

De Prato L, Ansari O, Hardy GE St J, Howieson J, O'Hara G, Ruthrof KX (2022). The cannabinoid profile and growth of hemp (*Cannabis sativa* L.) is influenced by tropical daylengths and temperatures, genotype and nitrogen nutrition. *Industrial Crops and Products* **178**: 114605

Dekanová V, Venarsky MP, Bunn SE (2022). Length-mass relationships of Australian aquatic invertebrates. *Austral Ecology* **47** 120-126

Delnevo N, Piotti A, Carbognani M, van Etten EJ, Stock WD, Field DL et al. [Byrne M] (2021). Genetic and ecological consequences of recent habitat fragmentation in a narrow endemic plant species within an urban context. *Biodiversity and Conservation* **30** 3457-3478

Densmore V, van Dongen R (2021). OzCBI: the Composite Burn Index adapted to assess burn severity and key fauna habitat features in Australian ecosystems. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 42

Desmond B, Crawford A, Cuneo P, Duval D, Guerin J, Messina A et al. (2021). A national partnership approach to bushfire recovery through seed conservation for Project Phoenix. *Australasian Plant Conservation* **30** 23-24

Douglas TK, Weston MA, Greenwell CN, Lilleyman A, Hamilton NA, Cherriman S et al. (2022). Research methods for birds. In *Wildlife Research in Australia: Practical and Applied Methods* (eds B Smith, H Waudby, C Alberthsen et al.) pp. 313-359. CSIRO Publishing, Collingwood, Vic

Duncan EM, Broderick AC, Critchell K, Galloway TS, Hamann M, Limpus CJ et al. [Tucker AD, Whiting S] (2021). Plastic pollution and small juvenile marine turtles: a potential evolutionary trap. *Frontiers in Marine Science* **8**: 699521

Dundas SJ, Osborne L, Hopkins AJM, Ruthrof KX, Fleming PA (2021). Bioturbation by echidna (*Tachyglossus aculeatus*) in a forest habitat, south-western Australia. *Australian Journal of Zoology* **69** 197-204

Dunlop J, Smith A, Burbidge AH, Thomas N, Hamilton NA, Morris K (2022). Industry environmental offset funding facilitates a large multi-species fauna translocation program. *Pacific Conservation Biology* **28** 231-246

Duong HT, Mazanec R, McComb JA, Burgess T, Hardy GE St J (2022). Quambalaria shoot blight resistance in marri (*Corymbia calophylla*): genetic parameters and correlations between growth rate and blight resistance. *Tree Genetics and Genomics* **18**: 8

Dziminski M (2022). 2021 annual report on the commercial harvest of kangaroos in Western Australia. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 32 p.

Dziminski M, Greatwich B, Murray C, Surprise S, Smith D, Watson W et al. (2021). Distribution and abundance of the greater bilby in the Fitzroy Catchment: a Kimberley stronghold. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 7-8

Edgeloe JM, Severn-Ellis AA, Bayer PE, Mehravi S, Breed MF, Krauss SL et al. [Sinclair EA] (2022). Extensive polyploid clonality was a successful strategy for seagrass to expand into a newly submerged environment. *Proceedings of the Royal Society of London Series B* **289** 1-10

Elliott C, Golos P (2021). It takes a community to restore a community: restoring the puzzle of banded ironstone plants. *For People & Plants* Special Issue 30-31

Elliott C, Golos P, Stevens J, Miller B, Commander L, Merino-Martín L (2022). Restoring a threatened ecological community: defining and achieving restoration targets. *Department of Biodiversity, Conservation and Attractions, Kensington, W.A. Information sheet* **107/2022** 2 p.

Elliott C, Lewandrowski W, Krauss S, Merritt D, Miller B, Stevens J (2022). *Tetratheca erubescens* translocation, final research report for Mineral Resources Limited, March 2021 to March 2022. Department of Biodiversity, Conservation and Attractions, Kings Park, W.A. 105 p.

Elliott CP, Commander LE, Williams MR, Golos PJ (2021). Seed movement in small-scale vegetation restoration. *Ecological Management and Restoration* **22** 274-279

English V, Lyons MN, Collins M (2021). Vegetation and flora survey of Nimalarragun wetlands, Dampier Peninsular. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 32 p.

Ensikat H (2021). Western Australia's Biodiversity Information Office. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 67-68

Erickson T, Masarei M, Guzzomi A, Ling E, Muñoz-Rojas M, Merritt D (2021). Overcoming the constraints to precision seed delivery in mined landscapes that possess rocky soils, steep terrain, and severe edaphic conditions. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 55

Erickson TE, Kildisheva OA, Baughman OW, Breed MF, Ruiz-Talonia L, Brown VS et al. [Merritt DJ, Ritchie AL] (2021). Seed enhancement technologies. In *Florabank Guidelines: Best Practice Guidelines for Native Seed Collection and Use* Second Edition pp. 12.1-12.27. Australian Network for Plant Conservation, Canberra

Evans RD, Thomas L, Kennington WJ, Ryan NM, Wilson NG, Richards Z et al. (2021). Population genetic structure of a broadcast-spawning coral across a tropical-temperate transition zone reveals regional differentiation and high-latitude reef isolation. *Journal of Biogeography* **48** 3185-3195

Falster D, Gallagher R, Wenk EH, Wright IJ, Indiarto D, Andrew SC et al. [Chapman AR, Gosper CR, Huisman J, Richardson B, Rye B, Yates C] (2021). AusTraits: a curated plant trait database for the Australian flora. *Scientific Data* **8**: 354

Farquharson KA, McLennan EA, Wayne A, Smith M, Peel E, Belov K et al. (2021). Metapopulation management of a critically endangered marsupial in the age of genomics. *Global Ecology and Conservation* **31**: e01869

Filipe J, Rymer P, Ahrens C, Byrne M, Hardy G, Andrew M (2021). Remotely-sensed functional traits can indicate adaptive capacity to climate change of trees from Mediterranean-type ecosystems. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 189-190

Filipe JC, Rymer, PD, Byrne M, Giles H, Mazanec R, Ahrens CW (2022). Signatures of natural selection in a foundation tree along Mediterranean climatic gradients. *Molecular ecology* **31** 1735-1752

Fisher R, Leis JM, Hogan JD, Bellwood DR, Wilson SK, Job SD (2022). Tropical larval and juvenile fish critical swimming speed (U-crit) and morphology data. *Scientific Data* **9**: 45

Fleming PA, Crawford HM, Stobo-Wilson AM, Dawson SJ, Dickman CR, Dundas SJ et al. [Palmer R] (2021). Diet of the introduced

red fox *Vulpes vulpes* in Australia: analysis of temporal and spatial patterns. *Mammal Review* **51** 508-527

Fossette S, Ferreira LC, Whiting SD, King J, Pendoley K, Shimada T et al. [Tucker AD] (2021). Movements and distribution of hawksbill turtles in the eastern Indian Ocean. *Global Ecology and Conservation* **29**: e01713

Freestone MW, Swarts ND, Reiter N, Tomlinson S, Sussmilch FC, Wright MM et al. [Phillips RD] (2021). Continental-scale distribution and diversity of *Ceratobasidium* orchid mycorrhizal fungi in Australia. *Annals of Botany* **128** 329-343

Funnekotter B, Bunn E (2022). Cryopreserving plants for long-term conservation. *Australasian Plant Conservation* **30(3)** 8-10

Funnekotter B, Bunn E, Mancera RL (2021). Cryopreserving recalcitrant seeded species: oxidative stress limits cryogenic survival. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 64

Funnekotter B, Hardstaff LK, Bunn E, Davis B, Sommerville KD, Ballesteros D (2021). Cryopreservation. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 307-341. Australian Network for Plant Conservation, Canberra

Gammon M, Bentley B, Fossette S, Mitchell N (2021). Metabolic rates and thermal thresholds of embryonic flatback turtles (*Natator depressus*) from the North West Shelf of Australia. *Physiological and Biochemical Zoology* **94** 429-442

Garnett ST, Barden P, Burbidge AH, Carey M (2021). Indo-Pacific little tern *Sternula albifrons sinensis* Gmelin, 1789. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 322-325. CSIRO Publishing, Melbourne

Garretson S, Branch K, Rayner K, Sims C, Cowen S (2022). Constructing a better future for Wirruwana. *Landscope* **37(3)** 22-27

Gibson L (2021). Life down under: the mysterious world of subterranean fauna. *Landscope* **37(1)** 42-47

Gibson L (2021). Research update 2021: Subterranean Fauna Research Program: closing the knowledge gaps. 20 p. Western Australian Biodiversity Science Institute, Perth

Gibson L, Greatwich B, Dziminski M (2021). Monitoring, mapping and safeguarding Kimberley bilbies: wrap-up factsheet. 4 National Environmental Science Programme, Northern Australia Environmental Resources Hub, Canberra

Goetze JS, Wilson S, Radford B, Fisher R, Langlois TJ, Monk J et al. [Holmes TH] (2021). Increased connectivity and depth improve the effectiveness of marine reserves. *Global Change Biology* **27** 3432-3447

Golos P, Elliott C (2021). We've got mine waste rock dumps covered. *For People & Plants* Special Issue 28-29

Golos P, Stevens J, Revell C (2022). Restoring native pasture in the Kimberley. *For People & Plants* **117** 37-38

Gosper C, Miller B, Kinloch J, van Dongen R, Adams E, Barrett S et al. [Cochrane A, McCaw L, Miller R, Yates C] (2022). Estimation of juvenile period in slow-maturing plants over space and time. *Department of Biodiversity, Conservation and Attractions, Kensington, W.A. Information sheet* **109/2022** 2 p.

Gosper C, Zdunic K, Barrett S, Loewenthal G, Yates C (2021). Quantifying *Banksia* decline in Fitzgerald River National Park at plot to landscape scales. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 50-51

Gosper CR, Percy-Bower J, Byrne M, Llorens TM, Yates CJ (2022). Distribution, biogeography and characteristics of the threatened and data-deficient flora in the Southwest Australian Floristic Region. *Diversity* **14**: 493

Hammer TA, Davis RW (2021). *Ptilotus crinitus* (Amaranthaceae), a new species from Western Australia's Kimberley region. *Swainsona* **35** 55-58

Hanford J, Papas P, Swapan P, Pinder A, VanderGragt M, Kelleway J (2022). Proceedings of the Fire in Wetlands Forum: a burning success: introduction to the proceedings. *Wetland Science & Practice* **40** 122

Hardstaff L, Sommerville K, Funnekotter B, Bunn E, Mancera R, Offord, C (2021). Cryopreserving recalcitrant seeded species: oxidative stress limits cryogenic survival. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 67

Hardstaff LK, Sommerville KD, Funnekotter B, Bunn E, Offord CA, Mancera RL (2022). Myrtaceae in Australia: use of cryobiotechnologies for the conservation of a significant plant family under threats. *Plants* **11**: 1017

Harris RJ, Wilson SK, Fulton CJ (2021). Interactive effects of sediments and urchins on the composition and structure of tropical macroalgal assemblages. *Marine Biology* **168**: 144

Harrison N, Phillips B, Wayne A, Steven R, Mitchell N (2021). Systematic review of methods for quantifying anti-predator responses and its application for Australia's critical weight range mammals. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 32

Harrison ND, Phillips BL, Hemmi JM, Wayne AF, Steven R, Mitchell NJ (2021). Identifying the most effective behavioural assays and predator cues for quantifying anti-predator responses in mammals: a systematic review protocol. *Environmental Evidence* **10**: 38

Harrison PA, Breed MF, Broadhurst L, Byrne M, Commander L, Coates D et al. [Krauss S, Millar M] (2021). Seed sourcing. In *Florabank Guidelines: Best Practice Guidelines for Native Seed Collection and Use* Second Edition pp. 5.1-5.33. Australian Network for Plant Conservation, Canberra

Hartmann H, Bastos A, Das AJ, Esquivel-Muelbert A, Hammond WM, Martínez-Vilalta J et al. [Ruthrof KX] (2022). Climate change risks to global forest health: emergence of unexpected events of elevated tree mortality worldwide. *Annual Review of Plant Biology* **73** 673-702

Herring MW, Barratt P, Burbidge AH, Carey M, Clarke A, Comer S et al. (2021). Australasian bittern *Botaurus poiciloptilus* Wagler, 1827. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 222-224. CSIRO Publishing, Melbourne

Hirst MJ, Commander LE, Emery NJ, Guja LK, Liyanage GS, Merritt DJ et al. [Turner SR] (2021). Seed germination and dormancy. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 187-239. Australian Network for Plant Conservation, Canberra

Hislop M (2021). *Styphelia undulata* (Ericaceae: Epacridoideae: Styphelieae), a distinctive, short-range endemic from the Geraldton sandplains. *Nuytsia* **32** 103-107

Hislop M (2021). New species of Western Australian *Styphelia* (Ericaceae: Epacridoideae: Styphelieae) from the *S. pendula* and the *S. conostephioides* groups. *Nuytsia* **32** 199-238

Hogg CJ, Ottewell K, Latch P, Rossetto M, Biggs J, Gilbert A et al. (2022). Threatened Species Initiative: empowering conservation action using genomic resources. *Proceedings of the National Academy of Sciences of the USA* **119**: e2115643118

Hopkins A, Fontaine J, Brace A, Bruce J, Hyde J, Walden L et al. [Ruthrof K] (2021). Microbial responses to hotter drought and wildfire in a Mediterranean-climate type forest. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 214

Hopkins A, Fontaine J, Brace A, Ruthrof K (2021). Soil fungal responses to the stacked disturbances of hotter drought and wildfire

in a Mediterranean-type forest. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 44

Hopkins AJM, Tay NE, Bryant GL, Ruthrof KX, Valentine LE, Kobryn H et al. (2021). Urban remnant size alters fungal functional groups dispersed by a digging mammal. *Biodiversity and Conservation* **30** 3983-4003

Hopley T, Webber BL, Raghu S, Morin L, Byrne M (2021). Revealing the introduction history and phylogenetic relationships of *Passiflora foetida sensu lato* in Australia. *Frontiers in Plant Science* **12**: 651805

Howell L, Mawson P, Frankham R, Rodger J, Upton R, Witt R et al. (2021). Integrating biobanking could produce significant cost-benefits and minimise inbreeding for Australian amphibian captive breeding programs. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 76

Howell LG, Mawson PR, Frankham R, Rodger JC, Upton RMO, Witt RR et al. (2021). Integrating biobanking could produce significant cost benefits and minimise inbreeding for Australian amphibian captive breeding programs. *Reproduction, Fertility and Development* **33** 573-587

Huisman J (2022). William Henry Harvey: father of Australian phycology. *Landscope* **37(3)** 34-39

Huisman J, Saunders G (2022). *Asteromenia*. *Landscope* **37(3)** 40

Huisman JM (2021). An interactive key to the genera of Australian seaweeds. In *35th ASPAB Annual Meeting, November 22-23rd, 2021: Programme* pp. 13

Huisman JM, D'Archino R, Nelson W, Boo SM, Petrocelli A (2021). Cryptic cryptogam revealed: *Hypnea corona* (Gigartinales: Cystocloniaceae), a new red algal species described from the *Hypnea cornuta* complex. *Pacific Science* **75** 263-268

Huisman JM, Saunders GW (2021). Resurrection of *Plocamium pusillum* Sonder (Plocamiaceae, Rhodophyta) from Australia. *Cryptogamie, Algologie* **42** 231-239

Huisman JM, Saunders GW (2022). Three new species of *Asteromenia* (Hymenocladiaceae, Rhodophyta) from Australia. *Botanica Marina* **65** 159-175

Hutton M, Raudino H, Murray K, Strydom S, Waples K (2021). Dugong abundance and distribution in Shark Bay and Ningaloo following a prolonged heating event. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 35

Hyde J, McGrath G, Hopkins A, Stevens E, Ruthrof K (2021). Initial responses of soil microbiology to forest thinning. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 211-212

Hyde J, Wills A (2021). Monitoring the effect of fire on invertebrate populations in the SW of Western Australia. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 43

Ireland L, Todd M, Hedger C, Hurley V, Luck GW, Smith K et al. [Burbidge AH] (2021). Eastern regent parrot *Polytelis anthopeplus monarchoides* Schodde, 1993. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 460-463. CSIRO Publishing, Melbourne

Jaensch RP, Burbidge AH, Garnett ST (2021). Western Australian Lewin's rail *Lewinia pectoralis clelandi* Mathews, 1911. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 62-63. CSIRO Publishing, Melbourne

Jobson RW, Baleeiro PC, Dillon S, Dunning L (2021). Phylogenomic resolution of Themeda triandra (Poaceae) in Australia: what is the taxonomic status of Themeda sp. Hamersley Station (M.E. Trudgen 11431)? In *Biodiverse Futures: Systematics in A Changing World, 12-16 July 2021, Virtual: Annual Conference of the Australasian Systematic Botany Society* pp. 67

Johnstone RE, Kirkby T, Warren K, Rycken SJE, Shephard J, Barrett G et al. [Williams MR, Mawson PR, Burbidge AH] (2021). Forest red-tailed black-cockatoo *Calyptorhynchus banksii naso* Gould, 1837. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 387-391. CSIRO Publishing, Melbourne

Johnstone RE, Kirkby T, Warren K, Shephard J, Rycken SJE, Williams MR et al. [Mawson PR, Burbidge AH] (2021). Baudin's black-cockatoo *Zanda baudinii* Lear, 1832. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 398-402. CSIRO Publishing, Melbourne

Joseph L, Burbidge AH, Delhey K, Hansen BD, Kleindorfer S, Maurer G (2021). Emu's first 120 years: landmark papers of change in austral ornithology. *Emu: Austral Ornithology* **121** 284-291

Kay WR, Mawson PR (2021). An efficient method for the euthanasia of cane toads (*Rhinella marina*) under northern Australian field conditions. *Animals* **11**: 2239

Keighery G, Keighery B (2021). Opening Pandora's Box: *Pandorea* (Bignoniaceae) in Western Australia. *Western Australian Naturalist* **32** 104-108

Keighery G, Keighery B (2022). Dioecy in *Tribulus suberosus* (Zygophyllaceae) and observations of pollination in related species. *Western Australian Naturalist* **32** 156-160

Keighery GJ, Long V (2022). The button mangrove *Conocarpus erectus* L. (Combretaceae) is naturalised in Western Australia. *Nuytsia* **33** 29-33

Keighery GJ, Mitchell AA (2022). The correct name for the weedy *Homalanthus* (Euphorbiaceae) in Western Australia. *Nuytsia* **33** 35-37

Kendrick GA, Orth RJ, Sinclair EA, Statton J (2022). Effect of climate change on regeneration of seagrasses from seeds. In *Plant Regeneration from Seeds: A Global Warming Perspective* (eds C Baskin, J. Baskin) pp. 275-283. Academic, London

Kestel JH, Phillips RD, Anthony J, Davis RA, Krauss SL (2021). Unexpectedly low paternal diversity is associated with infrequent pollinator visitation for a bird-pollinated plant. *Oecologia* **196** 937-950

Khan MSA, Abbott LK, Solaiman ZM, Mawson PR, Waite IS, Jenkins SN (2022). Complementary effect of zoo compost with mineral nitrogen fertilisation increases wheat yield and nutrition in a low-nutrient soil. *Pedosphere* **32** 339-347

Kinloch J (2022). Webmap: spatial updates of habitat suitability model for *Varanus panoptes*.

Koch K, Pink C, Hamilton N, Algar D (2021). A population genetic study of feral cats on Christmas Island. *Australian Journal of Zoology* **68** 120-125

Krauss S (2021). *Grevillea scapigera*, a 30-year journey of recovery. *For People & Plants* Special Issue 16-17

Krauss S (2022). Tracking soil microbiol community trajectories through time using eDNA as a measure of post-mining restoration success. *For People & Plants* **117** 39-41

Krige A-S, Thompson RCA, Wills A, Burston G, Thorn S, Clode PI (2021). A flying start: wildlife trypanosomes in tissues of Australian tabanids (Diptera: Tabanidae). *Infection, Genetics and Evolution* **96**: 105152

Ladouceur E, Shackelford N, Bouazza K, Brudvig L, Bucharova A, Conradi T et al. [Erickson TE] (2022). Knowledge sharing for shared success in the Decade on Ecosystem Restoration. *Ecological Solutions and Evidence* **3**: e12117

Lamont BB, Miller BP, Enright NJ, Yan ZG (2022). Isolation and self-regulation processes in simulated postfire microsites promote plant species diversity. *Acta Oecologica* **114**: 103795

Lavery TH, Eldridge M, Legge S, Pearson D, Southwell D, Woinarski JCZ et al. (2021). Threats to Australia's rock-wallabies (*Petrogale* spp.) with key directions for effective monitoring. *Biodiversity and Conservation* **30** 4137-4161

Lavery T, Watson DJ, Charles R, Chuguna V, Cox R, Fiebig Q et al. [Pearson D] (2021). Threats to Australia's rock-wallabies (*Petrogale* spp.) with key directions for effective monitoring: science for saving species, research findings factsheet, project 7.5. 6 p. National Environmental Science Programme, Threatened Species Recovery Hub, Canberra

Lawes MJ, Crisp MD, Clarke PJ, Murphy BP, Midgley JJ, Russell-Smith J et al. [Gosper CR] (2022). Appraising widespread resprouting but variable levels of postfire seeding in Australian ecosystems: the effect of phylogeny, fire regime and productivity. *Australian Journal of Botany* **70** 114-130

Lawrie AD, Chaplin J, Pinder A (2021). Biology and conservation of the unique and diverse halophilic macroinvertebrates of Australian salt lakes. *Marine and Freshwater Research* **72** 1553-1576

Legge S, Woinarski JCZ, Garnett ST, Geyle H, Lintermans M, Nimmo DG et al. [Burbidge AH] (2021). Estimates of the impacts of the 2019-20 fires on populations of native animal species. 116 p. National Environmental Science Programme, Threatened Species Recovery Hub, Canberra

Legge SM, Woinarski JCZ, Burbidge AH, Gardner M, Pierce R, Swann G et al. (2021). Gouldian finch *Chloebia gouldiae* Gould, 1844. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 789-792. CSIRO Publishing, Melbourne

Leseberg NP, McAllan IAW, Murphy SA, Burbidge AH, Joseph L, Parker SA et al. (2021). Using anecdotal reports to clarify the distribution and status of a near mythical species: Australia's night parrot (*Pezoporus occidentalis*). *Emu: Austral Ornithology* **121** 239-249

Leseberg NP, Murphy SA, Burbidge AH, Jackett NA, Olsen P, Watson J et al (2021). Night parrot *Pezoporus occidentalis* Gould, 1861. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 444-447. CSIRO Publishing, Melbourne

Lewandrowski W, Elliott C (2021). Life on the edge: translocation of rare cliff dwellers. *For People & Plants* Special Issue 32-33

Lewandrowski W, Elliott C, Stevens J, Tomlinson S, Miller B, Dolin C et al. [Turner S] (2021). Born to rock: seed traits of rare and common banded ironstone species from semi-arid ecosystems. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 32

Lewandrowski W, Tudor E, Tomlinson S, Stevens J (2022). Ecophysiological performance, plant water relations and niche characteristics of *Aluta quadrata*: annual report 1, March 2021-March 2022. Department of Biodiversity, Conservation and Attractions, West Perth 27 p.

Li P, Fanestil N, Lynn-Palevsky J, Jabaily R, Shepherd K (2022). Designing custom genetic loci to improve the phylogeny of *Dampiera* (Goodeniaceae). In *Evolution 2022, June 24-28, Cleveland, Ohio, USA* 1 p.

Liddicoat C, Krauss SL, Bissett A, Borrett RJ, Ducki LC, Peddle SD et al. (2022). Next generation restoration metrics: using soil eDNA bacterial community data to measure trajectories towards rehabilitation targets. *Journal of Environmental Management* **310**: 114748

Lohr C, Dziminski M, Miller E, Dunlop J, Morris K (2021). The reintroduction of bilbies (*Macrotis lagotis*) to Matuwa, an Indigenous Protected Area in Western Australia. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* p. 90. Conference Organising Committee, Perth

Lohr C, Nilsson K, Sims C, Dunlop J, Lohr M (2021). Habitat selection by vulnerable golden bandicoots in the arid zone. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 32-33

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. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 91-92

Lohr CA, Nilsson K, Johnson A, Hamilton N, Onus M, Algar D (2021). Two methods of monitoring cats at a landscape-scale. *Animals* **11**: 3562

Lohr CA, Nilsson K, Sims C, Dunlop J, Lohr MT (2021). Habitat selection by vulnerable golden bandicoots in the arid zone. *Ecology and Evolution* **11** 10644-10658

Lohr MT, Algar D, Hamilton N, Lohr CA (2022). Feral cats in the subtropics of Australia: the Shamrock Station Irrigation Project. *Sustainability* **14**: 1373

Marsh CJ, Sica YV, Burgin CJ, Dorman WA, Anderson RC, del Toro Mijares I et al [Friend JA] (2022). Expert range maps of global mammal distributions harmonised to three taxonomic authorities. *Journal of Biogeography* **49** 979-992

Martin BC, Middleton JA, Skrzypek G, Kendrick GA, Cosgrove J, Fraser MW (2022). Composition of seagrass root associated bacterial communities are linked to nutrients and heavy metal concentrations in an anthropogenically influenced estuary. *Frontiers in Marine Science* **8**: 768864

Martyn Yenson AJ, Nadarajan J, Funnekotter B, Sommerville KD (2022). Australian Academy of Science, Fenner Conference on the Environment: Exceptional times, exceptional plants. *Australasian Plant Conservation* **30(4)** 26-29

Martyn Yenson AJ, Offord CA, Meagher PF, Auld TD, Bush D, Coates DJ et al. (eds) (2021). *Plant germplasm conservation in Australia: strategies and guidelines for developing, managing and utilising ex situ collections in Australia*. 530 p. Australian Network for Plant Conservation, Canberra

Matusick G, Ruthrof KX, Hardy GE St J (2022). Stem functional traits vary among co-occurring tree species and forest vulnerability to drought. *Australian Journal of Botany* **70** 204-214

Mawson PR, Barton B, Burbidge AH, Garnett ST (2021). Muir's corella *Cacatua pastinator pastinator* Gould, 1841. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 417-418. CSIRO Publishing, Melbourne

McGrath G (2021). Ashfield Flats hydrological study. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 804 p.

McGrath G (2021). Ashfield Flats hydrological study: summary report. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 27 p.

McGrath G (2021). Changing estuarine processes impacting the hydroperiod of a temperate coastal saltmarsh. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 18

McKinney M, Gibson L, Kark S (2021). Island invasions: prioritising surveillance for cane toads on Kimberley islands: science for saving species, research findings factsheet, project 4.2.5. 4 p. National Environmental Science Programme, Threatened Species Recovery Hub, Canberra

McNee S, Newbey B, Comer S, Burbidge AH (2021). Western bristlebird *Dasyornis longirostris*: response to fire and persistence of home range in the Fitzgerald River National Park. *Australian Field Ornithology* **38** 172-192

Merritt D, Cochrane A, Commander L, Sommerville K, Breman E, Quarmby A (2021). Seed drying and storage. In *Florabank Guidelines: Best Practice Guidelines for Native Seed Collection and Use* Second Edition pp. 9.1-9.23. Australian Network for Plant Conservation, Canberra

Merritt D, Erickson T (2021). Pilbara mine sites a tough challenge. *For People & Plants* Special Issue 26-27

Merritt D, Krauss S, Stevens J (2022). Taking our research to the national mining stage. *For People & Plants* **118** 30-33

Merritt D, Muñoz-Rojas M, Turner S, Dalziell E, Dwyer J, Kildisheva O, [Lewandrowski W, Erickson T] (2021). Quantifying seed germination and establishment traits for ecological restoration in the Pilbara region of Western Australia. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 54

Merritt DJ, Whitehouse KJ, Hoyle GL, Crawford A, Wood JA, Satyanti A et al. (2021). Seed banking: orthodox seeds. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 119-157. Australian Network for Plant Conservation, Canberra

Miller B, Miller R, Cowan E (2021). Where there's smoke, there's fire. *For People & Plants* Special Issue 34-35

Miller RG, Fontaine JB, Merritt DJ, Miller BP, Enright NJ (2021). Experimental seed sowing reveals seedling recruitment vulnerability to unseasonal fire. *Ecological Applications* **31**: e02411

Monie K, Florentine S, Palmer G, Turner S (2021). Ecological knowledge essential to management of a threatened plant community with an uncertain future. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 224

Monks L (2021). Case study 15.3: Utilisation of *Banksia cuneata* (matchstick banksia) seed collections for translocation planting. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 467-469. Australian Network for Plant Conservation, Canberra

Monks L, Crawford A, Dillon R, Barrett S (2022). Remarkable mountain bells. *Landscope* **37(3)** 28-33

Monks L, Standish R, McArthur S, Dillon R, Byrne M, Coates D (2021). Genetic and mating system assessment of translocation success of the long-lived perennial shrub *Lambertia orbifolia* (Proteaceae). *Restoration Ecology* **29**: e13369

Moore C, Beringer J, Prober S, Byrne M, Silberstein R, Macfarlane C et al. (2021). Filling the ecosystem monitoring gaps in TERN: making Western Australian SuperSites more super. In *TERN Science Symposium, 5-6 July 2021 Online: Abstracts* pp. 24

Moore HA, Dunlop JA, Jolly CJ, Kelly E, Woinarski JCZ, Ritchie EG et al. (2022). A brief history of the northern quoll (*Dasyurus hallucatus*): a systematic review. *Australian Mammalogy* **44** 185-207

Moro D, Morris K, van Leeuwen S, Davie H (2021). A framework of integrated research for introduced predators in the Pilbara bioregion, Western Australia. *Australian Mammalogy* **43** 265-276

Moro D, Ruscalleda Alvarez J, van Dongen R (2021). Mapping fire history for the Great Victoria Desert. *Landscope* **37(2)** 49-52

Mounsey CM, Stevens JC, Renton M, Dixon KW, Miller BP (2022). The influence of environmental drivers and restoration intervention methods on postmine restoration trajectories. *Restoration Ecology* **30** 1-13

Munro T, Erickson T, Nimmo D, Price J (2021). Effect of topsoil seed enhancements on seedling emergence in degraded agricultural landscapes. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 109-110

Nazarova O, Hislop M (2021). *Convolvulus pyrophilus* (Convolvulaceae), a new post-fire ephemeral, and an updated illustrated key to the Western Australian species. *Nuytsia* **32** 159-165

Neumann M, Turner J, Lewis T, McCaw L, Cook G, Adams MA (2021). Dynamics of necromass in woody Australian ecosystems. *Ecosphere* **12**: e03693

Nge FJ, Thiele KR (2021). Review of the infrageneric classification of *Adenanthos* (Proteaceae): the subsections of *Adenanthos* are polyphyletic. *Nuytsia* **32** 59-61

Nistelberger H, Ottewell K (2021). Conserving Western Australian boodies (burrowing bettongs). In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 56

Nistelberger H, Ottewell K (2021). Conserving Western Australian boodies (burrowing bettongs). In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 31

Northover A, Friend T, Hill S, Button T, Comer S, Courtenay J et al. [Ottewell K, Cowen S, Gibson L] (2022). Recovering Gilbert's potoroo (*Potorous gilbertii*): a review of progress and future directions. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 38 p.

O'Donnell AJ, McCaw WL, Cook ER, Grierson PF (2021). Megadroughts and pluvials in southwest Australia: 1350-2017 CE. *Climate Dynamics* **57** 1817-1831

Obbens F (2021). Taxonomic notes on *Calandrinia remota* (Montiaceae) and a reassessment of the status of *C. polyandra* var. *leptophylla* and *C. polyandra* var. *monantha*. *Nuytsia* **32** 167-171

Offord CA, Mills E, Percival J, Shade A, Turner SR, Viler M et al. (2021). The role of the plant nursery in *ex situ* conservation. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 241-278. Australian Network for Plant Conservation, Canberra

Oliver D, Bain D, Bluff L, Smith G, Hines H, Andren M et al. [Burbidge AH] (2021). Eastern ground parrot *Pezoporus wallicus wallicus* (Kerr, 1792). In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 440-444. CSIRO Publishing, Melbourne

Ooi MKJ, Tangney R, Auld TD (2022). Fire and regeneration from seeds in a warming world, with emphasis on Australia. In *Plant Regeneration from Seeds: A Global Warming Perspective* (eds C Baskin, J. Baskin) pp. 229-242. Academic

Osmundson TW, Bougher NL, Robinson RM, Halling RE (2021). *Rubinoboletus phaseolisporus* (Boletaceae) from Western Australia is a *Tylopilus* with bean-shaped spores. *Nuytsia* **32** 87-97

Paczkowska G, Davis R (2022). A second lifeline for the critically endangered pyramid mulla-mulla, *Ptilotus pyramidatus*. *Bushland News* **121** p. 5-6

Page G, Zdunic K, Prober S (2021). Satellite-based monitoring of intra- and inter-annual vegetation dynamics in the rangelands. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 184-185

Palmer BJ, Beca G, Erickson TE, Hobbs RJ, Valentine LE (2021). New evidence of seed dispersal identified in Australian mammals. *Wildlife Research* **48** 635-642

Palmer R, Gibson L, Craig M, Pitt G (2022). Managing feral cats to protect northern quolls in the Pilbara. *Department of Biodiversity, Conservation and Attractions, Kensington, W.A. Information sheet* **106/2022** 2 p.

Parker CM, Percy-Bower JM (2022). Updates to Western Australia's vascular plant census for 2021. *Nuytsia* **33** 1-14

Pavey C, Clarke RH, Burbidge AH, Garnett ST (2021). Princess parrot *Polytelis alexandrae* Gould, 1863. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 464-466. CSIRO Publishing, Melbourne

Pavey CR, Molyneux J, Körtner G, Friend JA, Vaughan-Higgins R, Fancourt BA, Heiniger J et al. (2022). Marsupial carnivores. In *Wildlife Research in Australia: Practical and Applied Methods* (eds B Smith, H Waudby, C Alberthsen et al.) pp. 389-400. CSIRO Publishing, Collingwood, Vic

Peddle S, Borrett R, Bullock P, Tibbett M, Gardner M, Liddicoat C et al. [Krauss S] (2021). Soil DNA chronosequence analysis shows bacterial community re-assembly following post-mining forest rehabilitation. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 88-89

Peddle S, Borrett R, Liddicoat C, Bullock P, Bissett, A, Tibbett M et al. [Krauss S] (2021). Soil DNA chronosequence analysis shows bacterial community re-assembly following post-mining forest rehabilitation. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* p. 87. Conference Organising Committee, Perth

Penton CE, Davies HF, Radford IJ, Woolley L-A, Tiwi Land Rangers, Murphy BP (2021). A hollow argument: understory vegetation and disturbance determine abundance of hollow-dependent mammals in an Australian tropical savanna. *Frontiers in Ecology and Evolution* **9**: 739550

Penton CE, Radford IJ, Woolley L-A, von Takach B, Murphy BP (2021). Unexpected overlapping use of tree hollows by birds, reptiles and declining mammals in an Australian tropical savanna. *Biodiversity and Conservation* **30** 2977-3001

Peterson KA, Barnes M, Cowen S, Gibson L, Sims C, Jeynes-Smith C et al. (2021). Reconstructing lost ecosystems: a risk analysis framework for planning multispecies reintroductions under severe uncertainty. In *Vital Connections in Ecology 2021: Ecological Society of America Virtual Annual Meeting, August 2-6* pp. 1

Peterson KA, Barnes MD, Jeynes-Smith C, Cowen S, Gibson L, Sims C et al. (2021). Reconstructing lost ecosystems: a risk analysis framework for planning multispecies reintroductions under severe uncertainty. *Journal of Applied Ecology* **58** 2171-2184

Pinder A, McCaw L, McGrath G, Millar M, Miller B, Ruthrof K, Wayne A, Whitford K, Wills A, Byrne M (2021). Impact of silvicultural practices on biodiversity in forests used for timber production in Western Australia: a summary of new concepts and knowledge since 2011. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 53 p.

Pratchett MS, Caballes CF, Cvitanovic C, Raymundo ML, Babcock RC, Bonin MC et al. [Wilson SK] (2022). Knowledge gaps in the biology, ecology and management of Pacific crown-of-thorns sea star, *Acanthaster* sp. on Australia's Great Barrier Reef. *Biological Bulletin* **241 (2021)** 330-346

Radford IJ, Corey B, Carnes K, Shedley E, McCaw L, Woolley L-A (2021). Landscape-scale effects of fire, cats and feral livestock on threatened savanna mammals: unburnt habitat matters more than pyrodiversity. *Frontiers in Ecology and Evolution* **9**: 739817

Radford IJ, Corey B, Carnes K, Shedley E, McCaw L, Woolley L-A (2021). Using functional responses to threatening processes for informing conservation of Kimberley mammal diversity. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 14

Radford IJ, Oliveira SLJ, Byrne B, Woolley L-A (2021). Tree hollow densities reduced by frequent late dry season wildfires in threatened Gouldian finch (*Erythrura gouldiae*) breeding habitat. *Wildlife Research* **48** 511-520

Rate AW, McGrath GS (2022). Data for assessment of sediment, soil and water quality at Ashfield Flats Reserve, Western Australia. *Data in Brief* **41**: 107970

Raudino H, Bouchet P, Douglas C, Douglas R, Waples K (2021). Regional abundance estimates of bottlenose and humpback dolphins in the Pilbara, Western Australia. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 66

Rayner K, Garretson S, Sims C, Cowen S (2021). Guideline for ethical behaviour during animal photography and videography. Department of Biodiversity, Conservation and Attractions, Woodvale, W.A. 2 p.

Rayner K, Lohr CA, Garretson S, Speldewinde P (2021). Two species, one island: retrospective analysis of threatened fauna translocations with divergent outcomes. *PLoS One* **16**: 0253962

Rayner K, Sullivan M, Sims C, Cowen S (2022). A pain in the neck: weak links are not a reliable release mechanism for radio-tracking collars. *Australian Mammalogy* **44** 117-125

Rayner K, van Dongen R, Sims C, Cowen S (2021). Monitoring the outcomes of ecological interventions on Dirk Hartog Island through small vertebrates and landscape-scale vegetation. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 19-20

Reinke BA, Cayuela H, Bronikowski A, Janzen F, Lemaitre J-F, Gaillard J-M et al. [Pearson D, Tucker T] (2022). Diverse aging rates in ectothermic tetrapods provide insights for the evolution of aging and longevity. *Science* **376** 1459-1466

Rick K, Ottewell K, Lohr C, Thavornkanlapachai R, Byrne M, Kennington J (2021). Admixing increases genetic diversity with no evidence of outbreeding depression in a threatened bettong (*Bettongia lesueur*). In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 36-37

Rick K, Travouillon K, Mitchell N, Ottewell K (2021). Conservation genomics of island, mainland and reintroduced populations of golden bandicoots. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 68

Ritchie A (2021). Perth's globally unique Banksia woodlands, a threatened ecological community in review. 19 p.

Ritchie A (2021). Perth's globally unique Banksia woodlands, a threatened ecological community in review. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 52

Ritchie AL, Elliott CP, Sinclair EA, Krauss SL (2021). Restored and remnant Banksia woodlands elicit different foraging behaviour in avian pollinators. *Ecology and Evolution* **11** 11774-11785

Robinson J, Rogers A, Nash K, Wilson S (2021). How will tropical fisheries respond to climate change on coral reefs? In *14th International Coral Reef Symposium: 18-23 July 2021, Bremen, Germany* pp. 1

Robinson JPW, Maire E, Bodin N, Hempson TN, Graham NAJ, Wilson SK et al. (2022). Climate-induced increases in micronutrient availability for coral reef fisheries. *One Earth* **5** 1-11

Robinson OJ, Socolar JB, Stuber EF, Auer T, Berryman AJ, Boersch-Supan PH et al. [Burbidge AH] (2022). Extreme uncertainty and unquantifiable bias do not inform population sizes. In *Proceedings of the National Academy of Sciences of the USA* **119** p. 1-2

Robinson R (2022). *Fungi of the south-west forests*. 72 p. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. (Bush books)

Rodríguez-Prieto C, Huisman JM, Lin S-M (2022). Molecular phylogeny of foliose *Halymenia* and *Austroepiphloea* (Halymeniaceae, Rhodophyta) from the Indo-Pacific, with the description of *Halymenia taiwanensis sp. nov*. *Phycologia* **61** 384-395

Rose MT, Zhang P, Rose TJ, Scanlan CA, McGrath G, van Zwieten L (2022). Herbicide residues in Australian grain cropping soils at sowing and their relevance to crop growth. *Science of the Total Environment* **833**: 155105

Ross C (2021). DBCA long-term monitoring of seawater temperature and benthic habitats. In *Minderoo-UWA Marine Heatwaves Workshop 2021: Speaker Schedule* pp. 7-8

Ross CL, French B, Lester EK, Wilson SK, Day PB, Taylor MD et al. (2021). Coral communities on marginal high-latitude reefs in west Australian marine parks. *Diversity* **13**: 554

Ruscalleda-Alvarez J, Moro D, van Dongen R (2021). A multi-scale assessment of fire scar mapping in the Great Victoria Desert of Western Australia. *International Journal of Wildland Fire* **30** 886-898

Rutherford J (2021). Petrophysics of peat in the Muir-Byenup wetlands: why they dry, generate acid and burn. Part 2, focus on Tordit-Gurrup Lagoon. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 69 p.

Rutherford J, Paczkowska G (2021). Water monitoring at Greater Brixton Street Wetlands. *Bushland News* **119** p. 8

Ruthrof KX, Fontaine JB, Breshears DD, Field JP, Allen CD (2021). Extreme events trigger terrestrial and marine ecosystem collapses in the southwestern USA and southwestern Australia. In *Ecosystem Collapse and Climate Change* (eds JG Canadell, RB Jackson) pp. 187-217. Springer Nature, Cham, Switzerland

Ruthrof KX, Steel E, Yates R, Skinner P, Ballard N, De Prato L et al. (2021). Responses to controlled release potassium fertilisers in agriculture following phosphate mining. *Soil Research* **59** 727-736

Rycken SJE, Warren KS, Yeap L, Donaldson R, Mawson P, Dawson R et al. (2022). Forest specialist species in the urban landscape: do different levels of urbanization affect the movements of forest red-tailed black cockatoos (*Calyptorhynchus banksii naso*)? *Avian Conservation and Ecology* **17**: 11

Rye BL (2021). *Austrobaeckea*, a new south-western Australian genus of Myrtaceae: (Chamelaucieae: Hysterobaeckeinae). *Nuytsia* **32** 173-197

Saccò M, Blyth AJ, Venarsky M, Humphreys WF (2022). Trophic interactions in subterranean environments. In *Encyclopedia of Inland Waters* Second Edition pp. 1-11

Carter L, Mankad A, Campbell S, Ruscoe W, Oh KP, Brown PR et al. [Byrne M] (2022). Conditions for investment in genetic biocontrol of pest vertebrates in Australia. *Frontiers in Agronomy* **3**: 806569

Sampson J, Tapper S, Coates D, Hankinson M, McArthur S, Byrne M (2022). Genetic diversity and differentiation in south-western Australian bloodwoods (*Corymbia* section *Calophyllae*, Myrtaceae) with different ranges and abundance. *Australian Journal of Botany* **70** 146-157

Saunders BJ, Galaiduk R, Inostroza K, Myers EMV, Goetze JS, Westera M et al. (2021). Quantifying patterns in fish assemblages and habitat use along a deep submarine canyon-valley feature using a remotely operated vehicle. *Frontiers in Marine Science* **8**: 608665

Saunders D, Nguyen H, Cowen S, Marsh K, Bell S, Magrath M et al. (2022). Radio-tracking wildlife with drones: a viewshed analysis quantifying spatial benefits across diverse landscapes. *Wildlife Research* **49** 1-10

Saunders DA, Mawson PR, Dawson R, Johnstone RE, Kirkby T, Warren K et al. [Williams MR, Yates CJ, Burbidge AH] (2021). Carnaby's black-cockatoo *Zanda latirostris* Carnaby, 1948. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 402-407. CSIRO Publishing, Melbourne

Schmölz K, Pinder A, Kuchling G, Gollmann G (2021). Evaluating candidate wetlands for the assisted colonization of the western swamp turtle *Pseudemydura umbrina* in a changing climate: macro-invertebrate food resources and turtle diet. *Aquatic Conservation: Marine and Freshwater Ecosystems* **31** 1847-1858

Schneider L, Tucker AD, Vincent K, Fossette S, Young EJ, Whiting SD (2022). First assessment of mercury (Hg) concentrations in skin and carapace of flatback turtles (*Natator depressus*) (Garman) from Western Australia. *Frontiers in Environmental Science* **10**: 843855

Schultz N, Duncan C, Good M, Lewandrowski W, Cook S (2021). The risk takers and risk avoiders: germination sensitivity to water stress in an arid zone with unpredictable rainfall. In *Australasian Seed Science Conference, 6th-10th September 2021* pp. 27

Seidlitz A, Bryant KA, Armstrong NJ, Calver MC, Wayne AF (2021). Sign surveys can be more efficient and cost effective than driven transects and camera trapping: a comparison of detection methods for a small elusive mammal, the numbat (*Myrmecobius fasciatus*). *Wildlife Research* **48** 491-500

Seidlitz A, Bryant KA, Armstrong NJ, Wayne AF (2022). Animal detections increase by using a wide-angle camera trap model but not by periodically repositioning camera traps within study sites. *Pacific Conservation Biology* **28** 25-35

Severova EE, Rudall PJ, Macfarlane TD, Krasnova ED, Sokoloff DD (2022). Pollen in water of unstable salinity: evolution and function of dynamic apertures in monocot aquatics. *American Journal of Botany* **109** 500-513

Shaw R, Spencer P, Gibson L, Moritz C, Durrant B, Mokany K et al. [Byrne M, Ottewell K] (2021). A landscape approach to northern quoll conservation: from mechanism to process. In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 75

Shaw R, Spencer P, Gibson L, Moritz C, Durrant B, Mokany K et al. [Byrne M, Ottewell K] (2021). Ecological processes driving landscape-scale patterns in the Pilbara mammal community. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 98-99

Shelton LRJ, Thiele KR (2022). *Drummondita billyacatting* (Rutaceae), a new, range-restricted species from Western Australia. *Nuytsia* **33** 19-27

Shepherd K (2021). Managing health and a work/life balance in research and academia: myth or reality? In *Biodiverse Futures: Systematics in A Changing World, 12-16 July 2021, Virtual: Annual Conference of the Australasian Systematic Botany Society* pp. 26

Shepherd KA (2022). Ethical authorship. *Australasian Systematic Botany Society Newsletter* **191** p. 25-29

Shepherd KA, Wilkins CF (2021). A revision of *Lasiopetalum* (Malvaceae: Byttnerioideae) from the northern sandplains of Western Australia, including two new species. *Nuytsia* **32** 121-149

Silcock J, Collingwood T, Llorens T, Fensham R (2021). Introducing *The Action* plan for Australia's imperilled plants 2021. *Australasian Plant Conservation* **30(1)** 3-9

Sims C, Cowen S, Friend T, Comer S, Gibson Vega A, Garretson S, Gibson L (2022). Monitoring source populations of fauna for the Dirk Hartog Island National Park Ecological Restoration Project, 2021. Department of Biodiversity, Conservation and Attractions, Woodvale, W.A. 27 p.

Sims C, Rayner K, Knox F, Cowen S (2021). A trial of transmitter attachment methods for Shark Bay bandicoots (*Perameles bougainville*). *Australian Mammalogy* **43** 359-362

Sinclair E (2021). Out of sight: take a look underwater. *For People & Plants* Special Issue 36-37

Singor MJC, Elson S, Burbidge AH, Garnett ST (2021). Western hooded plover *Thinornis cucullatus tregellasi* (Mathews, 1912). In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 254-256. CSIRO Publishing, Melbourne

Skates L (2021). How to conserve Australia's flora: Kings Park scientists contribute to national guidelines. *For People & Plants* **117** 27-29

Skates L (2022). Summer scholars explore science at Kings Park. *For People & Plants* **118** 24-29

Skroblin A, Teunissen T, Peters A, Greatwich B, Legge SM, Burbidge AH et al. (2021). Southern eastern bristlebird *Dasyornis*

brachypterus brachypterus Latham, 1801. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 501-504. CSIRO Publishing, Melbourne

Sommerville KD, Bunn E, Rollason A, Turner SR (2021). Tissue culture. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 279-305. Australian Network for Plant Conservation, Canberra

Sommerville KD, Errington G, Funnekotter B, Newby Z-J (2021). Identifying and conserving non-orthodox seeds. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 159-186. Australian Network for Plant Conservation, Canberra

Southwell D, Skroblin A, Moseby K, Southgate R, Rogers D, Copley P et al. [Dziminski MA] (2022). Designing a track-based monitoring program to detect changes in species occupancy in the deserts of South Australia: Arid Zone Monitoring Project. 9 p. National Environmental Science Programme, Threatened Species Recovery Hub, Canberra

Steven B, Hyde J, La Reau JC, Brackney DE (2021). The axenic and gnotobiotic mosquito: emerging models for microbiome host interactions. *Frontiers in Microbiology* **12**: 714222

Stevens E, Hyde J, Beesley L, Thompson S, Morris L, Gleeson D (2021). Monitoring fish assemblages in the Canning River: establishing environmental DNA as a monitoring tool and determining a best practice protocol. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 12-13

Stevens J (2021). The United Nations Decade on Ecosystem Restoration. *For People & Plants* Special Issue 4-5

Stevens J, Ritchie A (2021). Model partnership restoring banksia woodland. *For People & Plants* Special Issue 24-25

Stobo-Wilson AM, Murphy BP, Crawford HM, Dawson SJ, Dickman CR, Doherty TS et al. [Palmer R] (2021). Sharing meals: predation on Australian mammals by the introduced European red fox compounds and complements predation by feral cats. *Biological Conservation* **261**: 109284

Stobo-Wilson AM, Murphy BP, Legge SM, Caceres-Escobar H, Chapple DG, Crawford HM et al. [Palmer R] (2022). Counting the bodies: estimating the numbers and spatial variation of Australian reptiles, birds and mammals killed by two invasive mesopredators. *Diversity and Distributions* **28** 976-991

Stobo-Wilson AM, Murphy BP, Legge SM, Chapple DG, Crawford HM, Dawson SJ et al. [Palmer R] (2021). Reptiles as food: predation of Australian reptiles by introduced red foxes compounds and complements predation by cats. *Wildlife Research* **48** 470-480

Stover R-A, Mills H, Davis R, Cowen S, Hopkins A (2021). Assessing the dietary impacts of the translocation of hare-wallabies to a designed island ecosystem. 1 p. Edith Cowan University, Joondalup, W.A

Stover R-A, Mills H, Davis R, Cowen S, Hopkins A (2021). Assessing the dietary impacts of the translocation of hare-wallabies to a novel island ecosystem. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* p. 74. Conference Organising Committee, Perth

Stover R-A, Mills H, Davis R, Cowen S, Hopkins A (2021). Assessing the dietary impacts of the translocation of hare-wallabies to a novel island ecosystem. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 74-75

Stover R-A, Mills H, Davis R, Cowen S, Hopkins A (2021). Assessing the dietary impacts of the translocation of hare-wallabies to a novel island ecosystem. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 234

Sun R, McArthur S, Prada D, Ottewell K (2021). Non-invasive genetic monitoring using scats reveals spatio-temporal habitat usage of the ghost bat in Pilbara, Western Australia. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 34

Sun R, Ottewell K, McArthur S (2021). Cave use by the ghost bat (*Macroderma gigas*) in the Brockman mining precinct. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 38 p.

Swann G, Davis R, Bruton M, Burbidge AH, Garnett ST (2021). Western partridge pigeon *Geophaps smithii blaauwi* Mathews, 1912. In *The Action Plan for Australian Birds 2020* (eds ST Garnett, GB Baker) pp. 47-50. CSIRO Publishing, Melbourne

Tangney R, Merritt DJ, Miller BP (2021). How seed traits influence seed fates in fire-prone ecosystems. In *13th Triennial Meeting of the International Society for Seed Science, 9-13th August 2021: Programme and Abstract Book* pp. 56

Tangney R, Merritt DJ, Miller BP (2022). Environmental factors driving seed hydration status of soil seed banks and the implications for post-fire recruitment. *Frontiers in Plant Science* **12** 1-10

Tangney R, Miller R, Fontaine J, Veber W, Ruthrof K, Miller B (2022). Fuel dynamics in Banksia woodlands. *Department of Biodiversity, Conservation and Attractions, Kensington, W.A. Information sheet* **108/2022** 2 p.

Tangney R, Miller R, Fontaine J, Veber W, Ruthrof K, Miller B (2022). Vegetation structure and fuel dynamics in fire-prone, Mediterranean-type Banksia woodlands. *Forest Ecology and Management* **505**: 119891

Tangney R, Paroissien R, Le Breton T, Thomsen A, Doyle C, Ondik M et al. [Miller R, Miller B] (2021). Fire season affects plant recovery following fire: evidence from a global meta-analysis. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 27

Tangney R, Paroissien R, Le Breton TD, Thomsen A, Doyle CAT, Ondik M et al. [Miller RG, Miller BP] (2022). Success of post-fire plant recovery strategies varies with shifting fire seasonality. *Communications Earth & Environment* **3**: 126

Thiele K (2021). Guinea flower (*Hibbertia proberae*). *Landscope* **37(1)** 35

Thomson VA, Wiewel AS, Palmer R, Hamilton N, Algar D, Pink C et al. (2022). Genetic insights into the introduction history of black rats into the eastern Indian Ocean. *Frontiers in Ecology and Evolution* **9**: 786510

Thorn S, Maxwell M, Ward C, Wayne A (2021). Remote sensor camera traps provide the first density estimate for the largest natural population of the numbat (*Myrmecobius fasciatus*). In *67th Annual Scientific Meeting of the Australian Mammal Society Virtual 2021: Conference Programme & Abstract List* pp. 80

Tiller C, Fletcher J, Comer S, Algar D (2021). Using activity and movement patterns to improve the rate of bait encounter during large-scale aerial baiting for feral cats. *Australasian Journal of Environmental Management* **28** 220-235

Tomlinson S, Smit A, Bateman PW (2022). The ecology of a translocated population of a medium-sized marsupial in an urban vegetation remnant. *Pacific Conservation Biology* **28** 184-191

Towers IR, Merritt DJ, Erickson TE, Mayfield MM, Dwyer JM (2022). Variable seed bed microsite conditions and light influence germination in Australian winter annuals. *Oecologia* **198** 865-875

Treloar S, Lohr C, Hopkins A, Davis R (2021). The potential for resource competition between the boodie (*Bettongia lesueur*) and

mala (*Lagorchestes hirsutus*) in the fenced Matuwa reserve, central Western Australia. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 35

Treloar S, Lohr C, Hopkins AJM, Davis RA (2021). Rapid population expansion of boodie (burrowing bettong, *Bettongia lesueur*) creates potential for resource competition with mala (rufous hare-wallaby, *Lagorchestes hirsutus*). *Ecological Management and Restoration* **22** 54-57

Tucker AD, Pendoley KL, Murray K, Loewenthal G, Barber C, Denda J et al. [Whiting SD] (2021). Regional ranking of marine turtle nesting in remote Western Australia by integrating traditional ecological knowledge and remote sensing. *Remote Sensing* **13**: 4696

Tudor E (2021). Thermal biology shows the way for post-mining restoration. *For People & Plants* **115** 30-33

Tuft K, Legge S, Frank ASK, James AI, May T, Page E et al. [Radford IJ] (2021). Cats are a key threatening factor to the survival of local populations of native small mammals in Australia's tropical savannas: evidence from translocation trials with *Rattus tunneyi*. *Wildlife Research* **48** 654-662

Turner S, Bunn E, Chia K, Lewandrowski W, Shade A, Viler M et al. [Elliott C] (2021). Nursery propagation of tubestock and restoration planting. In *Florabank Guidelines: Best Practice Guidelines for Native Seed Collection and Use* Second Edition pp. 13.1-13.38. Australian Network for Plant Conservation, Canberra

Turner SR, Bunn E (2021). Case study 7.6: Ecological insights provided through long-term burial and retrieval of seeds from the critically endangered *Symonanthus bancroftii (Solanaceae). In Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition *(eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 230-232. Australian Network for Plant Conservation, Canberra*

Umbrello L, Bullen R, Shaw R, McArthur S, Byrne M, van Leeuwen S et al. [Ottewell K] (2021). Conservation genomics of a threatened bat (*Rhinonicteris aurantia*) in an arid biodiversity hotspot. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 27-28

Valentine L, Ruthrof K (2021). Do quenda benefit bushland regeneration after fire? 1 video. University of Western Australia, Crawley, W.A.

van der Merwe M, Broadhurst L, Coates D, Rossetto M (2021). Genetic guidelines for acquiring and maintaining collections for ex situ conservation. In *Plant Germplasm Conservation in Australia: Strategies and Guidelines for Developing, Managing and Utilising Ex Situ Collections in Australia* Third edition (eds AJM Yenson, CA Offord, PF Meagher et al.). pp. 55-83. Australian Network for Plant Conservation, Canberra

van Dongen R, Cowen S, Huntley B, Brennan K (2021). Measuring the impact of feral goat removal on island environments using satellite imagery. In *Biodiversity Conference 2021: Resilient Landscapes, 15-17 September 2021, Perth, WA: Program* pp. 9-10

van Dongen R, Ruscalleda Alvarez J, Sinclair K, Zdunic K, Rampant P (2021). Great Victoria Desert vegetation monitoring report 2020-21. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 21 p.

Vaughan-Higgins RJ, Vitali SD, Sims C, Page M, Reiss A (2021). Streamlining disease risk analysis for wildlife using the Shark Bay bandicoot as a model. *Ecohealth* **18** 13-30

Verbeke BA, Lamit LJ, Lilleskov EA, Hodgkins SB, Basiliko N, Kane ES et al. [Rutherford J] (2022). Latitude, elevation and mean annual temperature predict peat organic matter chemistry at a global scale. *Global Biogeochemical Cycles* **36**: e2021GB007057

Walsh CAJ, Momigliano P, Boussarie G, Robbins WD, Bonnin L, Fauvelot C et al. (2022). Genomic insights into the historical and contemporary demographics of the grey reef shark. *Heredity* **128** 225-235

Walters SJ, Robinson TP, Byrne M, Wardell-Johnson GW, Nevill P (2021). Association of putatively adaptive genetic variation with climatic variables differs between a parasite and its host. *Evolutionary Applications* **14** 1732-1746

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

Waudby HP, Turner JM, Coulson G, Taggart DA, Watson D, Bengsen AJ et al. [Dunlop J] (2022). Wildlife capture methods. In *Wildlife Research in Australia: Practical and Applied Methods* (eds B Smith, H Waudby, C Alberthsen et al.) pp. 108-149. CSIRO Publishing, Collingwood, Vic

Wayne A, Maxwell M, Barrett A, Potts J (2022). A survey of ngwayir (western ringtail possum) in the Upper Warren, Western Australia, to inform a potential translocation to the Perup Sanctuary. Department of Biodiversity, Conservation and Attractions, Kensington, W.A. 29 p.

Wayne A, Maxwell M, Potts J, Barrett A, Geary B (2022). Ngwayir associations with management and environmental factors in the upper Warren. Department of Biodiversity, Conservation and Attractions, Manjimup, W.A. 58 p.

Webster CL, Kilminster KL, Sánchez Alarcón M, Bennett K, Strydom S, McNamara S et al. (2021). Population-specific resilience of *Halophila ovalis* seagrass habitat to unseasonal rainfall, an extreme climate event in estuaries. *Journal of Ecology* **109** 3260-3279

Wege JA (2022). *Stylidium milleri* (Stylidiaceae), a striking discovery from south-western Australia. *Nuytsia* **33** 15-18

West KM, Adam AAS, White N, Robbins W, Barrow D, Lane A et al. (2022). The applicability of eDNA metabarcoding approaches for sessile benthic surveying in the Kimberley region, north-western Australia. *Environmental DNA* **4** 34-49

Whelehan LM, Funnekotter B, Bunn E, Mancera RL (2022). The case for studying mitochondrial function during plant cryopreservation. *Plant Science* **315**: 111134

White D, Comer S, Wayne A (2021). Understanding genomic variation in the western ringtail possum and its application to effective conservation management: final report. NESP Threatened Species Recovery Hub, Brisbane 34 p.

Williams AAE (2021). Spotted jezebels. *Bushland News* **120** p. 34

Williams AAE, Williams MR (2021). News of some newly described sun-moths (Lepidoptera: Castniidae) from south-western Western Australia. *Western Australian Insect Study Society Newsletter* **Oct** p. 7-12

Williams AR (2022). *Austrostipa* (Poaceae) in Western Australia: new species, new records, keys, and character notes. *Nuytsia* **33** 39-101

Williams MR, Lamont BB, He T (2022). Dealing with the spectre of spurious correlations: hazards in comparing ratios and other derived variables with a randomization test to determine if a biological interpretation is justified. *Oikos* **2022**: e08575

Williamson SD, van Dongen R, Trotter L, Palmer R, Robinson TP (2022). Fishing for feral cats in a naturally fragmented rocky landscape using movement data. *Remote Sensing* **13**: 4925

Wilson L, van Dongen R, Cowen S, Robinson TP (2022). Mapping restoration activities on Dirk Hartog Island using remotely piloted aircraft imagery. *Remote Sensing* **14**: 1402

Wilson P, Pendoley K, Whiting SD, Pattiaratchi C, Meekan M, Thums M (2022). Response of turtle hatchlings to light emitting diodes at sea. *Marine and Freshwater Research* **73** 689-702

Wilson S, Holmes T (2022). How important are seaweed habitats for small-scale tropical fisheries? *Ningaloo Coast News* **Autumn** p. 2

Wynne JJ, Howarth FG, Mammola S, Ferreira RL, Cardoso P, Di Lorenzo T et al. [Venarsky MP] (2021). A conservation roadmap for the subterranean biome. *Conservation Letters* **14**: e12834

Yates CJ, Barrett S, Dilly M, Hopper SD, Stewart B, Williams MR (2021). Modelling the impact of canker disease and fire regimes on the population dynamics and extinction risk of the critically endangered and granite endemic shrub *Banksia verticillata* R.Br.. *Australian Journal of Botany* **69** 274-284

Zdunic K, Rampant P, Chapman J, van Dongen R, Murray K (2021). Linking drones to satellites: measuring and monitoring vegetation attributes. In *Ecological Society of Australia, 2021 National Conference: Book of Abstracts: held online from 22-26 November 2021* pp. 219-220

Zhou C, Keesing J, Serrano O, Werner A, Fang Y, Chen Y et al. [Kinloch J] (2022). Wildfires enhance phytoplankton production in tropical oceans. *Nature Communications* **13**: 1348

Summary of Research Projects

Biodiversity Information Office

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South Coast	Esperance Plains	South Coast	Is restoration working? An ecological genetic assessment	31
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	46

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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	40
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Kimberley, Pilbara, Swan, South Coast, South West, Warren	Victoria Bonaparte, Northern Kimberley, Central Kimberley, Dampierland, Gascoyne, Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Esperance Plains, Warren	Rangelands, Northern Agricultural, Swan, South West, South Coast	Taxonomic review and floristic studies of the benthic marine algae of north-western Australian and floristic surveys of Western Australian marine benthic algae	42
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All Regions	All IBRA Regions	All Regions	Taxonomy of undescribed taxa in the Ericaceae subfamily Styphelioideae, with an emphasis on those of conservation concern	39
All Regions	All IBRA Regions	All Regions	The Western Australian Herbarium specimen database	35
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	The Western Australian Plant Census and Australian Plant Census	34
Kimberley, Pilbara, Midwest, Swan, South Coast, South West, Warren	Victoria Bonaparte, Northern Kimberley, Central Kimberley, Dampierland, Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Esperance Plains, Warren	Rangelands, Northern Agricultural, Swan, South West, South Coast	The Western Australian marine benthic algae online and an interactive key to the genera of Australian marine benthic algae	43
Midwest, Goldfields, Wheatbelt, Swan, South Coast, South West	Gascoyne, Geraldton Sandplains, Avon Wheatbelt, Jarrah Forest, Esperance Plains	Rangelands, Northern Agricultural, Avon, Swan, South West, South Coast	The population ecology of critically endangered flora	47
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	45

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	58
All Regions	All IBRA Regions	All Regions	Evaluating the application of eDNA and metabarcoding as biodiversity and monitoring tools	52

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
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	57
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	Jarrah Forest		Investigating the causes of change in forest condition	56
Swan	Swan Coastal Plain	Swan	Lifeplan: A planetary inventory of life	53
Swan, Warren	Jarrah Forest, Warren	Swan, South West	Long-term stand dynamics of regrowth forest in relation to site productivity and climate	63
Warren	Jarrah Forest, Warren	South West	Responses of terrestrial vertebrates to timber harvesting in the jarrah forest	61
All Regions	All IBRA Regions	All Regions	Taxonomy, zoogeography and conservation status of aquatic invertebrates	59
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	54
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	60

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	55
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Western Australian flora surveys	62
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Western Australian wetland fauna surveys	64

Marine Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
			Benefits of marine parks for marine fishes in a changing climate	69
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	75
Pilbara	Ningaloo		Do marine reserves adequately represent high diversity cryptobenthic fish assemblages in a changing climate?	71
Pilbara	Pilbara, Pilbara (Offshore)	Rangelands	Habitat use, distribution and abundance of coastal dolphin species in the Pilbara	74
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	77
Pilbara	Pilbara, Pilbara (Nearshore)	Rangelands	Long-term monitoring in the area of the proposed Dampier Archipelago marine reserves	74
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Marine monitoring program	80
Kimberley, Pilbara	Northwest Shelf	Rangelands	North West Shelf Flatback Turtle Conservation Program	81
Pilbara	Pilbara, Pilbara (Nearshore)	Rangelands	Primary productivity and energy transfer between marine ecosystems.	70

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
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	78
Kimberley	All IMCRA Regions	Cocos Keeling Islands, Rangelands	Understanding movements and identifying important habitats of sea turtles in Western Australia	79
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	72
Kimberley	Oceanic Shoals, Bonaparte Gulf, Kimberley, Northwest Shelf, Cambridge-Bonaparte, Canning, King Sound, Eighty Mile Beach	Rangelands	WAMSI 2: Kimberley Marine Research Program	82

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	91
All Regions	All IBRA Regions	All Regions	Development of a systematic approach to monitoring and reporting on the outcomes of prescribed burns and bushfires	85
Swan	Geraldton Sandplains, Swan Coastal Plain	Northern Agricultural, Swan	Evaluation of synergies among fire and weed management in urban biodiversity and fire management	86
Goldfields, Wheatbelt, South Coast	Yalgoo, Avon Wheatbelt, Coolgardie, Mallee	Wheatbelt, Rangelands	Fire regimes and impacts in transitional woodlands and shrublands	90
	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

Kings Park Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Conservation biotechnology	98
All Regions	All IBRA Regions	All Regions	Conservation genetics	95
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	97
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Restoration science	94
All Regions	All IBRA Regions	All Regions	Seed science	93

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	103
Swan	Swan Coastal Plain	Swan	Behavioural observations of Perth Zoo collection animals for animal welfare purposes and establishment of baseline data	102
Midwest, Swan, South Coast	Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Esperance Plains	Northern Agricultural, Swan, South Coast	Dibbler breed for release program	105
Swan	Swan Coastal Plain	Swan	Memory of recent actions in large-brained mammals (*Elephas maximus*)	102
Wheatbelt, Swan, Warren	Avon Wheatbelt, Swan Coastal Plain, Jarrah Forest, Warren	Northern Agricultural, Swan, South West	Numbat breed for release program	106
Swan	Swan Coastal Plain	Swan	Olfactory and auditory based behavioural enrichment for Perth Zoo's Asian elephants	101

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
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	106
Swan, South Coast	Swan Coastal Plain, Mallee, Esperance Plains	Swan, South Coast	Western ground parrot husbandry	100
Swan, Warren	Geraldton Sandplains, Swan Coastal Plain, Jarrah Forest, Warren	Swan, South West	Western swamp tortoise breed for release program	104

Rivers and Estuaries Science

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
Swan	Swan Coastal Plain	Swan	Algal blooms: investigations and control	114
Swan	Swan Coastal Plain	Swan	Apply acoustic technologies to investigate fish communities and movement	108
Swan	Swan Coastal Plain	Swan	Incident investigations, response and advice	112
Swan	Swan Coastal Plain	Swan	Investigate habitat connectivity in relation to environmental flows and barriers	109
Swan	Swan Coastal Plain	Swan	Investigating fish communities as an indicator of estuarine condition	115
			Investigations of contaminants in the Swan Canning	111
Swan	Swan Coastal Plain	Swan	Model frameworks for estuarine reporting	116
Swan	Swan Coastal Plain	Swan	Seagrass monitoring and evaluation	113
Swan	Swan Coastal Plain	Swan	Swan Canning Water Quality Monitoring	110

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	118
Midwest	Yalgoo, Shark Bay	Rangelands	Dirk Hartog Island vegetation monitoring	125
All Regions	All IBRA Regions	Rangelands, Northern Agricultural, Avon, Swan, South West, South Coast	Remote sensing and spatial analysis for fire management	120
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Remote sensing monitoring	123
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Spatial analysis and modelling	122
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Spatial data management	119

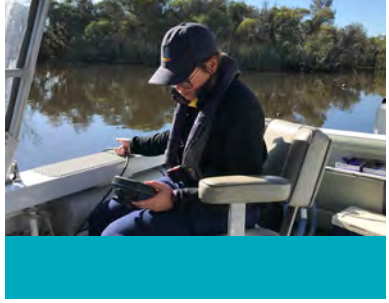
Species and Communities

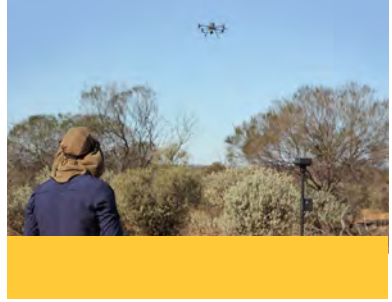
DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Ecological communities conservation and recovery	127
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Fauna conservation and recovery	132
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Flora conservation and recovery	130
All Regions	All IBRA Regions	All Regions	Off-reserve conservation	129
All Regions	All IBRA Regions	All Regions	Wetland conservation	126

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

DBCA Region	IBRA/IMCRA	NRM Region	Project Title	Page
All Regions	All IBRA Regions, All IMCRA Regions	All Regions	Online GIS biodiversity mapping (*NatureMap*)	135





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