Arid Zone Monitoring Project Report

Threatened Species Recovery Hub

National Environmental Science Programme

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This report provides an overview of the project. Note that specific outputs from the project, including shorter reports, species profiles, and scientific articles, which are hyperlinked in the report, will often have different author lists.

Cover images: Top- S. Legge, Bottom left- J. Hausheer, Centre: A. Stow, S. Right- Shultz, H. Bannister

Contents

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The Arid Zone Monitoring Project area encompasses the lands of many Indigenous groups: we acknowledge these Traditional Owners and their ongoing custodianship of Country and pay respects to their past and present Elders.

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The Arid Zone Monitoring Project distils the very large collective effort of many people – Traditional Owners, Indigenous rangers, university researchers, consultants, and government staff - who live and work in Australia's deserts. It has been a privilege for the project team to be a small part of their deep commitment to caring for Australia's deserts.

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Organisation	Contact names
Data providers	
SA government	Dan Rogers, Cat Lynch, Peter Copley
SA Arid Lands Landscape Region	Rob Brandle
Alinytjara Wilurara Landscape Region	Brett Backhouse
WA DBCA	Martin Dziminski, Lesley Gibson, Stephen van Leeuwen (previous role)
Envisage Environmental Services	Rick Southgate
Arid Recovery	Katherine Tuft, Katherine Moseby
Ex SA gov data supplier; Wild Deserts	Reece Pedler
Save the Bilby	Kevin Bradley
Australian Wildlife Conservancy	Danae Moore, Jeff Foulkes, David Roshier, Keith Bellchambers
Kiwirrkurra, Desert Support Services	Rachel Paltridge, Kate Crossing, Angie Reid

Organisation	Contact names
Data providers	
Central Land Council; 11 ranger groups: Anangu Luritjiku RangersAngas Downs Rangers Anmattyerr Rangers Kaltukatjara Rangers Ltyentye Apurte Rangers Muru-Warinyi Ankkul Rangers Tjarkura Rangers Warlpiri Yuendemu Rangers Warlpiri Willowra Rangers Warlpiri North Tanami Rangers Warlpiri Newhaven Rangers	Laurie Tait, Peter Donohoe, Sam Rando, Kim Webeck Danae Moore, Kim Webeck
Kanyirninpa Jukurrpa	Tracy Carboon, Tristan Cole
Nyikina Mangala	Damien Giles, Hamish Brace
Yawuru IPA	Mike Wysong, Julie Melbourne, Dean Mathews
Karajarri IPA	Sam Bayley, Ewan Noakes, Jackie Wemyss, Jesse Ala'i, Courtney Brown, Braedon Taylor, Jacqueline Shovellor
Bardi Jawi IPA	Daniel Oades, Bibido McCarthy, Damon Pyke
Nyul Nyul Rangers	Preston Cox, Neil Hamaguchi
Ngurrara IPA	Kevin Tromp, Frankie McCarthy, Chantelle Murray
Paruku IPA	Jamie Brown, Zack Wundke
Nyangumarta IPA	Ben Puglisi, Jake Loughbridge, Cenette Cadafalch; José Kalpers
Ngururrpa IPA	Kate Crossing, Eric Moora, Nathaniel Stretch, Angie Reid
Birriliburu IPA	Stella Shipway, Jessica Chapman
Wiluna rangers, Matuwa Kurrara Kurrara IPA	Dorian Moro
Ngaanyatjarra IPA (Blackstone Rangers, Warburton Rangers, Warakurna Rangers)	Alex Knight, Jenny Timbs, Hannah, Francois Mazieres, Bryony Nicholson
APY Land Management, including Walalkarra Rangers	Pip Mawby, Caro Silva, Wayne Davies, Neil Collins, Pippa Lyons, Ellen Colton-Ryan
Oak Valley Rangers, Maralinga Tjarutja AC	Ben Deslanders, Sam Doudle
Maralinga long walks	Joe Benshemesh, Malleefowl Recovery Team
Broome Bird Observatory	Nigel Jackett
Sheffield Resources	Gayle Williams
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Environs Kimberley	Malcolm Lindsay, Hamsini Bijlani
WWF Kimberley	Ellie Boyle, Leigh-Ann Woolley
WA Rangelands NRM	Chris Curnow
Indigenous Desert Alliance/ 10 Deserts	Sam Doudle (ex), Lindsey Langford, Hannah Cliff, Gareth Catt, Peter See (ex)
NT DENR	Brydie Hill
Bush Heritage Australia	Rebecca Spindler, Cissy Gore-Birch
Atlas of Living Australia	Peter Brenton, Peggy Newman, Martin Westgate
NESP TSR Hub Indigenous Reference group	Cissy Gore-Birch, Ollie Costello, Stephen van Leeuwen, Gerry Turpin, Teagan Goolmeer, Brad Moggridge

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Data management and access

The project collated and curated 69 datasets from 37 data providers. Data were shared with the project under the provisions of data licences with each data provider. The collated dataset is stored securely by the project team and is not publicly accessible. These data remain the Intellectual Property of each data provider, and cannot be shared with other parties either within, or external to the project. If you have questions about the data in this report, contact AridZoneMonitoring@gmail.com.

In the maps presented in this report, spatial information for all species is de-identified to at least one-degree spatial resolution, but usually more, as per the data licences. Data licences have a provision to allow data providers to request that some data not be displayed at all; no data providers have chosen to use this provision.

The data licences acknowledge that Research Outputs from the collated dataset may be made available under open licensing arrangements, whilst adhering to the requirement not to disclose high resolution spatial information, and also to seek input and approval from data providers on these outputs.

Recording data during surveys, Karajarri Rangers. Image: N. Rakotopare

Executive Summary

The Arid Zone Monitoring Project aimed to encourage and support the use of track-based monitoring that can contribute to regional and national scale analyses of species distributions and trends, as well as fulfil local objectives for survey and monitoring. This aim had two elements: the project sought to collate and analyse existing data to explore what could be achieved when desert groups and individuals share data into a national dataset. The project also sought to provide guidance about future monitoring designs and data collection, to help people achieve their local, regional, and national objectives more effectively. With these foundational steps in place, people are more likely to continue to collect track-based survey data, but in a form that is more powerful for regional and national-scale analyses.

The AZM Project established that a large volume of track-based data has been collected (15,000 surveys, comprising 49,000 detections of 76 species), and that it is possible to collate these data despite considerable heterogeneity in survey objectives and data collection methods. The project has demonstrated that the collated data has value for describing species distributions and building species habitat suitability models, and that it can be used to investigate temporal trends if collected appropriately, and thus can also be used to inform, and report on, management. Finally, and most importantly, the project has shown that it is possible to build a large and diverse partnership, that produces useable data compilations and analyses whilst respecting the Intellectual Property and diverse interests of the partners.

With this groundwork in place, for the next phase of the project (subject to new funding), we recommend a new project governance model. The model involves leadership from an Indigenous organisation and partnerships with universities, state and Commonwealth governments, and NGOs, to implement a collaborative national monitoring program, that supports groups and individuals to meet their local objectives for track-based monitoring.

This report provides an overview of the project development, data sharing arrangements and the process of data collation and curation; it provides the summary statistics of the AZM National Dataset, and describes the key outputs generated from the data. These outputs, including shorter reports, species profiles, and scientific articles, are hyperlinked in the report. The report is organised into sections; the section summaries are presented below. Use the contents page, or alternatively click on the section headings below to navigate directly to each section.

Project development

- We engaged with over 40 groups and individuals to shape a project that was sensitive to the objectives and needs of desert groups who carry out track-based surveys. Thirty-seven different groups and people had datasets to contribute into a national dataset; we developed data licences to facilitate that sharing, whilst respecting intellectual property, confidentiality, and data sensitivities.
- We defined a project area that encompassed the areas on which data providers collected data. This covered 3,273,140 km^2 of central Australia, including arid and semi-arid areas, and small areas of the low rainfall tropics

Collating data into the Arid Zone Monitoring National Dataset

- We received 69 datasets form 37 data providers from across the project area. Data were collected by Indigenous rangers, government scientists, university scientists, NGOs, and consultants, using a variety of survey methods over the period from 1982 to 2020.
- Datasets arrived as excel worksheets, outputs from cybertracker or app-based data collection systems such as fulcrum, and as scans of hardcopy datasheets. The contributed datasets had

disparate structures, data fields, and naming conventions. Some records were duplicated across two or more datasets.

- We developed a workflow to bring all datasets into a consistent format and structure, with aligned data fields and a consistent naming convention. We also developed an approach to identifying and omitting duplicate records.
- From an interim dataset of 90,737 records, the data cleaning workflow produced a final set of 48,525 presence records, from 14,815 surveys carried out at 5363 unique sites. There were also 11,778 absence records; with duplicates removed, 4086 records remained from 454 surveys at 343 sites.

Scale of the Arid Zone Monitoring National Dataset

- The 5363 unique survey sites (with 48,525 presence records from 14,815 surveys) are spread across the project area, but with some sampling gaps.
- Most sites, site-visits, and records were contributed from South Australia, followed by Western Australia.
- Indigenous groups were responsible, or partly responsible, for the largest number of records and sites. NGO records are mostly from repeated visits over several years to a smaller set of sites.
- Data for 1982 to 2000 were all from the southern deserts, whilst the northern deserts contributed data collected from 2000 on.
- The number of unique sites sampled per decade was highest in 2000-09 and 2010-20.
- Earlier datasets tended to be provided by SA government agencies, whilst Indigenous, NGO and NRM groups tended to contribute data from the last two decades.

What species are recorded?

- The list of species detected, and the number of records for each, reflects that track-based surveys are most useful for medium to larger species with tracks that can be easily identified. The method therefore favours medium-large mammals (bilby/rabbit size and above), including introduced mammal species, followed by large reptile species, and large bird species.
- Some threatened species, rare species, and species significant to Traditional Owners, such as bilbies, great desert skinks, dusky hopping mouse, crest-tailed mulgara and perentie, were detected more often compared to other species, because they were the focus of some surveys.
- The AZM National Dataset contains 39,817 records that were identified to 76 individual species: 27 native mammal species, 11 introduced mammal species, 4 bird species and 34 reptile species.
- An additional 8708 records (18% of all records) were identified to genus, family, or some other grouping. The proportion of unidentified species varied among classes, being lowest for introduced mammals and highest for reptiles, with the latter due to the difficulty of discriminating between goanna species, and between small reptile species.
- Data from WA, NT and SA comprised higher species richness than data from QLD, reflecting that the project area includes a smaller proportion of QLD with a small number of surveys carried out in this jurisdiction.
- Data from Indigenous groups and government agencies included more species than data from other data providers, reflecting that these data providers have shared more data into the AZM National Dataset.

Species detection maps

- We created detection maps for each of the species recorded in the AZM National Dataset. These maps are available in the species profiles listed in Appendix 3.
- The maps showed that track-based surveys are useful for clarifying the distributional limits of species.
- The maps also reaffirmed that track-based surveys are not suitable for documenting the distributions of smaller-bodied species with non-unique tracks, nor species that prefer rocky habitats over sandy substrates.

Species detection rates across bioregions

- We produced a series of maps to explore coarse-scale spatial variation in detection rate for each species.
- For a subset of species, we also looked at changes in the bioregional detection rates over time. However, this was only possible for species that are reasonably common, whose sign is usually recorded if detected, and are not the subject of focussed surveys (e.g. spinifex hoping mice, cats, camels).
- The full set of detection maps, and graphs of changes in detections over time (if available) are included in the individual species profiles.

Species distribution model

- We used species distribution modelling (SDM) to predict suitable habitat for 30 species and 4 species groups across the project area, based on the presence records in the AZM National Dataset. The analysis considered climate variables like annual, seasonal and daily temperature and rainfall; landform variables like elevation and slope; soil variables, like clay content; and habitat variables like the amount and condition of vegetation (NDVI) and fire frequency.
- This mapping can help identify places that groups and individuals can target in future surveys.
- SDMs have been used to optimise the design for a regional monitoring program for South Australia.
- A subsequent iteration of the mapping, that combined the AZM data with data available from the Atlas of Living Australia, were used to identify gaps in the national coverage of track-based surveys that could be priorities for future sampling in regional and national-scale monitoring.

Trend analyses

- Many project partners are interested in changes in animal populations over time. To address this you need time series information, with sites re-surveyed several times over several years, otherwise the variability in species abundance across areas and time could be biased by changes in detection rates, giving the false impression of population trends.
- About three-quarters of AZM sites were only visited once, and a further 15% were only visited twice (over two different years), such that time series information from repeated visits to sites in different years is limited.
- We developed a pragmatic approach to enhancing the data utility, by looking for regions where the same 30 km^2 grid cell had been resampled over time, even if the exact location of the site within that grid cell had varied. With this approach, we identified six regions where sites had been re-surveyed at least five times over five or more years. For these regions, we were able to explore the climatic and environmental drivers for changes in detections for the more commonly detected species.

- The work also highlights that to understand changes in detections across a broader suite of species (including rarer species), and in priority areas, setting up a robust monitoring design from the outset that can provide the data needed is essential.

Designing a track-based monitoring program for South Australia

- We used existing survey data to model what drives differences in occupancy across the range of a species, and to estimate the detectability of each species. Occupancy is the proportion of sites that have sign of a species; detectability is the probability of seeing and recording sign, if the sign is there.
- Changes in occupancy were then simulated, and the statistical power of different monitoring designs was estimated. We used a 'spatially explicit' simulation as we aimed to predict occupancy across the whole study area, including in places that haven't been previously surveyed by AZM partners.
- We explored the outcomes of differing survey designs by changing the number of sites surveyed, the survey frequency (within and across years), and where sites were positioned in the landscape.
- Overall, we found that if we monitored approximately 200 sites every year (with a small subset re-surveyed twice within a year to improve detectability estimates), with those sites located to optimise detections for all species, we would detect moderate to marked declines in most priority species.
- Increasing the number of sites surveyed, and optimising their locations for both the rare and common species, would increase our power to detect changes.
- One alternative to surveying 200 sites every year, was to reduce survey frequency whilst also increasing the number of sites in the program.
- As well as informing monitoring design for the South Australian case study, the work provides general guidance for designing a large-scale, regional monitoring program using track-based surveys.

Improving future survey design and data collection

- We carried out a series of inter-related analyses on monitoring design and data collection, to support groups and individuals to carry out surveys that are optimal for their objectives, and to collect data efficiently and effectively.
- Working with the South Australian partners, we developed optimised designs for track-based monitoring in South Australia, finding that 200 sites are needed to have a high chance at detecting moderate to marked declines in the species of interest, with the placement of sites depending on the monitoring objective.
- We carried out a spatial analysis based to identify priority areas for expanding track-based surveys to support a national-scale monitoring program.
- Using a detailed dataset collect in the Maralinga Tjaṟutja Lands of the Alinytjara Wiluṟara NRM region of SA, we examined the drivers for variation in detectability across species to advise how many sites need to be revisited in a year, and how often, to estimate detectability reliably.
- Working with tracking experts, we surveyed the range of data collection templates in use and produced a streamlined data collection sheet with core data fields that would support national monitoring. We finessed the data collection sheet after a field trial with APY land Management.

Reporting back

- The project has been a collaboration between diverse partners with different objectives, and different reporting needs. The project team therefore adapted many of the outputs on a group by group basis, and shared results back with partners via workshops and online meetings.

- Some information was designed to be publicly available, and other outputs were shared solely with the data provider, to maintain data confidentiality provisions.

Conclusions and next steps

- The project has:
    - established that a large volume of track-based data has been collected and that it is possible to collate these data despite considerable heterogeneity in survey objectives and data collection methods;
    - demonstrated that the collated data can be used to describe species distributions, build species habitat suitability models, and investigate temporal trends if collected appropriately;
    - carried out analyses to scope future regional and nationally scaled monitoring programs for medium-large desert animals
    - provided guidance on future monitoring design and data collection to project partners; and
    - shown that it is possible to build a large and diverse partnership that produces useable data compilations and analyses, whilst respecting the Intellectual Property and diverse interests of the partners.
- With this foundation in place, the next step is to work with project partners to shape phase two of the project. This could aim to establish a national and collaborative monitoring program, based on a partnership between a lead Indigenous organisation, universities, governments, and NGOs.

Introduction - Arid Zone Monitoring Project

Arid deserts cover 17% of the world's land mass and support substantial biodiversity, including species that are exclusive to deserts (Safriel *et al.* 2005). Yet deserts attract less conservation investment and biodiversity monitoring and research attention than other biomes (Durant *et al.* 2012), even though they have experienced high rates of biodiversity loss (Durant *et al.* 2014; Soultan *et al.* 2019). Biodiversity loss is now being exacerbated by climate change effects that are occurring faster in deserts than forested and mountainous environments (Loarie *et al.* 2009). In Australia's deserts, approximately 60% of mammal species have become extinct in the past 250 years, and the distributional range of many other species are reduced, due to habitat degradation, changed fire regimes, and invasive herbivores and carnivores (Burbidge and McKenzie 1989; McKenzie *et al.* 2007; Woinarski *et al.* 2015). The attrition is continuing, and understanding the distribution and trends of native and invasive species is fundamental for conservation management (Legge *et al.* 2018; Likens and Lindenmayer 2018).

Monitoring animal populations in Australia's deserts is challenging. In these low productivity environments, desert species are often spread patchily over very large areas, and at very low densities (Morton *et al.* 2011). Many species are nocturnal and cryptic, so detecting individuals is difficult (Dickman *et al.* 2018). Populations of many species are nomadic, or go through cycles of boom and bust in response to infrequent rainfall events (Letnic and Dickman 2010; Yang *et al.* 2010), which can make it difficult to distinguish trends from natural fluctuations. The deserts are also remote, with limited access, especially after heavy rainfall, making monitoring logistically difficult and expensive.

Track-based surveys – systematic searches of animal tracks, scats and diggings - is a method that can be used to monitor populations of many desert animal species over large areas (Allen *et al.* 1996; Southgate *et al.* 2005; Southgate and Moseby 2008). The technique can be achieved at larger scales than trapping surveys, as it is simpler, cheaper (do not require a large time or equipment investment) and appropriate for detecting a broader range of species than aerial counts (Keeping *et al.* 2018; Lunney *et al.* 2018). More importantly, it builds on the strong tracking traditions of Indigenous people who are and continue to be the custodians of desert Country. Track-based surveys combine Indigenous tracking skills and interests into a methodological framework that allows for quantitative analysis (Keeping *et al.* 2018). Similarly, the efforts and incidental sightings from citizen scientists can also be incorporated into national scale survey designs (Benshemesh *et al.* 2018).

In western conservation science practices, track-based surveys have been used for over 40 years to survey for invasive and threatened species in Australia's deserts, for specific purposes. For example, track-based surveys were used in the Tanami Desert to record the distribution of the bilby *(Macrotis lagotis*), a nationally threatened marsupial (Southgate *et al.* 2005; Southgate *et al.* 2007). They were used to understand the influence of habitat and seasonality on the occurrence of medium-large mammals (Paltridge and Southgate 2001), and the influence of fire and predators on the distribution of the brush-tailed mulgara (*Dasycercus blythii*) (Masters *et al.* 1997). Track-based surveys were also used to map changes in distribution of the mulgara, dusky hopping mouse (*Notomys fuscus*) and other key species after the arrival of rabbit calicivirus (Pedler *et al.* 2016). Recently, track-based monitoring has been used to highlight the changes in fauna abundance inside and outside conservation fences (McGregor *et al.* 2020; Moseby *et al.* 2020), and to examine whether cat hunting by Traditional Owners can reduce cat activity around threatened mammal populations like the bilby (Paltridge *et al.* 2020).

Track-based surveys have become a widely-used tool for many Indigenous ranger groups. They provide opportunities for people to get out on Country, share skills, and knowledge, including from older generations to younger generations. Survey data can help direct management actions on Indigenous Protected Areas, and can be used in Healthy Country reporting (Kiwirrkurra IPA and Paltridge 2020). However, although much data collected by Indigenous Rangers and Traditional

Owners may be used to make day-to-day local-scale decisions, the majority is neither collated, curated nor analysed.

If track-based survey data could be collated from the many groups and individuals that use the technique, and if the data collection conformed to a robust standardised sampling design, the combined dataset could be used to describe species distributions and trends at regional and even national scales. This idea was discussed over many years during arid zone species recovery and biodiversity management meetings, and the case for it was compellingly made in a report by Southgate and Moseby (2008). The standardised data collection method advocated in that report (a fixed area, fixed time search) was also included in a field guide designed to encourage uptake of the technique (Moseby *et al.* 2009).

These discussions and initiatives helped to encourage Indigenous ranger groups and some NGOs to include track-based survey approaches in their work programs over the past two decades. However, these data have generally not been collated, nor have the surveys been coordinated across groups. Organisations, groups and individuals have used track-based surveys to achieve varied objectives, which has led to several variations of the method, and data that are collected during surveys. The Bilby Blitz in 2017-18 was a departure from this pattern; it was a large-scale survey effort targeting bilbies, coordinated across many ranger groups operating within the bilby distribution (Paltridge 2016). Data from these surveys have been partly collated. Nevertheless, the general lack of data collation, synthesis, and reporting has resulted in many ranger groups expressing frustration about collecting data that never seems to lead anywhere. This is the context that led to the Arid Zone Monitoring Project.

Broadly, the Arid Zone Monitoring Project aims to encourage the use of track-based monitoring that can contribute to local, regional and national scale analyses of species distributions and trends. The core component of this aim was to support groups and individuals who use track-based monitoring, especially Indigenous groups, in two ways. First, by collating and analysing existing data to demonstrate what could be achieved if desert groups share data into a national dataset. This was crucial because if rangers and Traditional Owners can't see what is possible through such a collaboration, it is harder for them to see the value in continuing to collect data. Second, to provide guidance about future monitoring design and data collection fields that are useful, to help groups achieve their local objectives more effectively. With these foundational steps in place, groups are more likely to continue to collect track-based survey data, but in a form that is more powerful for local, regional and national-scale analyses. In addition, the project carried out a series of analyses to understand the sampling effort required to establish regional and national coordinated monitoring programs that would track changes in the populations of key native species (including threatened species) and invasive species across the deserts.

Project Objectives

1. Develop an approach to collating multiple, diverse datasets into a one national dataset.
2. Investigate the value of this national dataset for describing species distributions, correlates of occurrence, changes over time, and other spatio-temporal patterns.
3. Identify the requirements (in terms of sampling effort and design) of using track-based monitoring to track species distributions and trends at a national scale.
4. Improve the value of future sandplot monitoring, by providing guidance to collaborators on sample design for differing objectives, key data fields, and where training in data collection might enhance data quality.
5. Showcase the work being carried out by many groups across the arid zone.

This report provides an overview of outputs delivered against these objectives. The report is the primary documentation for objectives 1 and 2, which are therefore covered in more detail here. Objectives 3 and 4 include outputs available as downloadable documents, including as scientific papers; in these cases, we provide a summary here, with links to those more detailed outputs. Objective 5 has been achieved by communicating widely and making much of the project material available via an interactive website (summarised at the end of the report). The report is lengthy, so use the contents page to navigate to topics of interest.

The acronym AZM is used throughout the report to denote Arid Zone Monitoring.

Talking about the Arid Zone Monitoring Project with rangers from the southern Kimberley and western deserts, at Lake Paruku. Image: J. Dielenberg.

Section 1 - Project development

Key points:

- *We engaged with over 40 groups and individuals to shape a project that was sensitive to the objectives and needs of desert groups who carry out track-based surveys. Thirty-seven different groups and people had datasets to contribute into a national dataset; we developed data licences to facilitate that sharing, whilst respecting intellectual property, confidentiality, and data sensitivities.*
- *We defined a project area that encompassed the areas on which data providers have been collecting data. This covers 3,273,140 km2 of central Australia, including arid and semi-arid areas, and small areas of the low rainfall tropics.*

1.1 Building the collaboration

We developed the project collaboration over two years, by iteratively discussing the project with people and groups associated with survey work in the deserts. The purpose of these discussions was to understand how the project could be most useful to project collaborators, to get a sense of what data were available, to understand what the data sharing sensitivities were, and to begin the process of developing formal data sharing arrangements.

The array of collaborators is diverse, and geographically dispersed. They include individual ranger groups, supporting Indigenous organisations, state agency staff, university researchers and consultants, and NGO staff. We made personal contact with each person and group and attended many desert gatherings (e.g. NRM meetings, conferences of the Indigenous Desert Alliance), to build relationships and refine the aims of the project collaboratively. We hosted focus workshops in some geographic areas where a shared discussion among those collaborators was needed.

Once each collaborator was ready to participate in the project, we developed data licences with them. The template licence included these provisions: that the data would remain the intellectual property of the data provider, and be held confidentially by the project; that the project outputs would not disclose the locations of sensitive species records; and that project collaborators would approve the project outputs, and be given the opportunity to be co-authors in any outputs. Some project partners requested minor variations to the licence template. Developing the data licence with any one partner took up to 18 months, especially if the authority to approve rested with a group that met infrequently. For example, some Prescribed Body Corporate boards, Traditional Owner Ranger Advisory Committees, and Indigenous Protected Area management committees meet only bi-annually or annually.

We developed data licences for 35 project partners (with 11 of those being with ranger groups administered by the Central Land Council, under one umbrella data licence). Two additional collaborators preferred to join the project and share data without having a data licence in place. The full set of partners that shared data into the project database are shown in Figure 1.

As well as building the collaboration with people and groups that hold track-based data, we also interacted with several organisations interested in the project outputs, and with organisations that support Indigenous land management.

1.2 Defining the project area

The project area was defined by using IBRA subregional boundaries, such that all sites in the contributed data were enclosed by the boundary. This resulting project area included all of Australia's sandy deserts, with an extension in the northwest to include the Pindanland subregion, in the Dampierland bioregion. A small extension was also made into the Augustus, Fortescue, and Chichester subregions (Gascoyne and Pilbara bioregions), in order to include sites surveyed by Martu people and Kanyirninpa Jukurrpa (Figure 1). Defining the project boundary is necessary for setting the 'environmental envelope' used in distribution modelling. The project area covered 3,273,140 km^2, including the major deserts of arid and semi-arid Australia, and a small part of the low rainfall tropics in northern Australia with suitable sandy tracking surfaces.

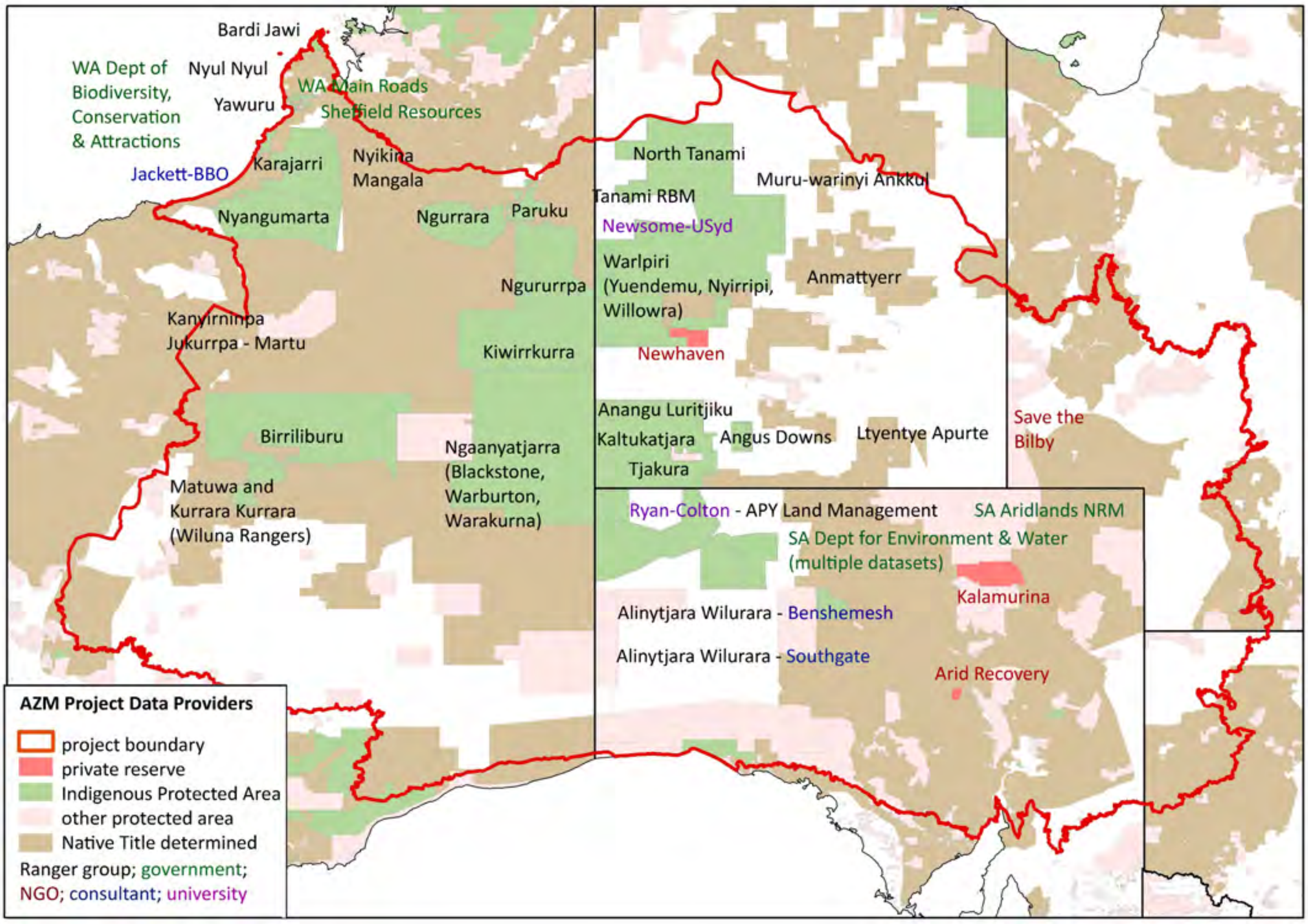


Figure 1: Map showing the locations of project collaborators that shared data, within the AZM project boundary.

Section 2 - Collating data into the Arid Zone Monitoring National Dataset

Key points:

- *We received 69 datasets form 37 data providers from across the project area. Data were collected by Indigenous rangers, government scientists, university scientists, NGOs and consultants, using a variety of survey methods over the period from 1982 to 2020.*
- *Datasets arrived as excel worksheets, outputs from cybertracker or app-based data collection systems such as fulcrum, and as scans of hardcopy datasheets. The contributed datasets had disparate structures, data fields, and naming conventions. Some records were duplicated across two or more datasets.*
- *We developed a workflow to bring all datasets into a consistent format and structure, with aligned data fields and a consistent naming convention. We also developed an approach to identifying and winnowing out duplicate records.*
- *From an interim dataset of 90,737 records, the data cleaning workflow produced a final set of 48,525 presence records, form 14,815 surveys carried out at 5363 unique sites. There were also 11,778 absence records; with duplicates removed, 4086 records remained from 454 surveys at 343 sites.*

Datasets were contributed by 37 data providers including Indigenous ranger groups, government scientists, university scientists, NGOs and consultants, who collected track-based data using a variety of survey methods over the period from 1982 to 2021. Their data collection aimed to meet a range of objectives, from surveys to describe occurrences of single species (and potentially changes over time) to general fauna surveys. Many datasets arose from programs that sought to provide opportunities for on-country trips and knowledge exchange. Some data were collected using standardised observational methods, such as the 2 ha plot searches, or road transects. Other data with species detections were collected opportunistically or using specialised trapping equipment. Given the diversity of data structures, data fields, and naming conventions, we developed a workflow to bring the information into a single dataset. There was also potential for duplicate records to exist across datasets, for example when data collectors had provided copies of their data to state depositories.

2.1 Classifying data received by the AZM project

To assist with data summary and analysis, we attributed datasets with consistent metadata:

- Dataset Identifier: Datasets were given a unique identifier to keep track of the origin of each record.
- Data provider: Datasets were received from across Australia from a range of data providers which we classified as either: Government (state government), Indigenous (including datasets that were jointly collected by Indigenous contributors with government or university contributors), Industry (consultancy, mining), NGO, Natural Resource Management group and University.
- Jurisdiction: The state or territory where surveys were carried out.

- Dataset typology: Datasets varied in terms of the collection methods used, and therefore the sorts of analyses they can be used for. A key division was between observational surveys (standardised and non-standardised) and surveys using specialised equipment, because these two approaches detect non-overlapping species sets, and data from specialised surveys were only available for a very small proportion of the AZM study area.

  Survey type: Datasets were classed into one of three survey types (Figure 2):

  - Observational surveys based on standardised methods;
  - Observational surveys that were not standardised (including incidental records);
  - Surveys using specialised trapping equipment or specimen collection.

  Sample type: Observational surveys using standardised methods were further classed into sample types as follows: 2 ha plots; 6 ha plots; sign-based transects (walking or driving); timed searches. Sample types for non-standardised surveys were classed as incidental, or unknown. Sample type for specialised surveys were classed as trapping or specimen collection (Figure 2).

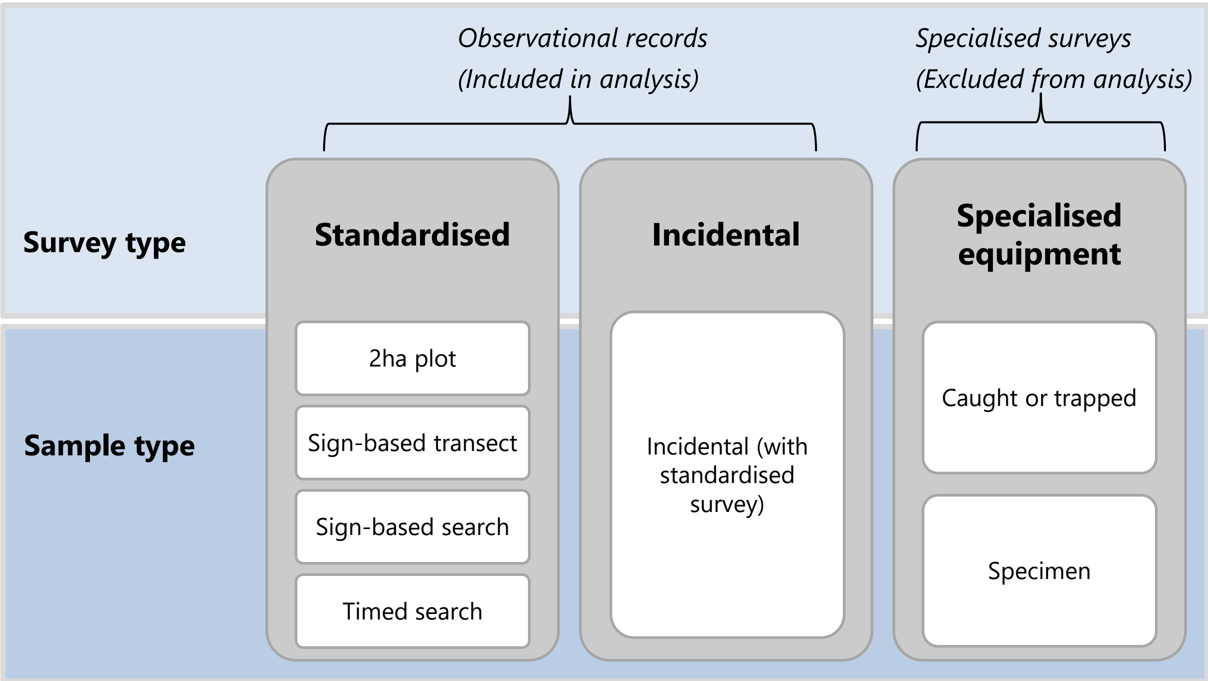


Figure 2: The types of contributed data classified by survey and sample type.

2.2 Data manipulation and cleaning workflow

Data were organised idiosyncratically both across and within datasets. Some datasets were internally very consistent in terms of structure and naming conventions, others contained considerable internal inconsistencies. To combine these various datasets, we needed bring all the data into a consistent format, and screen them to omit data that were unsuitable or erroneous (Figure 2; Appendix 1). Data manipulation and cleaning were performed with Microsoft Excel and through scripting with Program R. Expert knowledge was used to check species detections outside of their known distribution. Data were initially collated into an 'Interim Dataset'; we refer to the final, cleaned dataset as the 'AZM National Dataset'.

Step 1- Data reformatting:

Data submitted to the AZM project were reformatted to allow it to be imported into the Interim Dataset in a consistent format. The harmonisation of the data formats involved handling data supplied in varying software formats (e.g. Excel, pdf, scanned datasheets), and with varying spatial organisation. In some cases, data had to be re-arranged so that each observation in a dataset was represented in a unique row. We used the Tidy R package in Program R to transpose and mutate data into a standard format.

Step 2 - Consistency in species naming conventions:

We rationalised the naming conventions and names across the datasets, again using the Tidy R package. Submitted datasets identified species using common names, Latin names, shorthand names, language names or a mix of naming conventions. We grouped records of the same species and gave them a single, consistent common name (with its scientific equivalent) - for example: the label "Rabbit" is made up of records labelled as: "Rabbit (European Rabbit)", "Rabbit", "*Oryctolagus cuniculus*", "rabbit". Similarly, the label "Cow" is made up of records labelled as: "Cattle", "European cattle", "Bos sp.", "Cattle", "cattle", "*Bos taurus*", "*Bos taurus/Bos indicus*", "*Bostaurus*", "bullock", "cow", "Cow". Where possible, records that could not be identified to species were collapsed into genera or taxonomic groups. Some records with names that could not be rationalised were omitted from the AZM National Dataset. We chose to use common names as the primary key (with scientific names secondary) for ordering and displaying information as these names are more widely familiar to data providers than scientific names. See Appendix 1, Table S1.1, for details of species naming rationalisation.

Step 3 - Consistency in recording sign type conventions:

Submitted datasets included many different styles for recording sign types (Burrow, Digging, Track, Scat, Animal) and associated categories such as the age and abundance of sign. For example, animal records were often labelled as "TRUE", "FALSE", "yes", "no", "1" or "0" or by a descriptor of the age of sign (for instance "Fresh", "Old" etc). We standardised the language to 0 for no sign and 1 for a positive sign.

For each record, we applied a consistent convention for the age of sign. Of 88,276 suitable records 39,292 were recorded with age of sign attributes, and the remaining 48,984 records were unknown or missing age-attributed information. We grouped together all sign into categories of "fresh or 1-2 days old", "old or 3 days to 1 week", "very old or 2 weeks – 2 months", or "unknown or not recorded", using the Tidy R package.

Step 4 - Dataset typology:

Records were classed according to the survey type (observation based on standardised survey; observation from non-standardised survey; detection from survey with specialised equipment). Records derived from surveys with specialised equipment were excluded from the AZM National Dataset (Appendix 1, Table S1.2).

Step 5 - Data cleaning:

This step involves four processes:

1. We displayed the location of all survey sites and identified sites with misaligned spatial information, including:

- No spatial information.
- Sites in the ocean.
- Sites out of the usual operating area of the data provider.

In each case, we removed these sites from the dataset unless the location data could be verified or corrected (e.g. by conferring with the data provider). Data with no spatial information could sometimes be cross-checked with a validated data record. This is a common practice in data enhancement where data is made more complete by adding related information. If spatial data could not be added or repaired, the records were omitted from spatial analysis (Appendix 1; Table S1.3).

2. We examined data without a collection date:

For data that was submitted without a collection date, a 'placeholder' was used (1970) when including this data in the AZM National dataset. For summaries where date was required (i.e. spatial-temporal analyses and summaries), any data with the placeholder 1970 was omitted.

3. We examined individual records of species detections that were potentially erroneous:

We checked the detection data for every species for potentially erroneous records, such as detections that occurred well outside the currently known distributions. Where this was the case, we re-assigned the detection to the lowest taxonomic level possible, as follows:

- To another species name, based on knowledge of species distributions. For example, some records labelled black-headed python (*Aspidites melanocephalus*) were well-outside the known distribution, but well within the distribution of the woma python (*Aspidites ramsayi*); these records were re-assigned to woma python.
- To the genus, if assignment to species could not be made confidently. For example, detections of the western grey kangaroo (*Macropus fuliginosus*) in the north-western deserts of WA are well outside the known distribution of this species; the detections could have been euros (*Osphranter robustus*) or red kangaroos (*Osphranter rufus*), and there was no way to distinguish between these possibilities. These detections were re-assigned as 'large macropod' *Macropus/Osphranter sp*.
- To the next possible taxonomic grouping up, if assignment to genus was not possible (e.g. snake, reptile).

4. We examined records that were named as an animal type or group (rather than a species), to see if we could enhance information quality:

Some detections had been recorded with a group name that we were able to re-assign with more specificity. For example, all records recorded as "rock wallaby" from Ngaanyatjarra country were re-assigned to Warru (*Petrogale lateralis centralis)*, based on knowledge of rock-wallaby distributions. Similarly, most detections of "mulgara", "hopping mouse", and "marsupial mole" could be re-assigned to a species based on the location of the detection, and knowledge of species distributions (Appendix 1).

Step 6 - We divided Presence records and Absence records into separate datasets:

Records were classed as 'absence' data (where data collectors recorded species they did not detect) or 'presence' data (where data collectors recorded what they detected, but did not make a record of species that they were looking for, but didn't detect).

This classification allowed us to segregate records from the observational surveys into a 'presence dataset' and all 'absence' records into a 'absence dataset' (Figure 3). All data providers recorded presence data; however, absence data were recorded less frequently (of the 69 datasets we received, seven contained absence records). Data providers who submitted absence as well as presence data were usually sampling systematically in the same region over several years. Whilst the absence data is being used in other analyses and outputs, this report is based on summaries and analyses of the presence data.

Step 7 - We removed duplicate species records within datasets and specified "sites":

Not all groups used unique or consistent identifiers to identify survey sites, and since we collated data from many sources, the data from any single sampling event could potentially be present in two or more datasets. We therefore filtered the aggregated data in the Interim Dataset to remove such redundancy. We overlaid a 1 km by 1 km ($1km^2$) grid over the AZM study area, and gave every grid cell a unique ID. All species detections in a single grid cell with the same collection date were coalesced to one presence record.

The data manipulation and cleaning workflow is summarised in Figure 3.

A summary of the 69 datasets received by 37 data providers, their metadata and the number of records they contributed to the Interim and National Datasets is provided in Table 1.

Checking small reptile tracks.

Image: N. Rakotopare

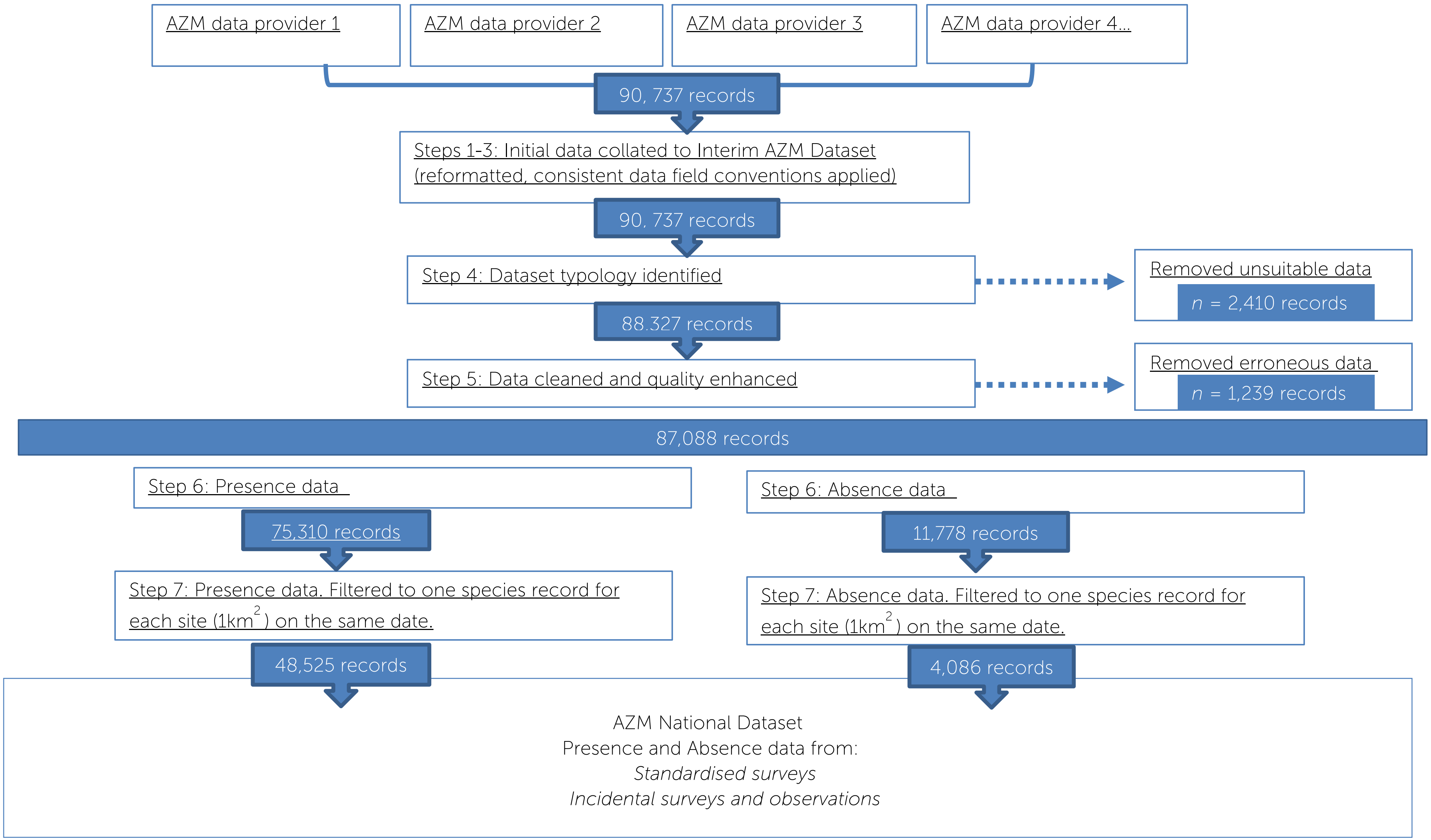


Figure 3: Data manipulation and cleaning workflow to collate data received from contributors into the AZM National Dataset. Blue boxes show the number of records retained after each manipulation and clean up step.

Table 1: Summary of records received from data providers, a) collated into the Interim Dataset prior to the cleaning and manipulation process resulting in b) the AZM National Dataset. Within the AZM National Dataset, the number of unique sites (N. unique sites) with AZM presence and absence records (N. records) was tallied for survey data that provided spatial coordinates.

Data provider	Dataset name (format: where-data source/holder)	Dataset ID	Data provider type	Survey type	Sample type	Interim Dataset	AZM National Dataset					
							Presence data			Absence data		
						N. records	N. records	N. unique sites	N. unique site visits	N. records	N. unique sites	N. unique site visits
Northern Territory												
AWC Newhaven	Newhaven AWC	15	NGO	Standard	2 ha plots	3656	3656	75	532			
CLC Anangu Luritjiku Rangers	Katiti Petermann ALA Anangu Luritjiku	45	Indigenous	Standard	2 ha plots	54	26	6	7			
CLC Angas Downs IPA Rangers	AngasDowns CLC AD	39	Indigenous	Standard	2 ha plots	2	2	2	2			
CLC Anmattyerr Rangers and Illeuwurru TOs	Illeuwurru CLC Anmattyerr	35	Indigenous	Standard	2 ha plots	67	42	15	15			
CLC Kaltukatjara Rangers	Katiti Petermann CLC Kaltukatjara	40	Indigenous	Standard	2 ha plots	6	6	1	1			
CLC Ltyentye Apurte Rangers	Ltyentye Apurte CLC LA	41	Indigenous	Standard	2 ha plots	57	41	7	7			
CLC Muru Warinyi Ankkul Rangers	Banka Banka Paltridge CLC MWA	53	Indigenous	Standard	2 ha plots	90	88	22	22			
	Hanson River Paltridge CLC MWA	52	Indigenous	Standard	2 ha plots	86	86	19	20			
	Kalumpulpa CLC MWA	34	Indigenous	Standard	2 ha plots	301	143	23	34			
	Lajamanu Tennant Creek Paltridge CLC MWA	54	Indigenous	Standard	2 ha plots	785	784	119	170			
	Mungalawurru CLC MWA	37	Indigenous	Standard	2 ha plots	274	127	22	22			
	Muru Warinyi Ankkul ALA MWA	47	Indigenous	Standard	2 ha plots	78	28	7	8			
	Tennant Creek CLC MWA	38	Indigenous	Standard	2 ha plots	244	200	60	65			
CLC North Tanami Rangers	Lajamanu CLC	55	Indigenous	Standard	2 ha plots	404	136	7	15			
	NorthTanami ALA NT	46	Indigenous	Standard	2 ha plots	58	47	9	10			

Data provider	Dataset name (format: where-data source/holder)	Dataset ID	Data provider type	Survey type	Sample type	Interim Dataset	AZM National Dataset					
							Presence data			Absence data		
						N. records	N. records	N. unique sites	N. unique site visits	N. records	N. unique sites	N. unique site visits
CLC Tjakura Rangers	Katiti Petermann ALA Tjakura	44	Indigenous	Standard	2 ha plots	22	17	5	5			
CLC Warlpiri Nyirripi Rangers	Warlpiri Nyirripi Paltridge CLC Warlpiri	42	Indigenous	Standard	2 ha plots	319	311	58	58			
CLC Warlpiri Willowra Rangers	Lander River CLC Warlpiri	36	Indigenous	Standard	2 ha plots	859	478	83	93			
CLC Warlpiri Yuendumu Rangers	Warlpiri Yuendumu ALA Warlpiri	43	Indigenous	Standard	2 ha plots	71	67	12	12			
Tanami Regional Biodiversity Monitoring	Tanami RBM	31	Indigenous Industry	Standard	Sign based transect	6745	2515	48	442			
	Tanami RBM	31	Indigenous Industry	Special equipment	Special equipment	2267						
	Tanami RBM	31	Indigenous Industry	Incidental	Incidental other method	339	100	5	55			
Tom Newsome	Tanami Newsome	30	University	Standard	Sign based transect	3085	1747	149	608			
Queensland												
Save the Bilby	SEQld Save the Bilby	32	NGO	Standard	2 ha plots	358	241	71	71	3	3	3
South Australia												
Arid Recovery	Arid Recovery AR	28	NGO	Standard	Sign based transect	11,340	7448	159	4576			
AW NRM & Rick Southgate	AWNRM SA gov	62	NRM	Standard	2 ha plots	15,940	1865	4	368	3915	312	409
AWC Kalamurina	Kalamurina AWC	14	NGO	Standard	2 ha plots	2865	2815	122	475			
Ellen Ryan Colton and APY Land Management	APY LM	25	Indigenous University	Standard	2 ha plots	86	46	7	7	3	1	1
	APY Ryan Colton	25	Indigenous University	Standard	Timed searches	50	37	3	17			

Data provider	Dataset name (format: where-data source/holder)	Dataset ID	Data provider type	Survey type	Sample type	Interim Dataset	AZM National Dataset					
							Presence data			Absence data		
						N. records	N. records	N. unique sites	N. unique site visits	N. records	N. unique sites	N. unique site visits
Joe Benshemesh and AW NRM	Maralinga Benshemesh	27	NRM	Standard	Timed searches	5	5	4	4			
SA Government	Maralinga Benshemesh	27	NRM	Standard	Sign based transect	2902	955	190	270			
	Ampurta2006 SA gov	5	Government	Standard	2 ha plots	1206	1199	133	234			
	Ampurta2015 SA gov	3	Government	Standard	2 ha plots	438	332	77	77			
	BDBSA SA gov	24	Government	Standard	Sign based search	6609	6607	1601	3071			
	DHM2012 SA gov	1	Government	Standard	2 ha plots	490	477	82	82			
	DHM2018 SA gov	4	Government	Standard	2 ha plots	830	631	22	95	1	1	1
	Quinyambie2008 SA gov	8	Government	Standard	2 ha plots	30	30	9	9			
	Quinyambie2015 SA gov	2	Government	Standard	2 ha plots	147	147	40	40			
	Simpson Tirari2008 SA gov	6	Government	Standard	2 ha plots	54	54	12	12			
	Simpson Various2005 06 SA gov	7	Government	Standard	2 ha plots	101	96	21	22			
	Simpson2006 SA gov	9	Government	Standard	2 ha plots	118	115	16	18			
	Strezlecki Various 2007 08 13 SA gov	10	Government	Standard	2 ha plots	48	47	10	10			
	Strezlecki2018 19 SAgov	12	Government	Standard	2 ha plots	389	375	54	54			
Western Australia												
Kanyirninpa Jukurrpa	Martu KJ	58	Indigenous	Standard	2 ha plots	11529	5822	708	1088	1	1	1
Birriliburu Rangers Mungarlu Ngurrarankatja Rirraunkatja AC	Birriliburu ALA MNR	50	Indigenous	Standard	2 ha plots	1665	997	60	186			
Karajarri Lands Trust Association	Karajarri KTLA	60	Indigenous	Standard	2 ha plots	291	152	33	33			
Kiwirrkurra Rangers and TOs	Kiwirrkurra ALA Kiwirrkurra	48	Indigenous	Standard	2 ha plots	1532	5					
	Kiwirrkurra DSS Kiwirrkurra	20	Indigenous	Standard	2 ha plots	1212	1116	186	239			

Data provider	Dataset name (format: where-data source/holder)	Dataset ID	Data provider type	Survey type	Sample type	Interim Dataset	AZM National Dataset					
							Presence data			Absence data		
						N. records	N. records	N. unique sites	N. unique site visits	N. records	N. unique sites	N. unique site visits
Ngaanyatjarra Council	Ngaanyatjarra ALA NC	49	Indigenous	Standard	2 ha plots	12	12	2	2			
	Ngaanyatjarra NC	57	Indigenous	Standard	2 ha plots	8	2	1	2			
	Ngaanyatjarra NC	57	Indigenous	Standard	Sign based transect	77	16	15	16			
	Ngaanyatjarra NC	57	Indigenous	Standard	Sign based search	349	161	132	161			
	Ngaanyatjarra NC	57	Indigenous	Special equipment	Special equipment	7						
Ngurrara Rangers Yanunijarra AC	Ngurrara	26	Indigenous	Standard	2 ha plots	37	34	7	7			
Ngururrpa Rangers and TOs	Ngururrpa DSS Ngururrpa	22	Indigenous	Standard	2 ha plots	666	506	94	132			
Nigel Jackett	Nita Downs Jackett	19	Industry Indigenous	Standard	2 ha plots	37	27	12	14			
Nyikina Mangala Rangers Walalakoo AC	Nyikina Mangala	61	Indigenous	Standard	Timed searches	128	28	27	28			
Nyul Nyul Rangers	Nyul Nyul NN	21	Indigenous	Standard	2 ha plots	83	79	28	28			
Nyumba Buru Yawuru	Yawuru NBY	11	Indigenous	Standard	2 ha plots	101	60	20	21			
Paruku Rangers Tjurabalan AC	Paruku Tjurabalan	59	Indigenous	Standard	2 ha plots	9	3	3	3	4	4	4
Sheffield Resources	Yeeda MtJ Sheffield	23	Industry	Standard	Sign based transect	95	36	23	36			
WA DBCA and Yawuru Country Managers Karajarri Rangers Nyangumarta Rangers	DBCA	17	Indigenous Government	Standard	T2wo ha plots	437	393	43	86			
	Karajarri	17	Indigenous Government	Standard	2 ha plots	1246	1177	243	353			
	Nyangumarta	17	Indigenous Government	Standard	2 ha plots	661	543	82	113			

Data provider	Dataset name (format: where-data source/holder)	Dataset ID	Data provider type	Survey type	Sample type	Interim Dataset	AZM National Dataset					
							Presence data			Absence data		
						N. records	N. records	N. unique sites	N. unique site visits	N. records	N. unique sites	N. unique site visits
	Yawuru	17	Indigenous Government	Standard	Two ha plots	394	350	54	79			
WA Main Roads	Dampierland WA Main Roads	18	Government	Standard	Two ha plots	28	23	5	5			
	Dampierland WA Main Roads	18	Government	Standard	Sign based transect	185	29	6	29			
	Dampierland WA Main Roads Southgate	33	Government	Standard	Two ha plots	1184	946	105	166			
Wiluna Rangers Tarlka Matuwa Piarku AC	Wiluna	16	Indigenous	Standard	Two ha plots	4889	1839	83	271	159	21	35
Total						90,737	48,525	5363	14,813	4086	343	454

2.3 Summary of the types of data in the National Dataset

Most data in the National Dataset are presence records from 2 ha plot surveys, with many records also derived from transect-based surveys. Timed search data were collected by searching for animal detection signs within around live animal trapping sites within a chosen time-period. Sign-based search data were collated through timed search transects and either carried out on foot or by a slow-moving vehicle. All absence data were collected from standardised 2 ha plot surveys (Table 2).

Table 2: Summary of records (N. records) contained in the AZM National Dataset by survey type. One site (n. sites) is a 1 km2 location. A site visit is a 1 km2 location visited (sampled) on one date. One record is one species detected in one site visit.

Presence data			
	N. records - presence	N. sites - presence	N. site visits - presence
All standardised surveys			
2 ha plots	28,841	3001	5500
Sign-based search	6768	1733	3232
Sign-based transect	12,746	590	5977
Timed searches	70	34	49
subtotal	*48,425*	*3757*	*11,687*
All incidental surveys and observations			
Incidental other method	100	5	55
subtotal	*100*	*1609*	*3128*
Total presence records	*48,525*	*5363*	*14,813*
Absence data			
All standardised surveys	N. records - absence	N. unique sites - absence	N. site visits - absence
2 ha plots	4086	343	454
Total absence records	*4086*	*343*	*454*

Section 3 – Scale of the Arid Zone Monitoring National Dataset

Key points:

- *The 5363 unique sites (with 48,525 presence records from 14,815 surveys) are spread across the project area, but with some sampling gaps.*
- *Most sites, site-visits, and records were contributed from South Australia, followed by Western Australia.*
- *Indigenous groups were responsible, or partly responsible, for the largest number of records and of sites. NGO records are mostly from repeated visits over several years to a smaller set of sites.*
- *Data for 1982 to 2000 were all from the southern deserts, whilst the northern deserts contributed data collected from 2000 on.*
- *The number of unique sites sampled per decade was highest in 2000-09 and 2010-20.*

3.1 Spatial scale of the dataset

The unique sites (each 1 km^2) in the AZM National Dataset are dispersed across the project area, but with some sampling gaps in the middle of the Great Sandy Desert, parts of the Great Victoria Desert, and parts of central-east NT (Figure 4).

Looking for tracks, APY Lands.

Image: Ellen Ryan-Colton.

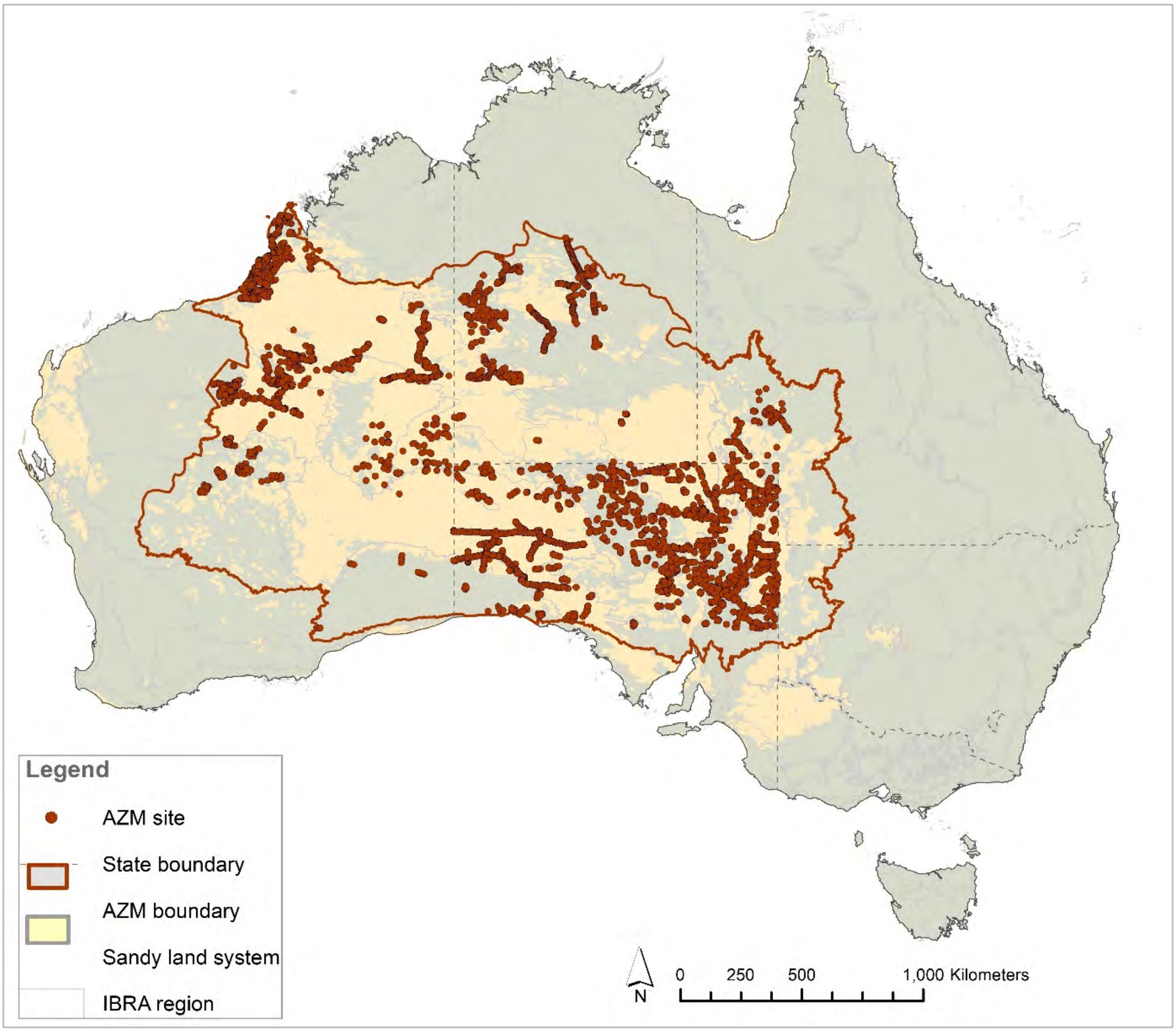


Figure 4: AZM project boundary (red) within Australia. Sandy land systems are represented in light yellow. Each red dot is an AZM site, which contains a record of at least one species in 1 km2.

3.2 Who provided the data?

Most records in the AZM National Dataset were provided by government, Indigenous groups, and NGOs. When factoring in data that were collected collaboratively by Indigenous groups and other data provider types, Indigenous groups were responsible, or partly responsible, for the largest number of records and of sites (Figure 5). Compared with other data provider types, the NGO records are mostly repeated samples (site visits) over several years from a smaller set of sites.

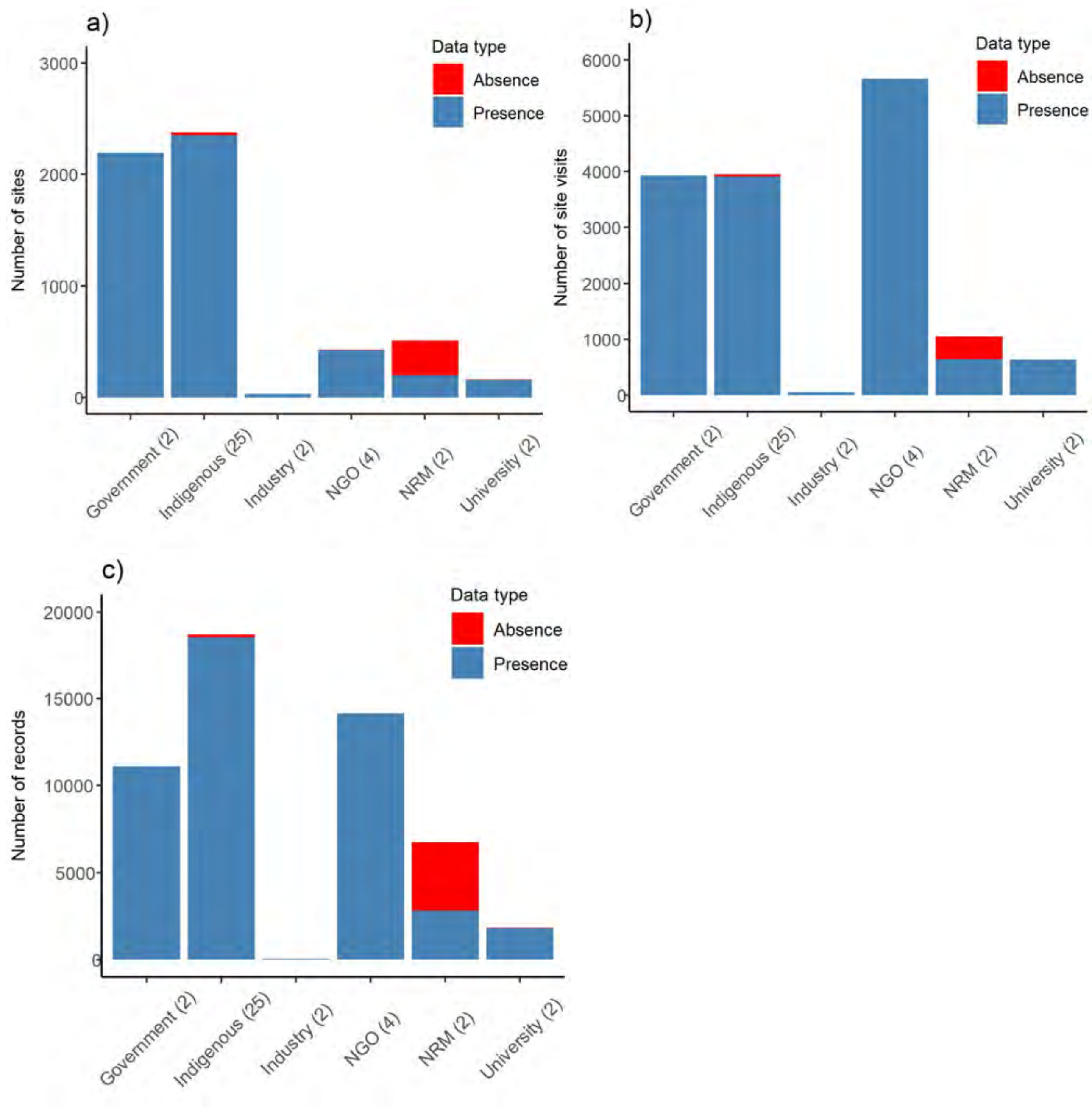


Figure 5: The number of a) sites; b) site-visits, and c) records for both presence (blue) and absence (red) data, by data provider type (group) in the AZM National Dataset. Number of data providers displayed as: Group (N. Data Providers). One site is a 1 km^2 location sampled on one date. A site visit is a 1 km^2 location visited (sampled) on one date. One record is one species detected in one site-visit. Indigenous Industry, Indigenous University, Indigenous Government – are all collapsed to the Indigenous category. Industry Indigenous – is collapsed to the Industry category.

3.3 Data by jurisdiction

Most sites, site-visits, and records were contributed from South Australia, followed by Western Australia (Figure 6). Many of the South Australian records were collected by government, working with arid zone ecologists, using sandplot monitoring across large parts of the state to identify the distribution of species and locate rare species like dusky hopping mice (*Notomys fuscus)* and crest-tailed mulgara (*Dasycercus cristicauda)*.

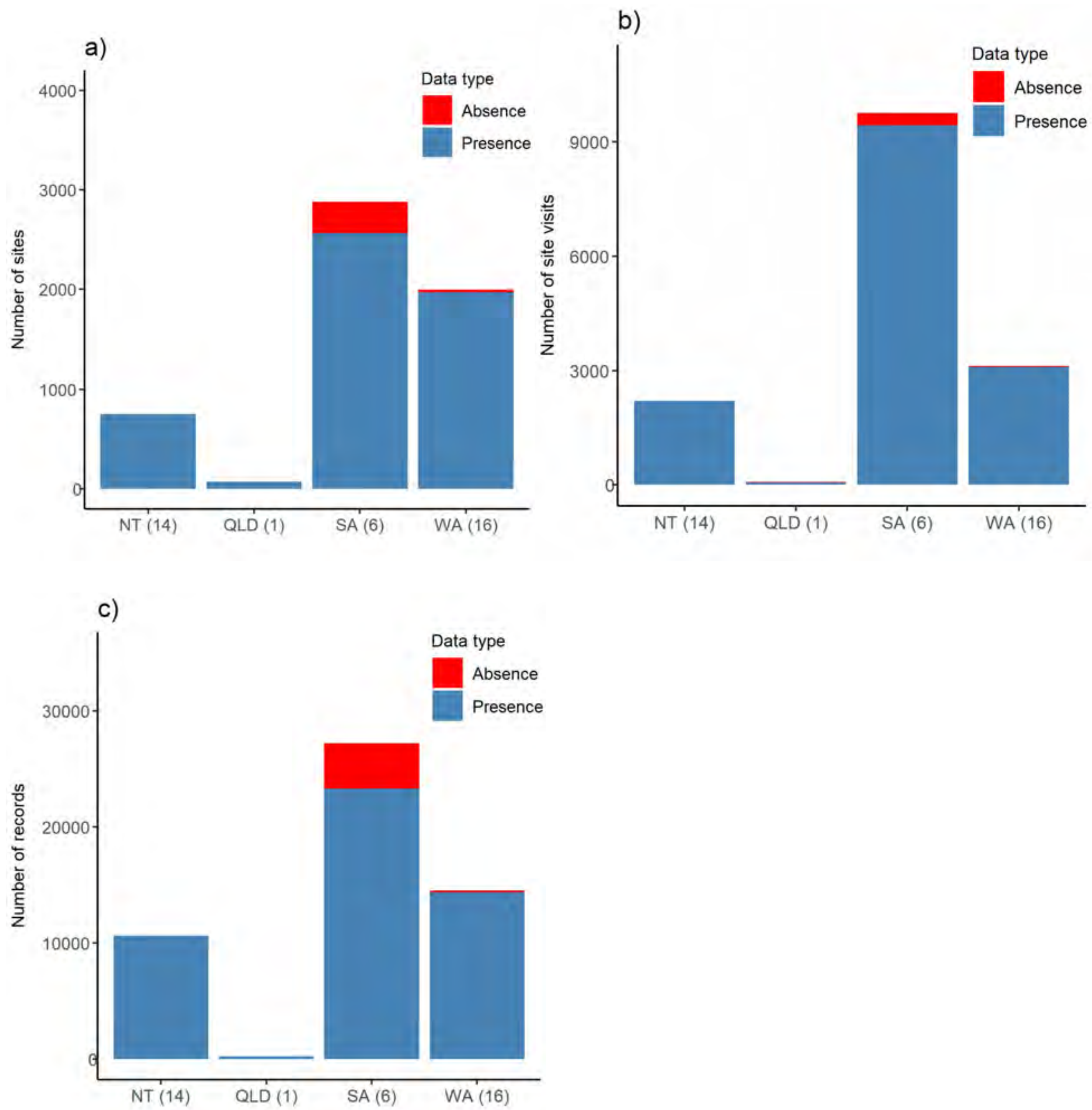


Figure 6: Number of a) sites; b) site-visits, and c) records of presence (blue) and absence (red) in the AZM National Dataset, by jurisdiction. Number of data providers displayed as: Jurisdiction (N. Data Providers). One site is a 1 km2 location. A site visit is a 1 km2 location visited (sampled) on one date. One record is one species detected in one site-visit. The numbers adjacent to the jurisdiction labels indicate the number of data providers in that jurisdiction.

3.4 Survey locations over time

The AZM Dataset contains records for the period 1982 to 2021. Few records were provided for the 1980s, and early records (1980s - 90s) were limited to SA. We received data from Western Australia and Northern Territory starting from early 2000s (Figure 7). It is unlikely that there is extensive survey data (that we were unable to source) from WA and NT from earlier decades. The number of unique sites sampled per decade was highest in 2000-09 and 2010-20.

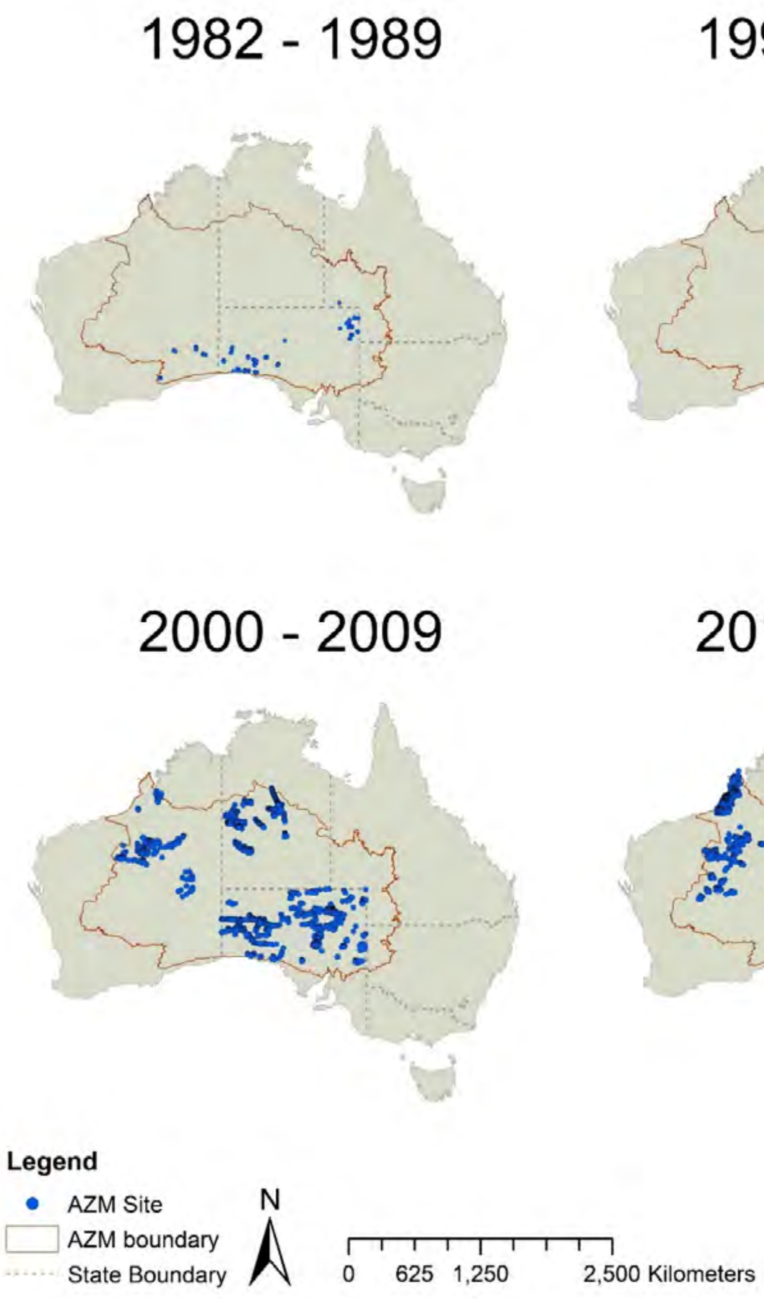


Figure 7: Location of sites in the AZM National Dataset by decade from 1980s. Forty-two records from 2020 are included in 2010-2020 site visit count. The number of unique sites sampled each decade is 1982-1989 = 87, 1990-1999 = 847, 2000-2009 = 3517, 2010-2021= 4387. Note that 418 records were submitted without date meta-data and thus were omitted from these maps.

Over time the types of organisations or individuals carrying out surveys has shifted. While the SA government has provided data from the 1980s, data from Indigenous, NGO and NRM groups became available over the last two decades (Figure 8). Of particular note is the enormous contribution of Indigenous groups and NGOs to the collective dataset in the past 20 years.

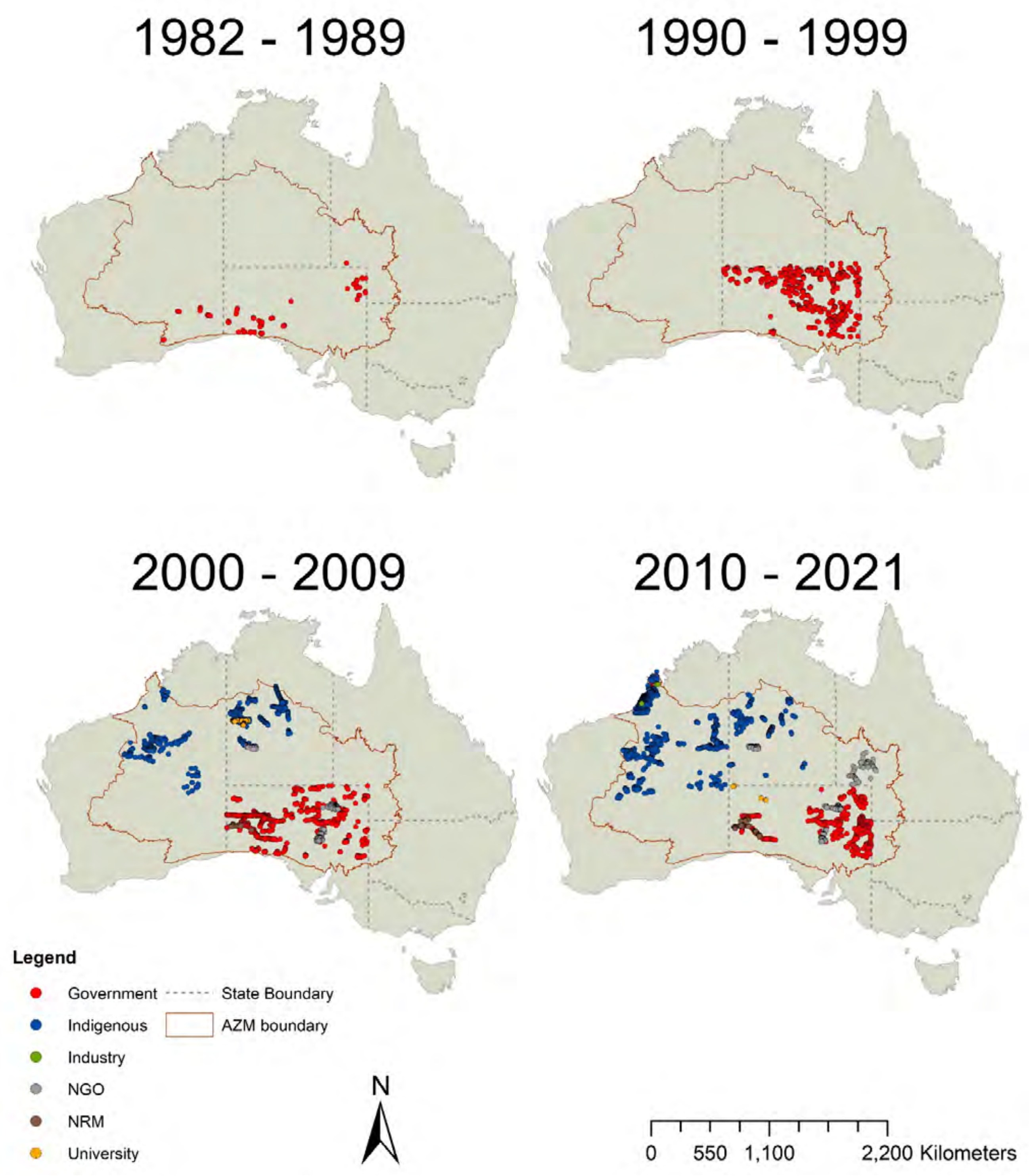


Figure 8: Surveys by all data providers (dot coloured by respective data provider group), for each decade.

Section 4 - What species are recorded?

Key points:

- *The list of species detected, and the number of records for each, reflects that track-based surveys are most useful for medium to larger species with tracks that can be easily identified. The method therefore favours medium-large mammals, including introduced mammal species (i.e. bilby/rabbit and above), followed by large reptile species, and large bird species.*
- *Some threatened species, rare species, and species significant to Traditional Owners, such as bilbies, great desert skinks, dusky hopping mouse, crest-tailed mulgara and perentie, were detected often compared to other species, because they are the focus of some surveys.*
- *The AZM National Dataset contains 39,817 records that were identified to 76 individual species: 27 native mammal species, 11 introduced mammal species, 4 bird species and 34 reptile species.*
- *An additional 8708 records (18% of all records) were identified to genus, family, or some other grouping. The proportion of unidentified species varied among classes, being lowest for introduced mammals and highest for reptiles, with the latter due to the difficulty of discriminating between goanna species, and between small reptile species.*
- *Data from WA, NT and SA comprised higher species richness than data from QLD, reflecting that the project area includes a smaller proportion of QLD with a small number of surveys carried out in this jurisdiction.*
- *Data from Indigenous groups and government agencies included more species than data from other data providers, reflecting that these data providers have shared more data into the AZM National Dataset.*

4.1 Detections of species

The AZM National Dataset contains 39,817 records of 76 species: 27 native mammal species, 11 introduced mammal species, 4 bird species and 34 reptile species. The dataset also contains 8,708 records (18% of all records) where sign was not attributed to a species, but was identified to genus level (3 mammal and 5 reptile genera), or a higher group level (3 mammal groups, 1 bird group, 5 reptile groups, 1 frog group and 1 invertebrate group) (Table 3).

Mammal species are the most frequently detected (Figure 9). Within mammals, introduced species dominate the records: five of the top seven most frequently recorded species are introduced: rabbits (*Oryctolagus cuniculus)* ranked first, cats (*Felis catus*) were the third most commonly detected mammal species, followed by camels (*Camelus dromedarius*), then foxes (*Vulpes vulpes*), with cow (*Bos taurus*) coming in at rank seven for mammals. Dingoes (*Canis familiaris lupus*) were the most detected native species, followed by spinifex hopping mouse (*Notomys alexis*) at rank five.

Out of 27 native mammal species, 11 were detected fewer than 10 times. These were all small-sized (five small rodents and dasyurids), or rocky habitat specialists (e.g. yellow-footed rock-wallaby (*Petrogale xanthopus*), Kowari (*Dasyuroides byrnei*)), or extremely rare in the desert (common brushtail possum (*Trichosurus vulpecula*), golden bandicoot *(Isoodon auratus*); Table 3). There were also 1429 records of small mammals that were not further identified, reinforcing that discriminating among small mammal species is not usually possible. The only small mammal species that could be reliably identified to genus level, and then to species on the basis of distribution, was the hopping mice (*Notomys* sp.), as they have distinctive tracks. The two large desert macropods, Euros (*Osphranter robustus*) and red kangaroos (*Osphranter rufus*), were recorded moderately often. However, records of 'large macropod', which could have been either euros or red kangaroos, or occasionally even grey kangaroos (*Macropus giganteus*), were recorded almost as frequently (46% of all large macropods; Table 3; Figure 9), showing that distinguishing between the tracks of these species is challenging. All the introduced mammals have tracks that allow for identification to species, apart from the house mouse (*Mus musculus)*, which was potentially recorded as small mammal on some surveys.

Within reptiles, two of the larger goanna species, the Gould's goanna (*Varanus gouldii*), and the perentie, (*Varanus giganteus)*, were most commonly detected. Of the 34 reptile species recorded, 19 had fewer than 10 records. These were all small species (geckos, dragons, skinks), or varanids – a species-rich group, where co-occurring species are very hard to distinguish from tracks. For example, 58% of goanna records are for the genus, and do not discriminate to one of the seven species recorded in the database (Table 5; Figure 9).

Within birds, species identifications are made for larger birds like emu (*Dromaius novaehollandiae*) and bustard (*Ardeotis australis*), whilst tracks of smaller bird species can rarely be distinguished to species.

Some threatened and rare species ranked high in terms of their total detections: for example, the bilby (*Macrotis lagotis*) (listed as Vulnerable in the EPBC Act) was the 9th most commonly detected mammal, and the dusky hopping mouse (*Notomys fuscus*) (Vulnerable, EPBC Act) ranked 11th. The great desert skink (*Liopholis kintorei*) (Vulnerable, EPBC Act) was the third most frequently detected reptile species (Figure 9). These high rankings are because some of the track-based surveys have focused on target species, including threatened species and culturally significant species, skewing their apparent detection rates compared to other species.

The total detections for species are influenced by where surveys have taken place, relative to the distributions of species. For example, some species with small distributions in the southern deserts, such as crest-tailed mulgara (*Dasycercus cristicauda*), nevertheless have reasonably high numbers of detections, because there has been considerable survey effort in the region that includes these species' distributions.

Marlu, red kangaroo, and its tracks. Images: J. Dunlop, S. Legge

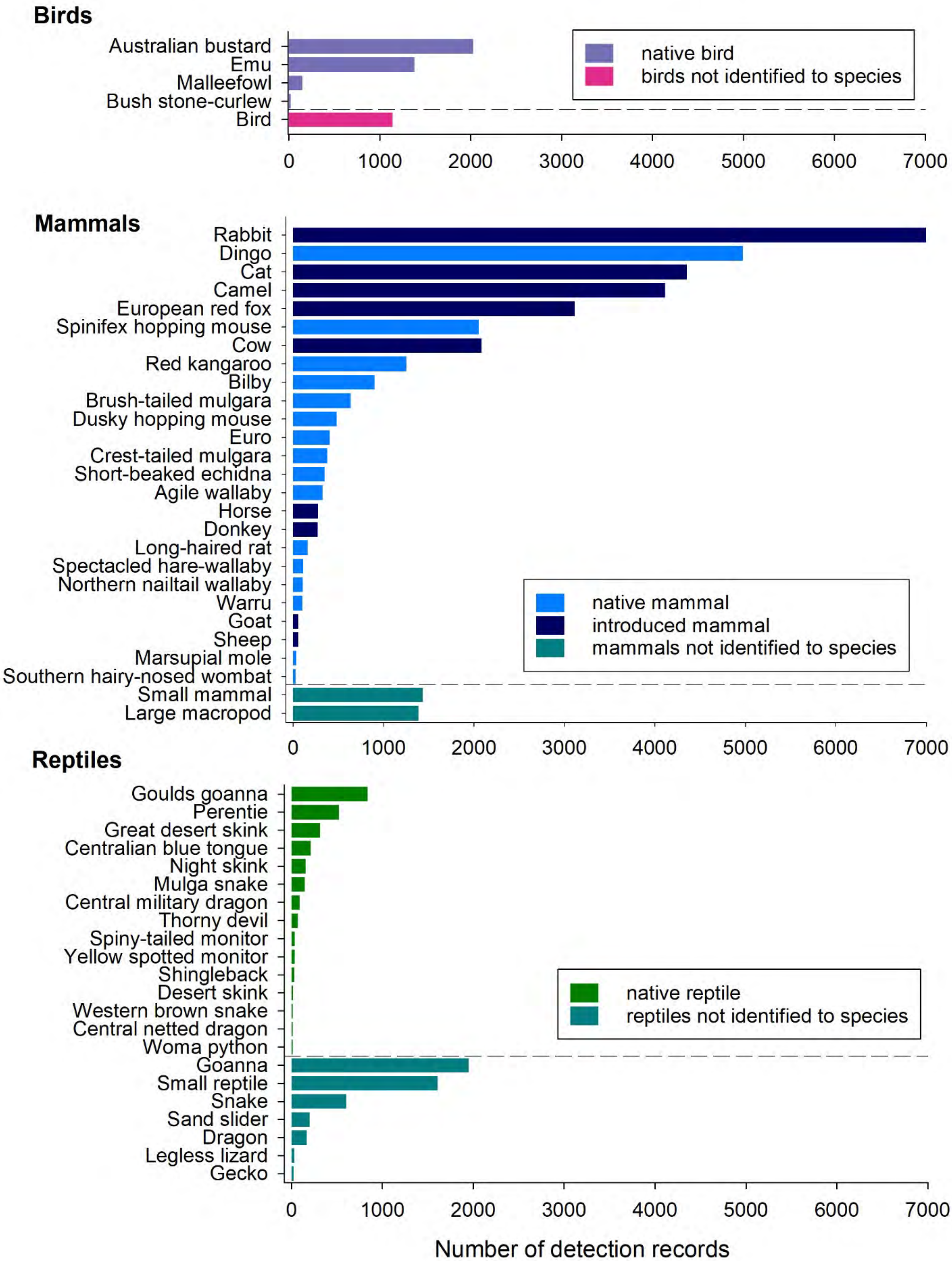


Figure 9: Histogram of detections of bird, mammal and bird species and groups. Only species with > 25 records (mammals) and >10 records (reptiles) are shown. Species with fewer records are listed in Table 5. Frogs (28 records) and invertebrates (114 records) not displayed.

Table 3: Number of detections (N. records) for each species, separated by presence and absence records. Species are arranged in alphabetic order of the scientific name, within the vertebrate Class (and native versus Introduced for mammals). In some records, sign was not attributed to a species, but was identified to genus level, or a higher group level. These detections are also tallied below.

Common Name	*Genus species* name	National conservation status under EPBC Act	Presence N. records	Absence N. records
Native mammal				
Dingo	*Canis familiaris lupus*		4966	278
Brush-tailed mulgara	*Dasycercus blythii*		637	
Crest-tailed mulgara	*Dasycercus cristicauda*		377	
Kowari	*Dasyuroides byrnei*	Vulnerable	2	
Golden bandicoot	*Isoodon auratus*		6	
Spectacled hare-wallaby	*Lagorchestes conspicullatus*		109	
Southern hairy-nosed wombat	*Lasiorhinus latifrons*		25	
Forrest's short-tailed mouse	*Leggadina forresti*		1	
Greater bilby	*Macrotis lagotis*	Vulnerable	901	16
Agile wallaby	*Notamacropus agilis*		326	
Spinifex hopping mouse	*Notomys alexis*		2053	348
Dusky hopping mouse	*Notomys fuscus*		481	1
Northern marsupial mole	*Notoryctes caurinus*		22	1
Southern marsupial mole	*Notoryctes typhlops*		11	
Northern nail-tail wallaby	*Onychogalea unguifera*		107	
Euro	*Osphranter robustus*		406	2
Red kangaroo	*Osphranter rufus*		1249	387
Warru	*Petrogale lateralis centralis*	Vulnerable	103	
Yellow-footed rock-wallaby	*Petrogale xanthopus*	Vulnerable	2	
Fat-tailed pseudantechinus	*Pseudantechinus macdonnellensis*		2	
Plains mouse	*Pseudomys australis*	Vulnerable	3	
Sandy inland mouse	*Pseudomys hermannsburgensis*		4	
Central pebble-mound mouse	*Pseudomys johnsoni*		23	
Long-haired rat	*Rattus villosissimus*		161	
Fat-tailed dunnart	*Sminthopsis crassicaudata*		1	
Short-beaked echidna	*Tachyglossus aculeatus*		348	381
Common brushtail possum	*Trichosurus vulpecula*		7	
Genera				
Pseudomys sp	*Pseudomys* sp		4	
Dunnart	*Sminthopsis* sp		37	
Large macropod	*Osphranter* sp (& *Macropus* sp)		1385	348
Groups				
Bat	Bat		3	
Medium large mammal	Mammal		17	
Small mammal	Small mammal		1388	
Introduced mammals				
Cow	*Bos taurus*		2084	2
Camel	*Camelus dromedarius*		4109	257
Goat	*Capra hircus*		60	
Donkey	*Equus asinus*		269	1
Horse	*Equus caballus*		276	

Common Name	*Genus species* name	National conservation status under EPBC Act	Presence N. records	Absence N. records
Cat	*Felis catus*		4352	362
House mouse	*Mus musculus*		5	
Rabbit	*Oryctolagus cuniculus*		7038	230
Sheep	*Ovis aries*		55	
Pig	*Sus scrofa*		16	
European red fox	*Vulpes vulpes*		3116	218
Birds				
Australian bustard	*Ardeotis australis*		2025	402
Bush stone curlew	*Burhinus grallarius*		20	
Emu	*Dromaius novaehollandiae*		1379	421
Malleefowl	*Leipoa ocellata*	Vulnerable	148	404
Groups				
Bird	Bird		1139	
Reptiles				
Stimsons python	*Antaresia stimsoni*		3	
Woma python	*Aspidites ramsayi*		11	
Crested dragon	*Ctenophorus cristatus*		5	
Central military dragon	*Ctenophorus isolepis*		86	
Central netted dragon	*Ctenophorus nuchalis*		14	
Painted dragon	*Ctenophorus pictus*		2	
Yellow-faced whip snake	*Demansia psammophis*		1	
Lally's two-line dragon	*Diporiphora lalliae*		1	
Macquarie river turtle	*Emydura macquarii*		1	
Tree dtella	*Gehyra variegata*		1	
Long-nosed dragon	*Gowidon longirostris*		1	
Burtons legless lizard	*Lialis burtonis*		1	
Desert skink	*Liopholis inornata*		15	
Great desert skink	*Liopholis kintorei*	Vulnerable	313	6
Night skink	*Liopholis striata*		152	
Thorny devil	*Moloch horridus*		71	4
Common knob-tailed gecko	*Nephrurus levis*		3	
Western bearded-dragon	*Pogona minor*		1	
Central bearded dragon	*Pogona vitticeps*		9	
Mulga snake	*Pseudechis australis*		144	
Western brown snake	*Pseudonaja mengdeni*		14	
Ringed brown snake	*Pseudonaja modesta*		1	
Western beaked gecko	*Rhynchoedura ornata*		1	
Centralian blue-tongue	*Tiliqua multifasciata*		213	
Western blue-tongue	*Tiliqua occipitalis*		1	
Shingle-back	*Tiliqua rugosa*		29	
Central pebble dragon	*Tympanocryptis sp*		3	
Spiny-tailed monitor	*Varanus acanthurus*		34	
Short-tailed pygmy monitor	*Varanus brevicauda*		3	
Perentie	*Varanus giganteus*		523	
Gould's goanna, sand goanna	*Varanus gouldii*		838	
Mertens water monitor	*Varanus mertensi*		1	
Yellow-spotted monitor	*Varanus panoptes*		33	
Black-headed monitor	*Varanus tristis*		5	
Genera				
Blind snake	*Anilios* sp		2	

Common Name	*Genus species* name	National conservation status under EPBC Act	Presence N. records	Absence N. records
Ctenotus sp	*Ctenotus* sp		8	
Egernia sp	*Egernia* sp		1	
Sand sliders	*Lerista* sp		200	
Goanna	*Varanus* sp		1949	12
Groups				
Dragon	Agamidae		168	
Gecko	Gekkonidae		23	
Legless lizard	Legless lizards		29	
Small reptile	Reptile		1609	
Snake	Snake		602	5
Frogs				
Frog	Anuran		28	
Invertebrate				
Invertebrate	Arthropoda		114	
Total			48,525	4,086

Pulling up to a survey site.
Image: N. Rakotopare.

4.2 Detections of species groups

Overall, 18% of records were not identified to species. The proportion of unidentified species varied among classes:

- 19% of native mammal records were not identified to species, and instead identified to genus or some other grouping (e.g. small mammal);
- 0% of medium-large introduced species were not identified to species; some small mammal records may have been house mice;
- 64% of reptile records were identified to genus (e.g. *Varanus* sp.), family (e.g. dragon), or other grouping (e.g. snake).

The variation among classes in the proportions of records that were, and were not, identified to species level may obscure which classes or genera are recorded most often.

We therefore explored the relative detections across classes, and groups within the classes. First, we created a hierarchy with up three species group levels to aggregate detections. The group levels were based on a combination of taxonomy and size (for instance: Crest-tailed mulgara: dasyurid - small-medium mammal - mammal; full list of species and groupings in Appendix 2). Frogs and invertebrates each comprised less than 1% of all records, and were omitted from further exploration.

By considering detections that were made to genus or a higher group level, the proportion of all detections that were reptiles increased, driven by the large number of detections of 'goannas', and of 'small reptiles', whereas the proportion of records attributed to introduced mammals reduced (Table 4). Even accounting for detections not identified to species level, mammals still comprised the most records followed by reptiles then birds. Within mammals, records of introduced species were more numerous than those of native species (Table 4). See Appendix 2 for further detail.

Table 4: The proportion of records in each Class (with mammals split to native and introduced), based on whether only those identified to species are included, versus the larger dataset.

Class (with native and introduced mammals split)	% of records using records identified to species only	% of records including those identified to genus or other group
Native mammals	31%	31%
Introduced mammals	54%	44%
Reptiles	6%	15%
Birds	9%	10%

4.3 Species detections by jurisdiction and data provider

The datasets contributed from WA, NT and SA each contain records for more than 50 individual species. Surveys within each of these states have been extensive (Figure 10a) and carried out by 16, 14 and 6 data providers respectively. In SA, one data provider (the SA government) is a collation of data from several researchers and consultants, whose work was often funded by government grants. In contrast, the data from QLD contains a smaller number of species (Figure 10b), reflecting that the sandy regions required for track-based surveys have a limited extent in the far south-western part of the state that overlaps with the project area, and the data shared was only from one data provider.

Indigenous and government contributors provided information on a substantial number of species (Figure 10b). This reflects the high number of sites these contributors have provided data for (Indigenous: 2351 and Government: 2196; Table 3), and the spatial extent over which these data provider types operate (Figure 1).

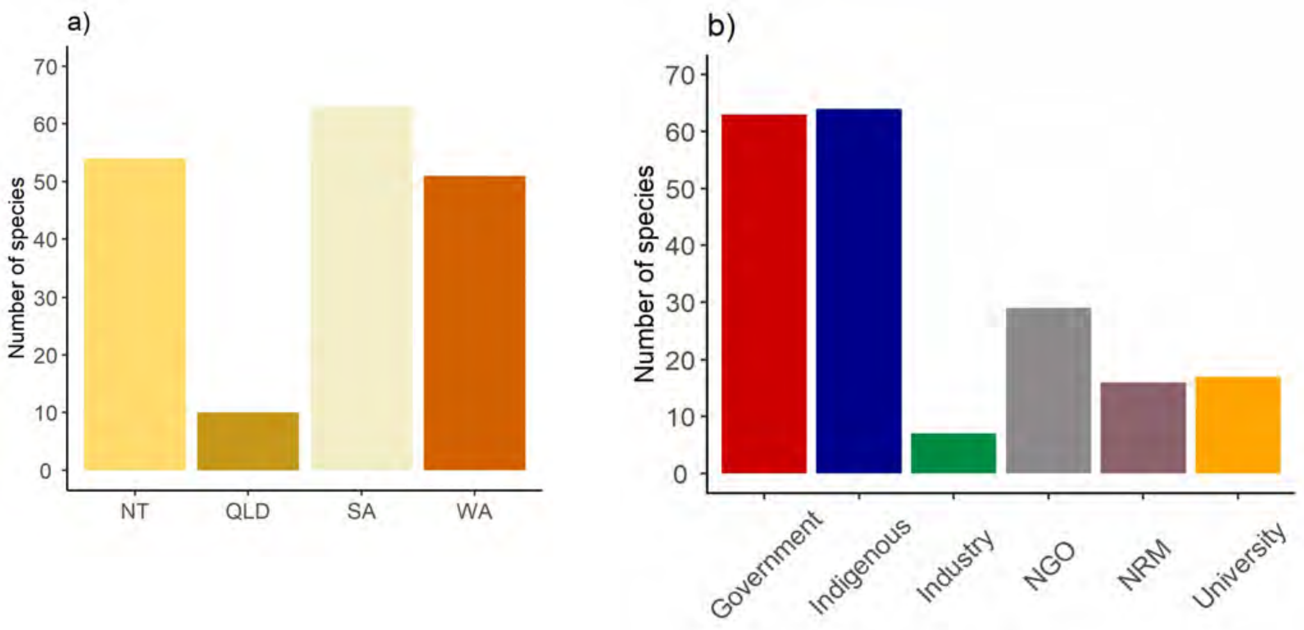


Figure 10: Species richness by a) jurisdiction, and b) data provider type, based on presence records in the AZM National Dataset. (Note that unidentified species groups are omitted from plot = bat, medium-large mammal, rodent, bird, small mammal, dragon, gecko, snake, small reptile, frog, invertebrate).

When the species richness is tallied within each vertebrate Class, it appears that reptiles have been recorded more often in the WA and NT, than in SA and QLD (Figure 11a). Note this does not mean reptiles are more common in WA and the NT, only that people record them more often. Introduced mammals are more commonly recorded in SA (Figure 11a); this may reflect a genuine difference between jurisdictions, as the densities of several introduced species are higher in the southern deserts.

Birds and reptiles were more commonly recorded by Indigenous groups, introduced mammals were more commonly recorded by NGOS, and native mammals were most often recorded by Industry and University researchers (Figure 11b). Breakdowns of detections by the subgroups described in Section 4.2, for jurisdiction, data provider type and data provider, are available in Appendix 2.

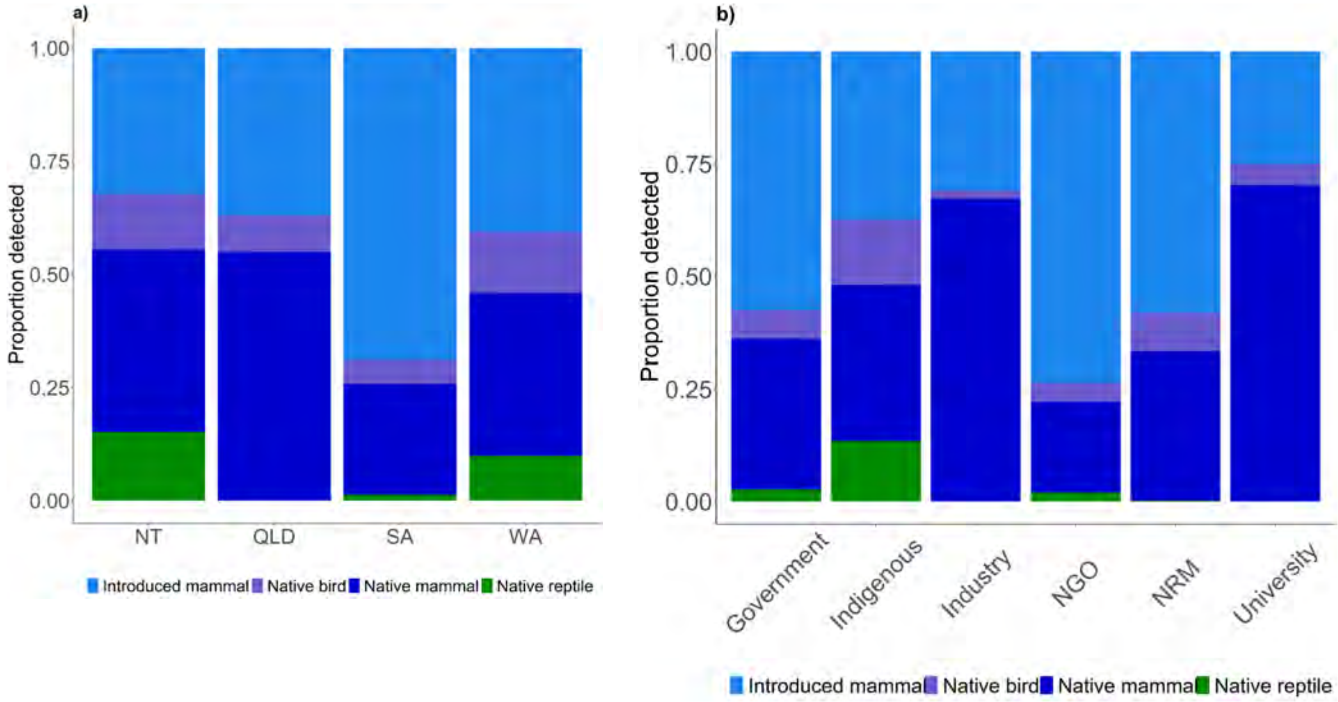


Figure 11: Number of records of each species, arranged by a) jurisdiction, and b) data provider type (for mammals, native or introduced, reptiles and birds), within the AZM National Dataset. Frogs (28 records), invertebrates (114 records), and records not identified to species level (mammals 2,868 records, birds 1,142 records, reptiles 4,765 records) are not displayed.

Ngurrara Rangers, on survey.
Image: H. Bijlani.

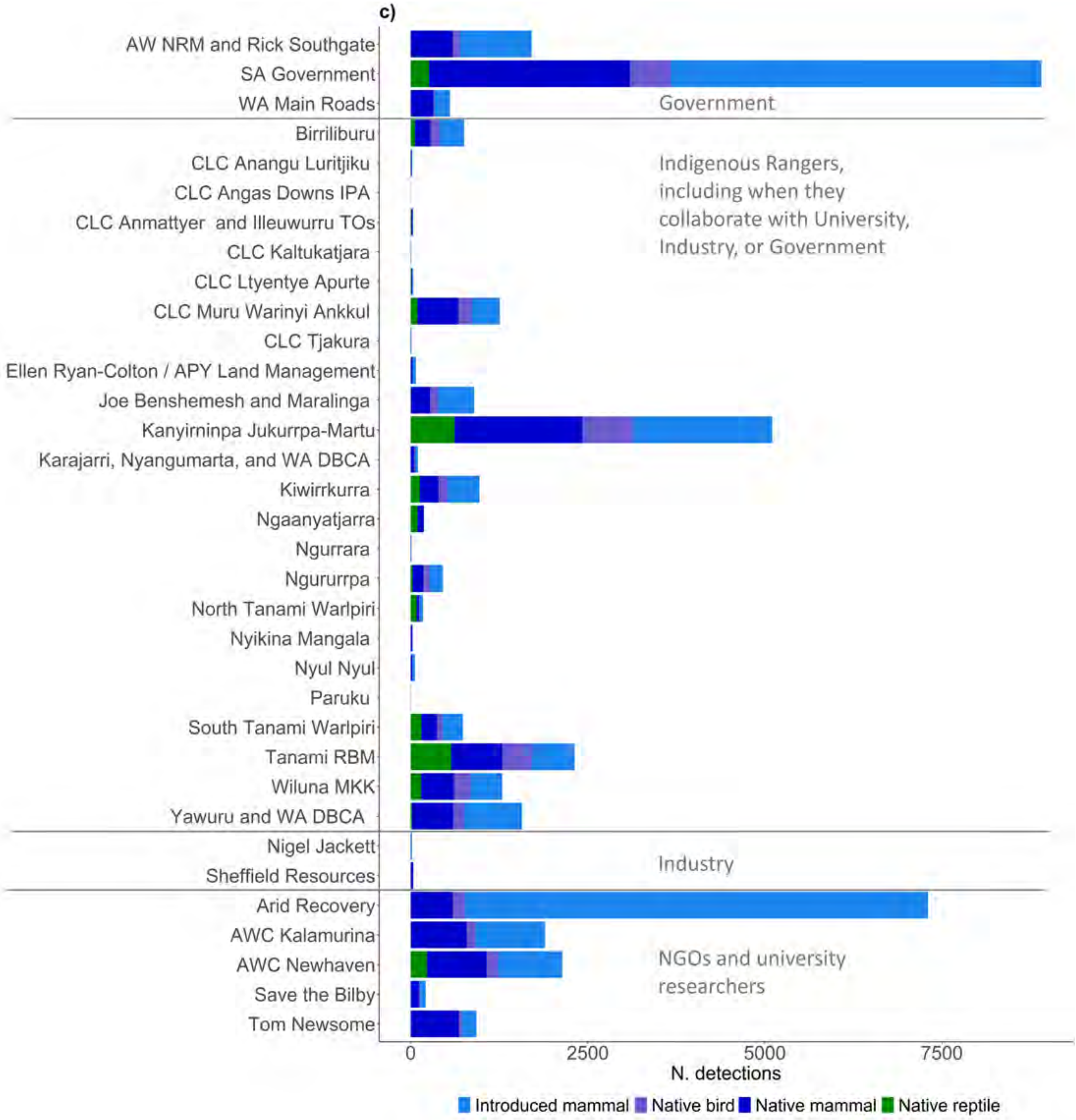


Figure 11c: Number of records of each species, arranged by data provider type then alphabetically by data provider, for mammals, native or introduced, reptiles and birds, within the AZM National Dataset. Frogs (28 records), invertebrates (114 records), and records not identified to species (mammals 2,868, birds 1,142, reptiles 4,765 records) are not displayed. Information regarding the omitted detections (records not identified to species) in Table 5.

Section 5 - Species detection maps

Key points:

- *We created detection maps for each of the species recorded in the AZM National Dataset. These maps are available in the species profiles listed in Appendix 3.*
- *The maps show that track-based surveys are useful for clarifying the distributional limits of species.*
- *The maps also reaffirm that track-based surveys are not suitable for documenting the distributions of smaller-bodied species with non-unique tracks, nor species that prefer rocky habitats over sandy substrates.*

5.1 Approach

For each species, we mapped the sites where that species had been detected, as well as all the other sites that had been surveyed, but where the species was not detected. For species of interest, we produced maps showing all the detections in the AZM National Dataset, as well as a series of four maps showing the detections in each decade (1982-1990; 1991-2000; 2002 to 2010; 2011-2020). On the maps, we also displayed the overall bioregional distributions of the species, by shading bioregions in which the species has been documented in authoritative scientific sources. These were Mammal Action Plan (Woinarski *et al.* 2014) for native mammals, the ABRS Faunal Directory (https://biodiversity.org.au/afd/home) for introduced mammal species and for birds, and IUCN mapping for reptiles (https://datadryad.org/stash/dataset/doi:10.5061/dryad.83s7k). The latter source contains distribution data as polygons; in ARCMap we intersected this with the bioregional mapping (DAWE 2020) to code bioregions (species present or absent) and produce display for the reptiles that were similar to those for the mammals and birds.

5.2 Outputs

Exemplar maps, showing all the detections in the AZM National Dataset for one native mammal, one reptile, and introduced mammal, are shown in Figure 12. The full suite of maps for every species in the AZM National dataset, broken into decadal intervals, is provided in the individual species profiles listed in Appendix 3.

Key observations from the species detection maps are:

- Track-based surveys are a valuable tool to document the distributions, including the distributional limits, of species. For example,
  - The Wiluna MKK Rangers, Kanyirninpa Jukurrpa (Martu), Karajarri rangers, and the Muru Warinyi Ankkul Rangers have all detected great desert skinks near the edge, or outside, the distribution recognised by scientific sources, summarised in mapping by the IUCN Red List (Figure 12a). The records represent significant range extensions.
  - Rangers, working with WA DBCA, have recorded many detections of bilbies in the northwest of the project area, increasing knowledge about the distribution of the species (Figure 12b).

    - Some introduced species, such as rabbits and foxes, are recorded regularly further north than their core distribution (Figure 12c).
- Track-based surveys are not the most useful technique for some desert species.
    - Smaller mammals, birds and reptiles are often difficult to identify from their tracks.
    - Species that prefer rockier habitats, including donkeys and goats, as well as rock-wallabies, are probably better surveyed using other methods.
    - Some species often targeted during track-based may be better sampled with alternative survey techniques. A good example is the two species of marsupial mole *Notorcytes caurinus, N. typhlops*, with only 34 detection records in the AZM National Dataset between them, despite being a species of great interest to many groups who survey. Digging mole sampling trenches is a much better survey technique for detecting marsupial moles.
- The time series is longest for the southern deserts, whereas data from the northern deserts has only accumulated in the AZM National Dataset in the last 20 years (e.g. Figure 12c bilby). We are aware that there are other, older data from the northern deserts that are not captured in the National Dataset.

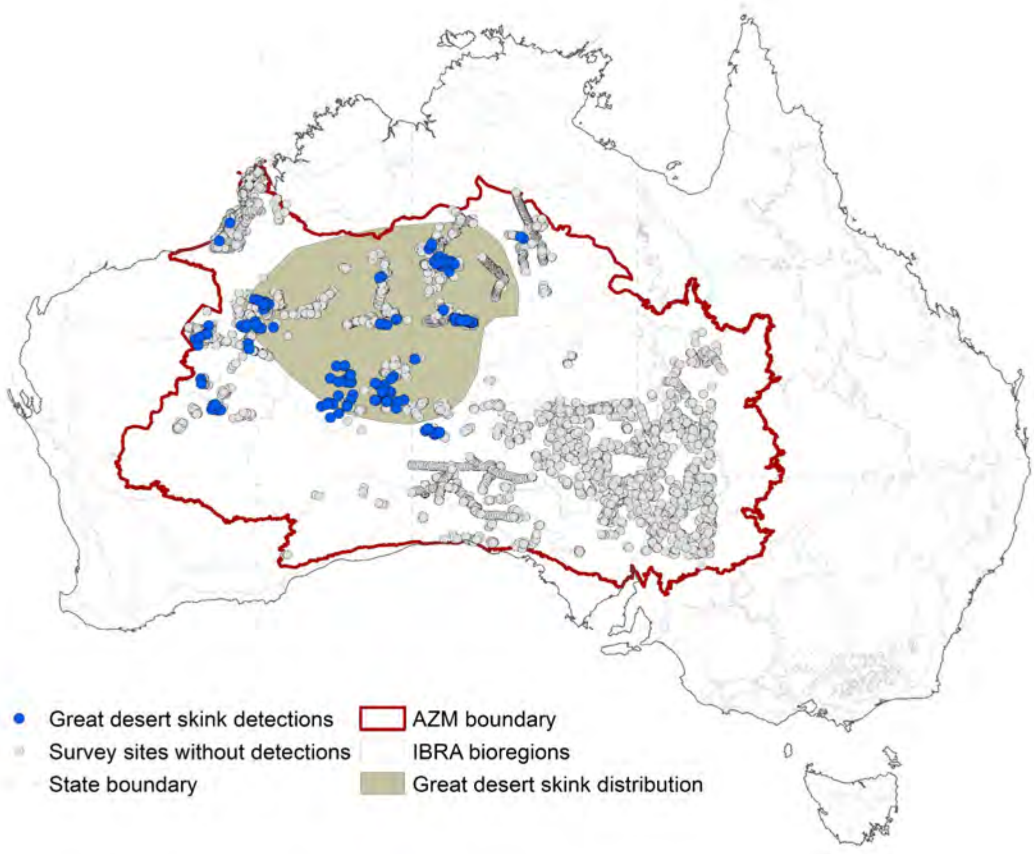


Figure 12a. Exemplar detection map for a reptile species, the great desert skink (Liopholis kintorei) recorded in the AZM National Dataset. Presence records are blue circles, all other sites where great desert skinks were not recorded are grey circles, and the project boundary is red. The background distribution in the map (green) is from mapping used by the IUCN Red List. This example highlights how AZM detection records can extend the known distribution of some species.

Native mammal: Bilby

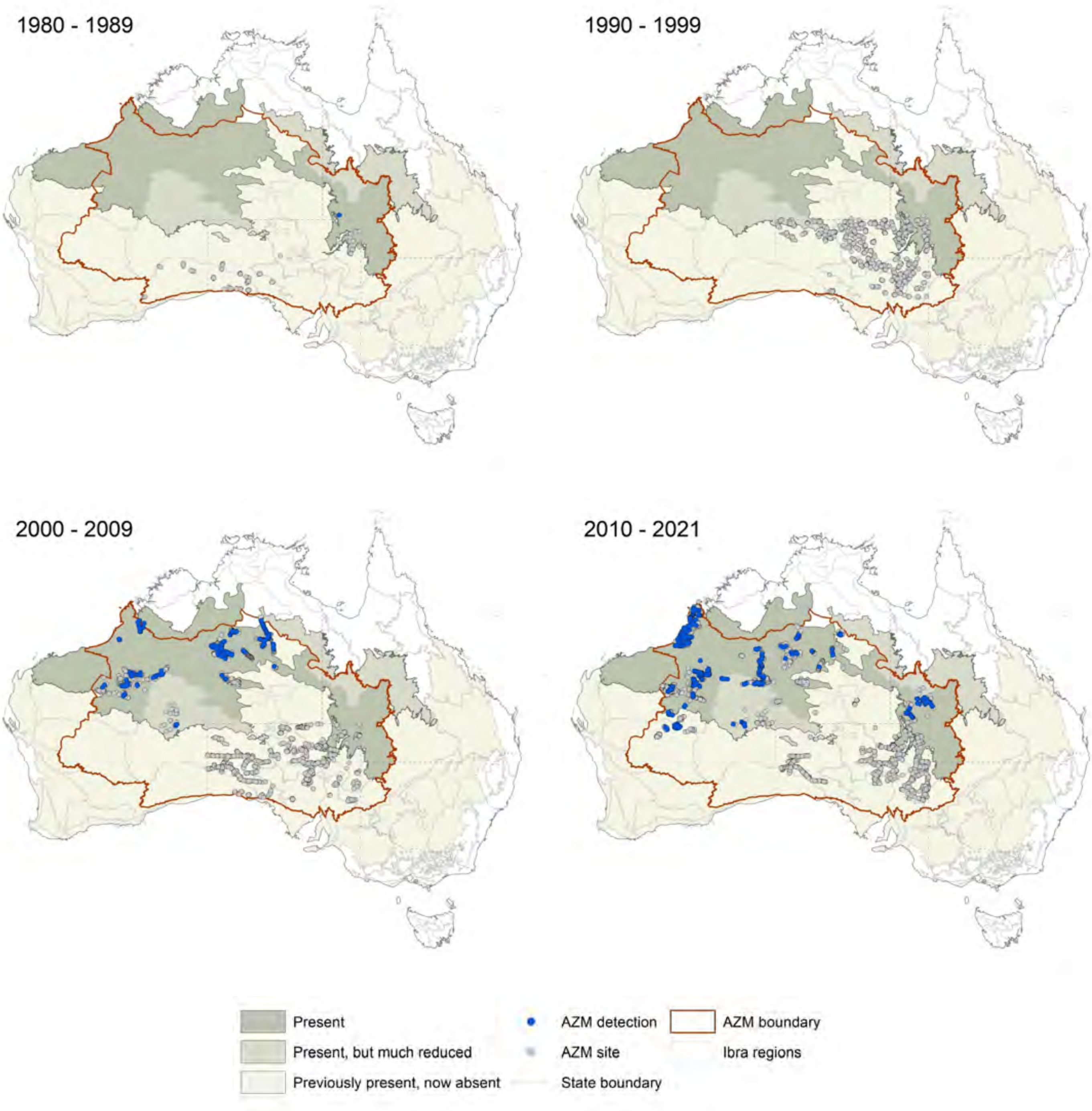


Figure 12b. Exemplar detection maps for a native mammal species (the bilby) recorded in the AZM National Dataset. Each map shows, for the decade indicated, presence records in blue circles, all other sites in the AZM National Dataset in grey circles, and the project boundary is red. The background distributions in each map are based on data obtained from the Mammal Action Plan.

Introduced mammal: European fox

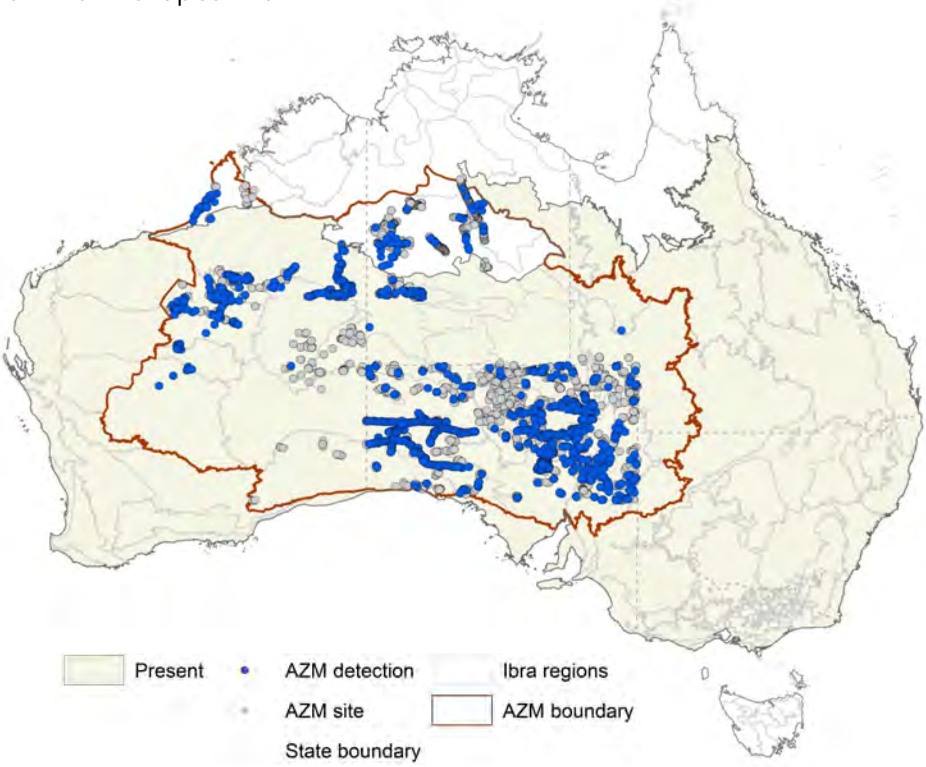


Figure 12c. Exemplar detection map for an introduced mammal species (fox) recorded in the AZM National Dataset. Presence records are in blue circles, all other sites where the fox was not recorded in grey circles, and the project boundary is red. The background distribution in the map is from data from the Australian Faunal Database.

Fox, and its tracks. Images: Arid Recovery, N. Rakotopare.

Section 6 – Species detection rates across bioregions

Key points:

- *We produced a series of maps to explore coarse-scale spatial variation in detection rate for each species.*
- *For a subset of species, we also looked at changes in the bioregional detection rates over time. However, this is only possible for species that are reasonably common, whose sign is usually recorded if detected, and which are not the subject of focussed surveys (e.g. spinifex hoping mice, cats, camels).*
- *The full set of detection maps, and graphs of changes in detections over time (if available) are included in the individual species profiles.*

6.1 Approach

We created detection rate maps to explore spatial variation in detection rates. We calculated the detection rate for every bioregion, by dividing the number of detections of that species in the bioregion, by the total number of surveys carried out in the same bioregion. In ARCMap, we attributed each bioregion with the detection rate for each species, and used a standard shading scale to display the spatial variation in detection rates.

For some species, we also calculated the detection rates in each bioregion in five-year blocks, to explore temporal patterns in detection rate, at a coarse level. We note this is not a robust trend analysis, because of variation in the spatial and temporal sampling of sites over time. However, for species that are detected moderately often (to avoid large swings in detection from sampling bias), have tracks that are easy to identify (so their sign tends to be recorded if it is seen), and are not the subject of targeted surveys (which cause inflated detection rates), this approach may give some indication of coarse change over time.

6.2 Outputs

An example of a map displaying the spatial variation in the detection rates (in this case, for cats) is shown in Figure 13. Cats were detected more frequently in northern and western bioregions than southern and eastern bioregions. When detection rates in each bioregion are calculated for each five-year interval, with the values for north and west bioregions averaged, and the values for south and east bioregions averaged, it suggests that cat detections have remained stable over the past 15 years in the northern and western deserts but may have increased in the southern and eastern deserts.

Detection maps for species are available in the species profiles listed in Appendix 3.

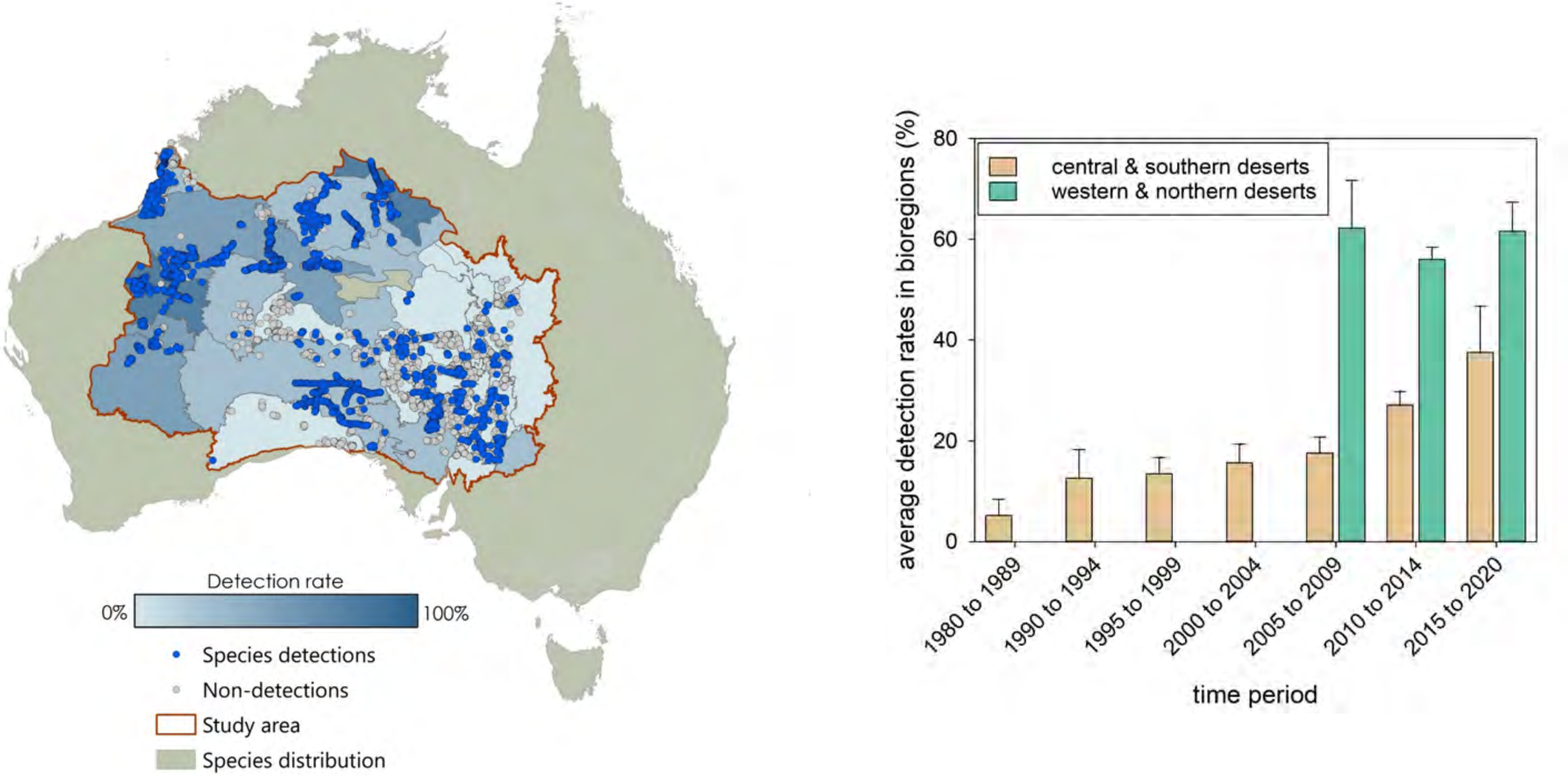


Figure 13. The map shows spatial variation in the detection rates of cats, at bioregional scale. Blue dots show surveys where cats were recorded, grey dots show surveys where cats were not recorded. The graph shows change in bioregional detection rates over time, with the average across northern and western bioregions shown separately from the average across the southern and eastern bioregions. Whiskers show standard errors of the means.

Section 7 – Species distribution models

Key points:

- *We used species distribution modelling (SDM) to predict suitable habitat for 30 species and 4 species groups across the project area, based on the presence records in the AZM National Dataset. The analysis considered climate variables like annual, seasonal and daily temperature and rainfall; landform variables like elevation and slope; soil variables like clay content; and habitat factors like the amount and condition of vegetation (NDVI) and fire frequency.*
- *This mapping can help identify places that groups and individuals can target in future surveys.*
- *SDMs have been used to optimise the design for a regional monitoring program for South Australia.*
- *A subsequent iteration of the mapping, that combined the AZM data with data available from the Atlas of Living Australia, were used to design identify gaps in the national coverage of track-based monitoring sites that could be priorities for future sampling in regional and national-scale monitoring.*

7.1 Approach

Species distribution models are the most widely used modelling framework for predicting where species are likely to occur across a landscape. We mapped the most suitable habitat areas for species of interest across the project area, based on the detection data submitted to the AZM project. The purpose of this modelling was to:

- Provide information on the climatic, topographic and environmental factors that influence the distribution species.
- Produce predictive maps (limited to within the AZM project boundary) that could highlight areas for future surveys or conservation management (refuge areas, or indicate areas where management could be most effective).
- Identify regions with highest likely species richness or good representation of key species, that may be potential areas for focussing future sampling (e.g. where species richness is high).
- Provide a foundation for developing optimised survey design recommendations for regional and national monitoring programs.

We created SDMs for 30 species in the AZM National dataset, each with >20 detections (but usually much more). We also created SDMs for an additional four species groups:

- Small mammals (in Table 11a: *Small mammal", "Native rodent", "Dunnart", "Long-haired rat", "Southern marsupial mole", "Northern marsupial mole", "Sandy inland mouse", "Central pebble mound mouse", "Fat tailed pseudantechinus", "Kowari", "Forrests short tailed mouse", Central short-tailed mouse*);
- Large macropods (in Table 11a: *"Euro", "Red kangaroo", "Large macropod"*);
- Goannas (in Table 11a*: "Goanna","Goulds goanna", "sand goanna", "Yellow- spotted monitor", "Floodplain monitor, "Blackheaded monitor", "Short tailed pygmy monitor"*); and
- Feral livestock (in Table 11a: *"Cow", "Donkey", "Horse"*).

We compiled a list of 23 climatic, topographic and environmental variables thought to broadly influence species habitat preferences across arid Australia (Table 5). Note that the layers used must be consistently available across the extent of the modelled area (AZM project boundary), so any localised spatial data, or site-level data recorded during surveys (e.g. substrate type or vegetation cover), cannot be included. In addition, it is difficult to include some biotic factors that might influence the distribution of species, such as predators or disease as maps of these variables are also needed across the entire study region.

To refine our list of spatial variables, we removed highly correlated variables from the analysis. This reduced our candidate set to 18 variables: annual rainfall, rainfall in driest period, mean annual temperature, diurnal temperature range, isothermality, aspect, elevation, topographic relief, terrain roughness, topographic wetness index, distance to permanent natural water features, NDVI, soil bulk density, soil nitrogen content, soil fertility, soil phosphate content, soil clay content, soil calcrete content and fire frequency.

We modelled habitat suitability for species with >20 track-based presence records using *Maxent*. SDMs use either presence-only or presence-absence data to predict the distribution of species. Absence data were recorded inconsistently in the AZM National Dataset (of the 69 datasets we received, seven contained confirmed absence records), thus we used presence-only data. Presence-only SDMs must account for sampling bias, where a species might appear to be located in a particular area, but this might be an artefact of only looking in particular locations. Track-based surveys in the deserts are generally biased towards tracks/roads. We therefore modelled sampling bias as a function of accessibility and the location of existing surveys: we generated 10,000 random samples from the background landscape weighted positively to the density of the occurrence data in the study region and towards more accessible areas. This offset the fact that sampling occurred in higher densities in these areas.

Table 6. The physiographic, bioclimatic, edaphic, land cover and disturbance-related layers recorded consistently across the AZM project boundary used in the species distribution modelling. All layers are stored on a private cloudstor.

Attribute name	Attribute	Source Dataset(s)	Units of measurement	Description of layer, and any transformation performed
aus12	Annual Precipitation	ANUCLIM-BIOCLIM (ANU-Fenner School)	mm	Annual Precipitation - The sum of all the monthly precipitation estimates.
aus13	Precipitation of Wettest Period	ANUCLIM-BIOCLIM (ANU-Fenner School)	mm	Precipitation of Wettest Period - The precipitation of the wettest week
aus14	Precipitation of Driest Period	ANUCLIM-BIOCLIM (ANU-Fenner School)	mm	Precipitation of Driest Period - The precipitation of the driest week
aus16	Precipitation of Wettest Quarter	ANUCLIM-BIOCLIM (ANU-Fenner School)	mm	Precipitation of Wettest Quarter - The wettest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
aus01	Annual Mean Temperature	ANUCLIM-BIOCLIM (ANU-Fenner School)	degrees C	Annual Mean Temperature - The mean of all the weekly mean temperatures. Each weekly mean temperature is the mean of that week's maximum and minimum temperature.

Attribute name	Attribute	Source Dataset(s)	Units of measurement	Description of layer, and any transformation performed
aus02	Mean Diurnal Temperature Range	ANUCLIM-BIOCLIM (ANU-Fenner School)	degrees C	Mean Diurnal Range (Mean(period max-min)) - The mean of all the weekly diurnal temperature ranges. Each weekly diurnal range is the difference between that week's maximum and minimum temperature.
aus03	Isothermality	ANUCLIM-BIOCLIM (ANU-Fenner School)	dimensionless	Isothermality 2/7 - The mean diurnal range (parameter 2) divided by the Annual Temperature Range (parameter 7). Similar to a standard deviation.
aus04	Temperature Seasonality (C of V)	ANUCLIM-BIOCLIM (ANU-Fenner School)	dimensionless	Temperature Seasonality (C of V) - The temperature Coefficient of Variation (C of V) is the standard deviation of the weekly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). For this calculation, the me
aus05	Maximum Temperature of Warmest Period	ANUCLIM-BIOCLIM (ANU-Fenner School)	degrees C	Maximum Temperature of Warmest Period - The highest temperature of any weekly maximum temperature.
aus06	Minimum Temperature of Coldest Period	ANUCLIM-BIOCLIM (ANU-Fenner School)	degrees C	Minimum Temperature of Coldest Period - The lowest temperature of any weekly minimum temperature.
aus07	Temperature Annual Range	ANUCLIM-BIOCLIM (ANU-Fenner School)	degrees C	Temperature Annual Range (5-6) - The difference between the Max Temperature of Warmest Period and the Min Temperature of Coldest Period.
fert	inherent rock fertility	DEWHA-ERIN/GA	index	An index of inherent rock fertility derived by de Vries (2009) for use in modelling spatial patterns of biodiversity. The 1:1 M surface geology was reclassified using a scheme from the Broad Classification of Parent Material for Pedologic Purposes (Gray and Murphy 1999). Rock voids without data including lakes were filled by neighbourhood statistics.
ntotn0	plant-available soil nitrogen	CSIRO-NLWRA	kgN ha-1	Mean annual store of total plant-available soil nitrogen (kgN ha-1) in the “Base” (pre-1788) scenario (Raupach et al. 2001). Modelled soil property sourced at 5km grid resolution were cubic-resampled to 1km grid; small areas without data including lakes were filled by neighbourhood statistics.
ptotn0	plant-available soil phosphorous	CSIRO-NLWRA	kgP ha-1	Mean annual store of total plant-available soil phosphorus (kgP ha-1) in the “Base” (pre-1788) scenario (Raupach et al. 2001). Modelled soil property sourced at 5km grid resolution were cubic-resampled to 1km grid; small areas without data including lakes were filled by neighbourhood statistics.
roughness	terrain roughness	ANU-Fenner School	%	Topography - Standard deviation of the 9 second grid cells according to the values of mrVBF and mrRTF (i.e. mrVBF & mrRTF both < 2.5)
twi	topographic wetness index	ANU-Fenner School	dimensionless	Erosion-Deposition - Maximum of the Topographic Wetness Index (TWI) values in each 36 second grid cell. TWI was calculated as ln(a/tan ß) where a is the upslope area per unit contour length and tan ß is the local slope (dimensionless)
dem1km	digital elevation model	CSIRO/GA	m	Elevation in metres. A resampled version of the 9-second digital elevation model for Australia (version 3) using the cubic algorithm. Potential to

Attribute name	Attribute	Source Dataset(s)	Units of measurement	Description of layer, and any transformation performed
				enhance this representation of the land by including minor islands from the coastline mask and assigning altitude values near sea-level to updated grid-cells representing low-lying islands and coastal flats.
relief	topographic relief - elevation range	ANU-Fenner School	m	Elevation Diversity - Range of the 9 second DEM elevation values in each 36 second grid cell (m)
distanywater	weighted distance to fresh water (permanent or non-permanent)	CSIRO/GA	geographic degrees	Euclidean distance (in geographic degrees) from any point in a grid to any water feature weighted by minor/major waterbody or watercourse. Water features were sourced from GA topographci data.
calcrete	calcrete in or below soil profile	ASRIS/CSIRO	presence	Relative presence of calcrete in or below the soil profile – calculated as the average of up to 5 PPF's (McKenzie et al. 2000) per map unit of the 1:2.5M Australian Atlas of Soils. Small areas without data including lakes were filled by neighbourhood statistics.
clay	clay content in soil profile	ASRIS/CSIRO	%	Median %clay content – calculated as the average of up to 5 PPF's (McKenzie et al. 2000) per map unit, weighted by the depth of the A and B horizon, of the 1:2.5M Australian Atlas of Soils. Small areas without data including lakes were filled by neighbourhood statistics.
pedality	soil structure (grade of pedality)	ASRIS/CSIRO	grade	Median grade of pedality (soil structure) – calculated as the average of up to 5 PPF's (McKenzie et al. 2000) per map unit, weighted by the depth of the A and B horizon, of the 1:2.5M Australian Atlas of Soils. Small areas without data including lakes were filled by neighbourhood statistics.
soildepth	solum depth	ASRIS/ANU-Fenner School	m	The weighted average of the solum depth values (m) (McKenzie et al. 2000) per map unit of the 1:2.5M Australian Atlas of Soils (data sourced from Western and McKenzie 2004). Small areas without data including lakes were filled by neighbourhood statistics.
ndvi 250	normalised difference vegetation index	Google Earth Engine	dimensionless	The normalised difference vegetation index. Created via google earth engine 'MODIS/006/MOD13Q1' satellite data
fire frequency	Number of fires since 2000	MODIS	m	Fire frequency since 2000, based on MODIS imagery, proceed by B. Murphy (pers. comm)

Limitations of the SDMs

SDMs are a useful tool, but they have some limitations. Specifically:

- SDMs may not always provide perfect results. The SDM approach assumes that species are at equilibrium with the environment, that we have sampled both the species and the environmental data perfectly, and that we have incorporated all major factors determining species range limits. But in reality, species respond dynamically to change, and many biotic and abiotic processes are acting on the species, not all of which can be incorporated in the modelling.

- SDMs predict the distribution of *potential* suitable habitat for species, rather than their actual distribution. Because of this, SDMs can have trouble accurately predicting the distributions of species with small, restricted ranges (i.e. they will tend to 'overpredict' the distribution extent).
- The predictions from SDMs are only as good as the detection data the goes into them.
- Presence-only models, like the ones built here, are influenced by sampling bias. If not accounted for, the SDMs may predict the locations of surveys rather than the distribution of species themselves. Separating sampling bias from true relationships between species and the environment is notoriously difficult.
- Environmental variables such as soil variables are poorly mapped in the arid regions of Australia.
- Given the nature of the data submitted to the AZM project, the SDMs will be most robust for species that occupy areas with sandy substrates; they will not work as well for animals that prefer to spend time in rocky habitats (like donkeys (*Equus asinus*), or Warru).

7.2 Outputs and applications

Exemplar outputs from the modelling for one widely distributed species (dingo), and another with a restricted distribution (dusky hopping mouse) are shown in Figure 14. The SDMs for the 30 species included in this analysis have also been included in the individual species profiles, listed in Appendix 3. SDMs developed for South Australia were used in a detailed study to design future track-based monitoring for that state. Finally, the AZM National Dataset was combined with data from the Atlas of Living Australia, to identify priority areas for future surveys in a national-scale monitoring program using track-based surveys.

Sand dune, Great Sandy Desert. Image: N. Rakotopare.

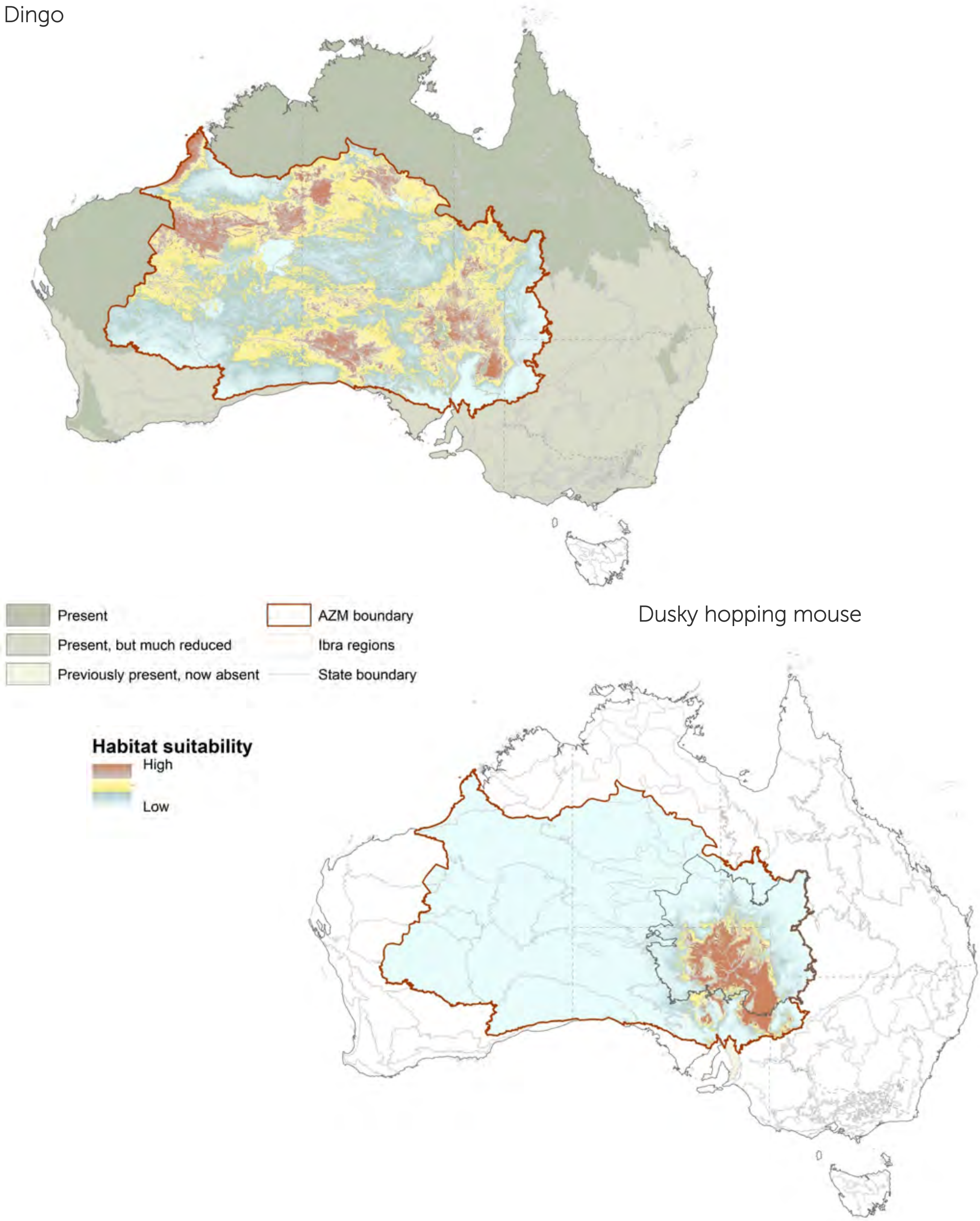


Figure 14. Predicted habitat suitability for two native mammal species, the dingo (top) and the dusky hopping mouse (bottom), based on records in the AZM National Dataset. The accepted distribution for each species is represented by the grey-green colour (dingo) and the grey outline (dusky hopping mouse).

Section 8 – Trend analyses

Key points:

- *Many project partners are interested in changes in animal populations over time. To look at this question, you need time series information, with sites re-surveyed several times over several years, because otherwise the variability in species abundance across areas and across time will likely bias analyses of detection rates.*
- *About three-quarters of AZM sites were only visited once, and a further 15% were only visited twice (over two different years). Time series information from repeated visits to sites in different years is limited.*
- *We developed a pragmatic approach to enhancing the data utility, by looking for regions where the same 30 km^2 grid cell had been resampled over time, even if the exact location of the site within that grid cell had varied. With this approach, we identified six regions where sites had been re-surveyed at least five times over five or more years. For these regions, we were able to explore the climatic and environmental drivers for changes in detections for the more commonly detected species.*
- *The work also highlights that to understand changes in detections across a broader suite of species (including rarer species), and in priority areas, setting up a robust monitoring design from the outset that can provide the data needed is essential.*

8.1 Approach

A key question shared by many partners in the AZM Project is whether species of interest are changing in abundance over time. To answer this question, time series information from sites that have been revisited over several years is needed. However, most sites (73%) in the AZM National Dataset are only visited once, 15% are visited twice, 4% are visited three times, and only 7% are visited four or more times (Figure 15). Repeat visits within the same year, which are conducted to estimate detectability rather than change over time, count as 'one site visit' in this analysis. There was also considerable variation in where sites were located and surveyed each year, as well as variation between years in how many sites are visited and surveyed. This can cause detection rates to be heavily influenced by the interacting effects of variability in abundance across sites, and variability in abundance changes over time at different sites.

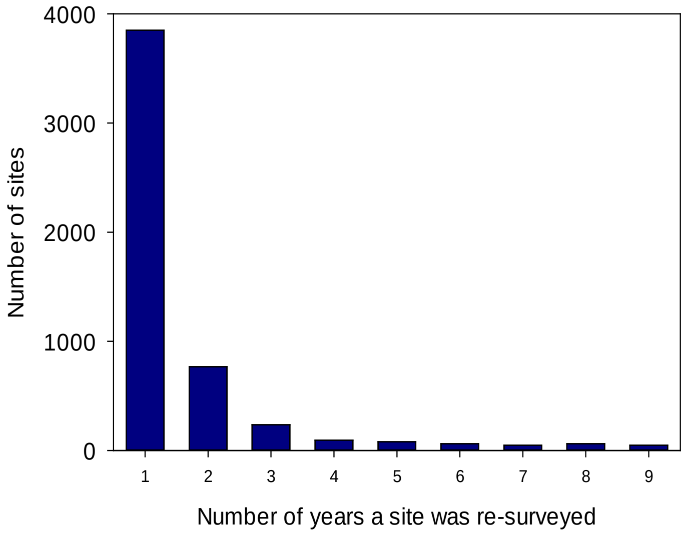


Figure 15. Frequency histogram showing the number of times (years) that each site in the AZM Dataset has been visited and surveyed.

We developed an approach for examining national/regional trends in detection rates that mitigated against potential spatial and temporal biases, given sites were rarely re-visited over time. We identified regions that had been sampled relatively consistently across space and time, by gridding the study area with 30 km by 30 km cells and finding cells that had been sampled 1-5 times over 1 to >5 years (Figure 16). Areas that have had sufficient re-surveying to allow for trend analysis are limited (Figure 17).

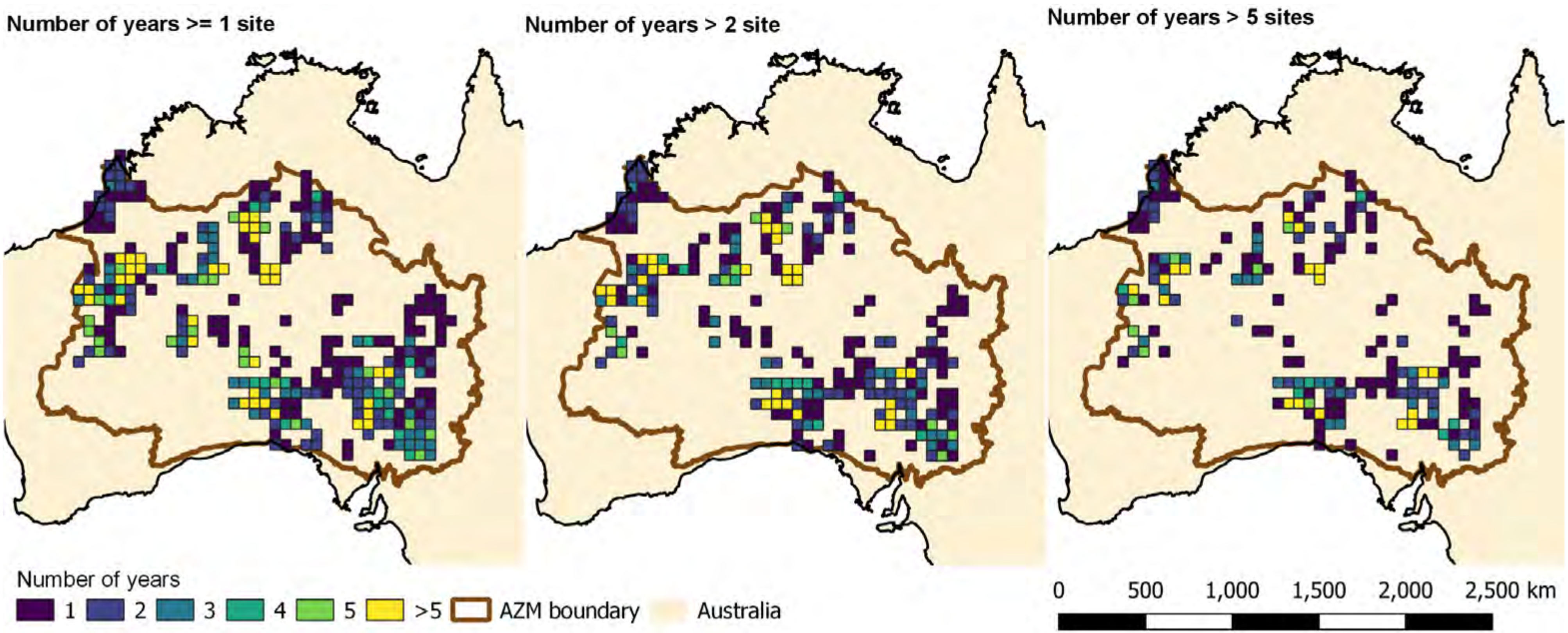
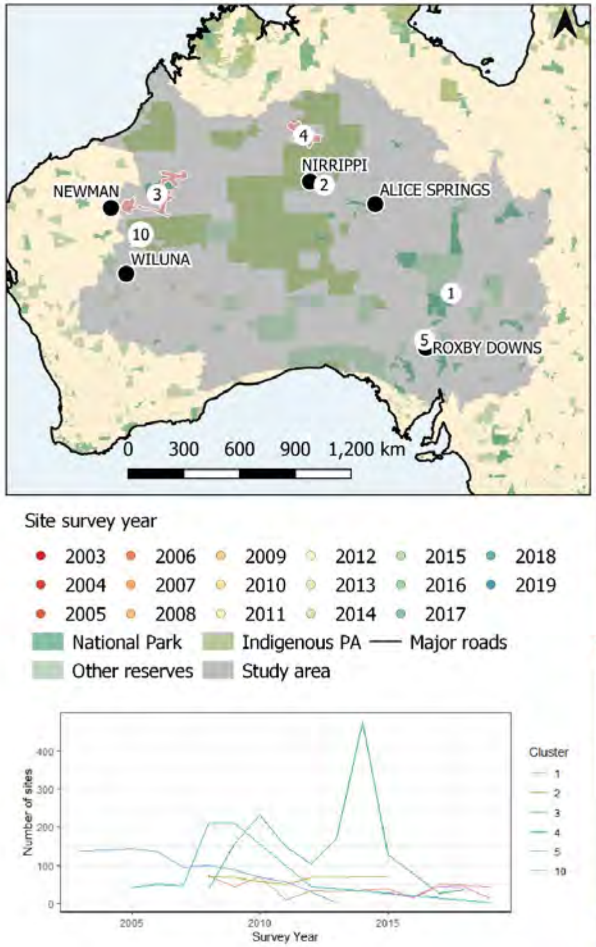
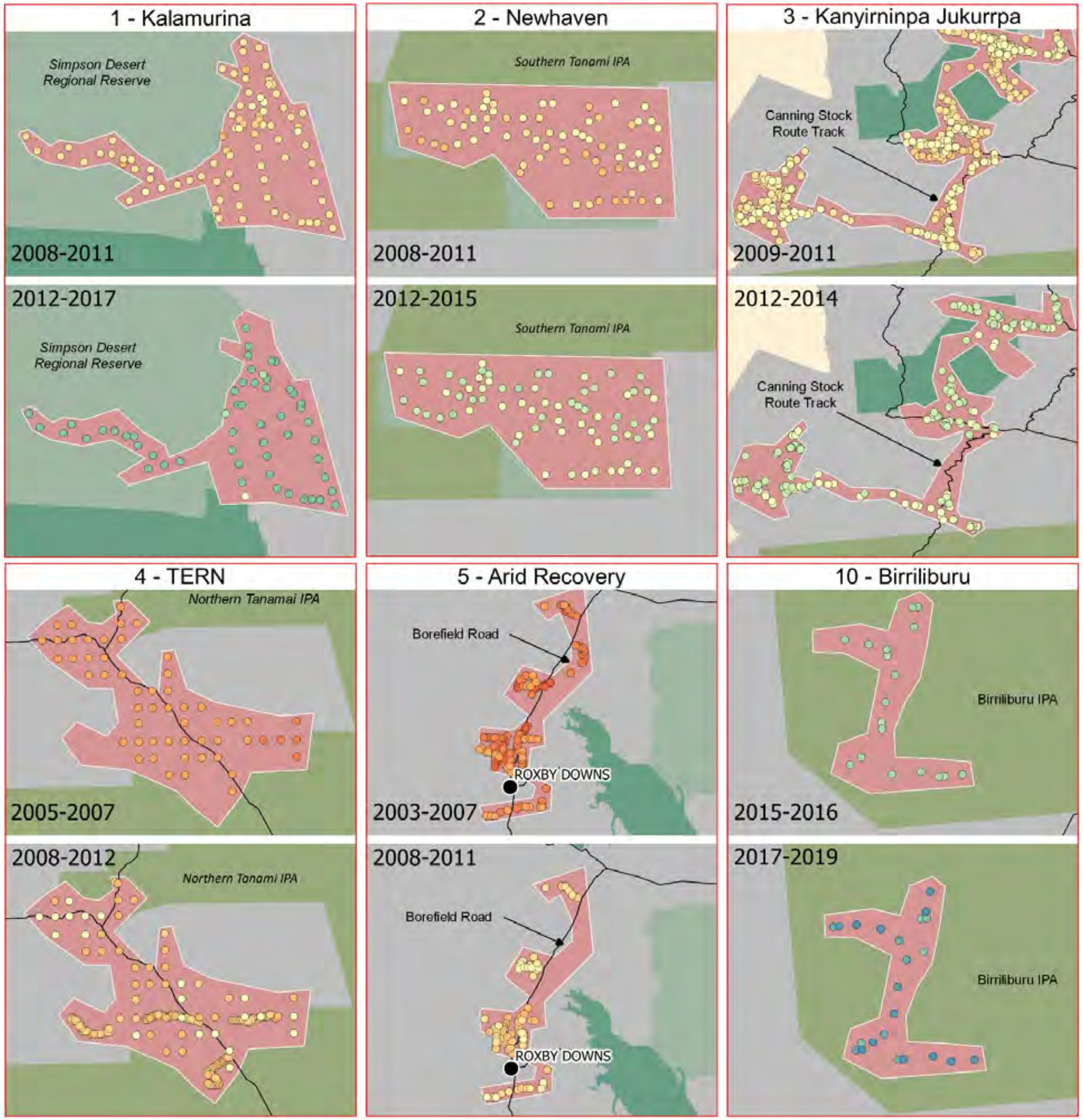


Figure 16. The number of years sites have been re-surveyed using a standardised monitoring method within the grid cell, with a) at least one site; b) at least two sites; and c) at least five sites. The figures display 60 km by 60 km grids for visibility, but the analysis used 30 km by 30 km grids.





Regions with spatial clusters of sites sampled consistently over time.

To be confident in identifying real trends over time, we need consistent sampling of the same area across multiple years. Ideally, repeated surveys should vistit the same site each year but sampling consistently within the proximity of previous surveys is the next best thing.
Each site shows the distribution of sites between two sampling time periods

Figure 17. Some examples of areas with over 5 sites sampled within a 30 km by 30 km grid, in multiple years.

8.2 Outputs

Within these locations, enough detections to make inferences on trends were available for only some species. For these species, we examined environmental and climatic drivers for changes in detection rates, and looked for common patterns across the six locations. For example, brush-tailed mulgara detections increased with increasing green vegetation biomass (as estimated by NDVI), and decreased after fire. Cat detections also increased with green vegetation biomass, and also increased straight after fire at some sites (the opposite pattern to mulgara).

The complete analysis is due to be completed in early 2022. Although the analytical approach is providing insight to the drivers for changes in detections for more common species, the work also highlights that to understand changes in detections across a broader suite of species (including rarer species), and in priority areas, setting up a robust monitoring design from the outset that can provide the data you need is very important.

Section 9 – Designing a track-based monitoring program for South Australia

Key points:

- *We used existing survey data to model what drives differences in occupancy across the range of a species, and to estimate the detectability of each species. Occupancy is the proportion of sites that have sign of a species; detectability is the probability of seeing and recording sign, if the sign is there.*
- *Changes in occupancy were then simulated, and the statistical power of different monitoring designs was estimated. We used a 'spatially explicit' simulation as we aimed to predict occupancy across the whole study area, including in places that haven't been previously surveyed by AZM partners.*
- *We explored the outcomes of differing survey designs by changing the number of sites surveyed, the survey frequency (within and across years), and where sites were positioned in the landscape.*
- *Overall, we found that if we monitored approximately 200 sites every year (with a small subset re-surveyed twice within a year to improve detectability estimates), with those sites located to optimise detections for all species, we would detect moderate to marked declines in most priority species.*
- *Increasing the number of sites surveyed, and optimising their locations for both the rare and common species, would increase our power to detect changes.*
- *One alternative to surveying 200 sites every year, was to reduce survey frequency whilst also increasing the number of sites in the program.*
- *As well as informing monitoring design for the South Australian case study, the work provides general guidance for designing a large-scale, regional monitoring program using track-based surveys.*

9.1 Approach

For a monitoring program that aims to detect change in species of interest, key decisions need to be made about the number of sites, where the sites are located, and how often they sites are re-surveyed. Getting these decisions right is important, not just so the monitoring can detect the changes you are interest in, but also so that you don't waste resources by sampling many more or less sites than you need to achieve your monitoring objective.

We used existing 2-hectare plot data from South Australia to design a track-based monitoring program for this region. The program aimed to detect significant changes in the populations of 11 priority species, including both common and rarer species. The monitoring program may be carried out by multiple people and groups, each collecting data in their local area, and collaborating to collate data, in order to examine regional trends. The same approach can be applied to design monitoring for other regions, or even for a national monitoring program.

We carried out a series of spatially explicit simulations to optimise the design of future track-based monitoring in South Australia. The steps are summarised described below:

We gathered information for the simulation

We used existing data, from past surveys in South Australia, for the simulation. The existing data were collected from 550 2-ha plot sites, spread over 730,000km^2. Sites had been surveyed (once to several times) over a 13 year period (Figure 18). On average, 186 sites were surveyed each year.

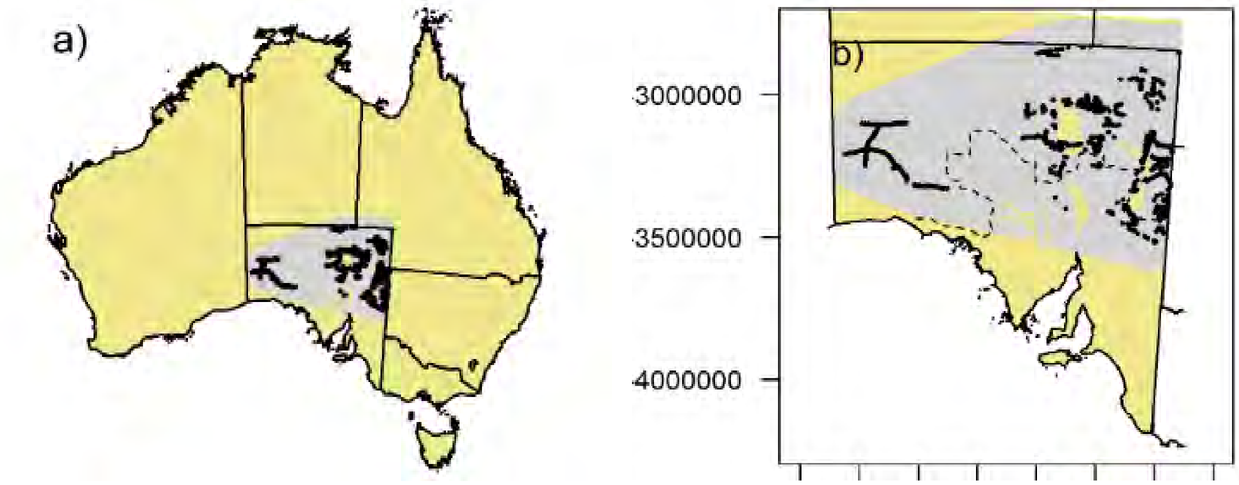


Figure 18: Location of 2-ha plot sites (black dots) in (a) Australia, and (b) South Australia (b). The grey shaded region is the study area. The black dotted line is the dog-proof fence. Salt lakes or pans, were not included in the analysis.

We decided what species we wanted to monitor

In a workshop involving government and non-government stakeholders from South Australia, 11 priority species were selected to be the focus of the monitoring program. They included:

- Introduced species with widespread distributions: camel (*Camelus dromedaries*), red fox (*Vulpes vulpes*), cat (*Felis catus*), rabbit (*Oryctolagus cuniculus*), and cow (*Bos* spp.). Monitoring these species is important for understanding the level of threat they pose, and informing management actions and outcomes.
- Native species with widespread distributions, and of cultural significance to Traditional Owners: dingo (*Canis lupus dingo*), emu (*Dromaius novaehollandiae*), large macropods (*Osphranter rufus*, *Macropus fuliginosus*), and goanna (*Varanus* spp.).
- Native species with limited distributions and conservation significance: crest-tailed mulgara (*Dasycercus cristacauda*), dusky hopping mouse (*Notomys fuscus*), great desert skink (*Liopholis kintorei*).

We built species distribution models (SDMs) to inform the simulation

We used the existing survey data from the 550 sites to build SDMs that predicted the distributions of each of the 11 priority species, based on climate, terrain, soil and vegetation data. We used different modelling approaches for each species and combined them in an 'ensemble' model, which predicts the probability of occupancy for each species, within a 1 km^2 grid cell that we overlaid on the study area (e.g. Figure 19). We also estimated single-visit detection probabilities from the existing dataset.

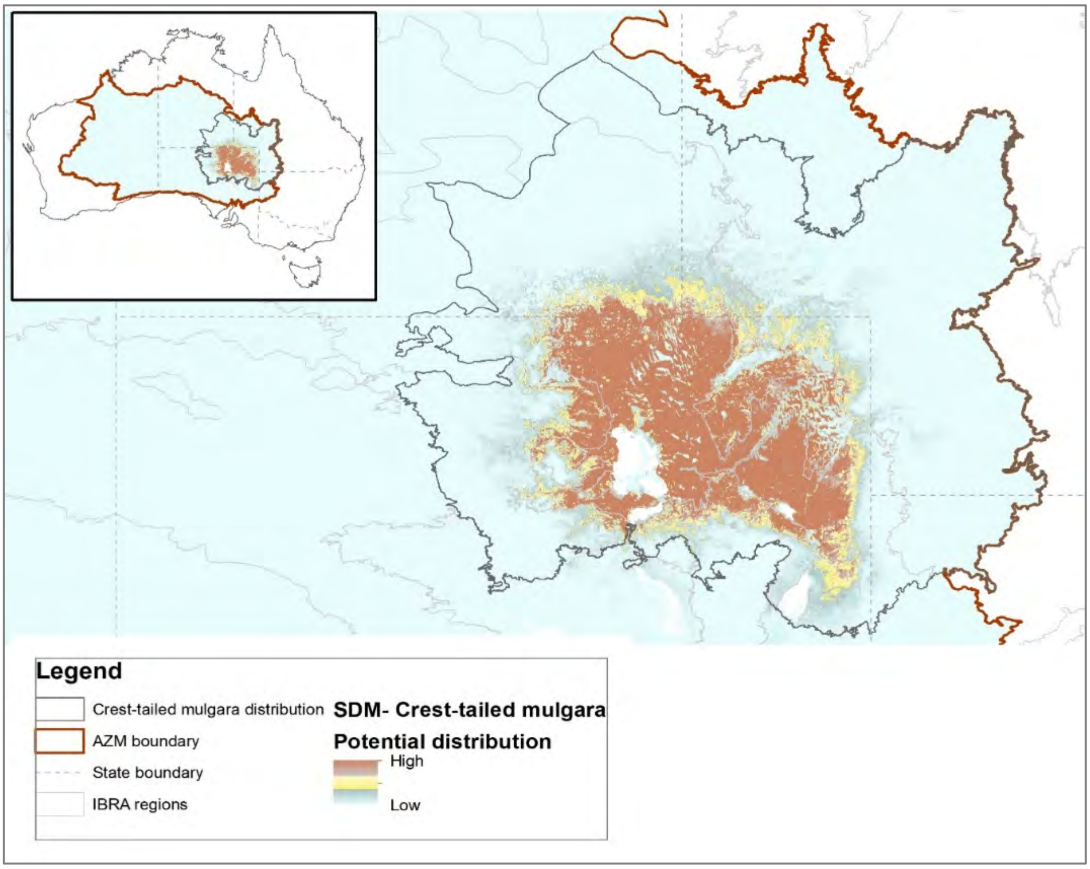


Figure 19: Map shows an example output of a species distribution model (SDM) for crest-tailed mulgara. Areas where crest-tailed mulgara are likely to be found are coloured brown. Where they are least likely to be found are coloured light blue. The known bioregional distribution of crest tailed mulgara is outlined in grey. The red outline is the AZM study boundary within Australia and encompasses the sandy-desert regions.

We considered different locations for sites

We used a spatial prioritisation tool called Zonation. Using the SDM maps as input layers for Zonation, we identified regions in the landscape with the highest predicted occupancy and representation of the 11 priority species. We then considered three different scenarios for positioning sites (Figure 20):

- Scenario 1: Only a subset of the existing network of 2-ha plots were monitored.
- Scenario 2: New site locations were optimised to target all 11 priority species equally.
- Scenario 3: New site locations were optimised to target just the two species of conservation concern.

We simulated future changes in occupancy

We simulated both increases and decreases in occupancy of the 11 priority species, during each year of a future monitoring program lasting 15 years. We then simulated different sampling designs (varying the number of sites from 50 to 700, and the survey frequency from once a year to once every 5 years), in the three different location scenarios. The simulations were each run 1000 times to calculate the statistical power - the statistical power in this case is the proportion of times that the simulated change in occupancy was detected from the simulated datasets. A summary of the approach is in Figure 21, and an example of the outputs that the simulation produces is in Figure 22.

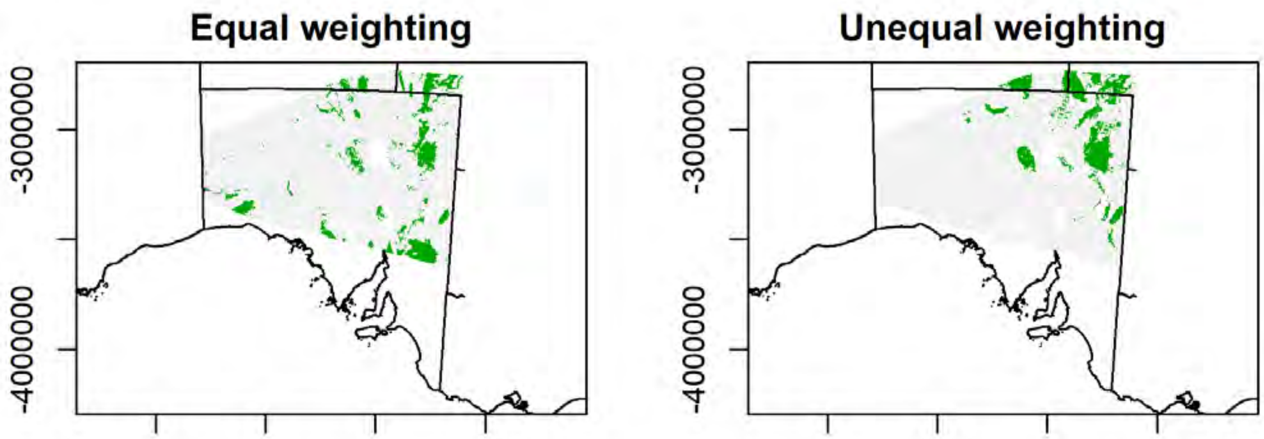


Figure 20: The areas prioritised by Zonation (green) for positioning sites, in scenario 2: when all species are weighted equally (left) and in scenario 3: when the range-restricted species, crest-tailed mulgara and dusky hopping mouse, are prioritised (right). Notice how the best places to position sites changes when the design scenario changes.

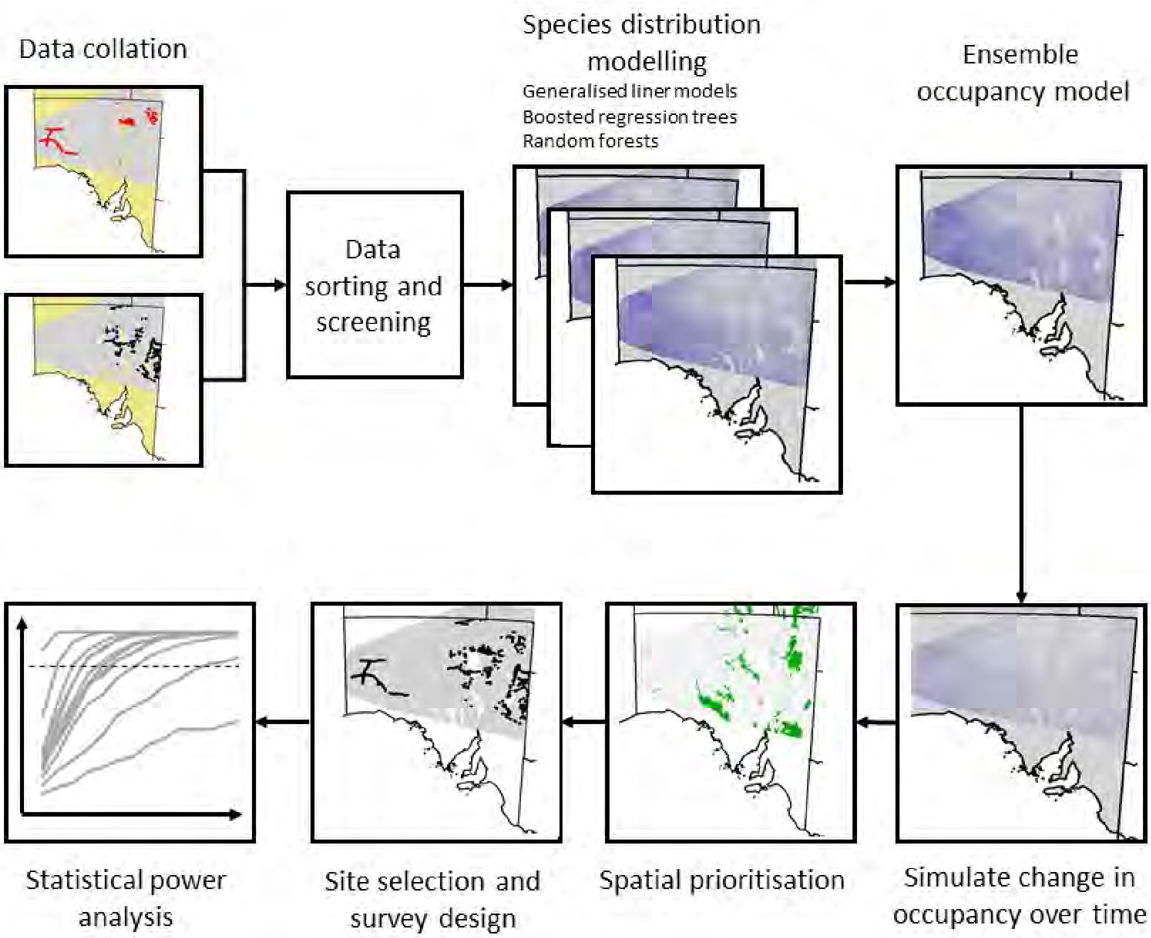


Figure 21: Spatially explicit power simulation framework. Species distribution models (SDMs) were built for each priority species. For each of three scenarios about where sites are located in the landscape (i.e., use existing sites, place sites where SDMs indicate are the best places for all species, or place sites to prioritise rare species), we then simulated changes in occupancy over time, and then applied a spatially explicit simulation tool to evaluate the likely performance of alternative monitoring designs at detecting occupancy trends over the next 15 years.

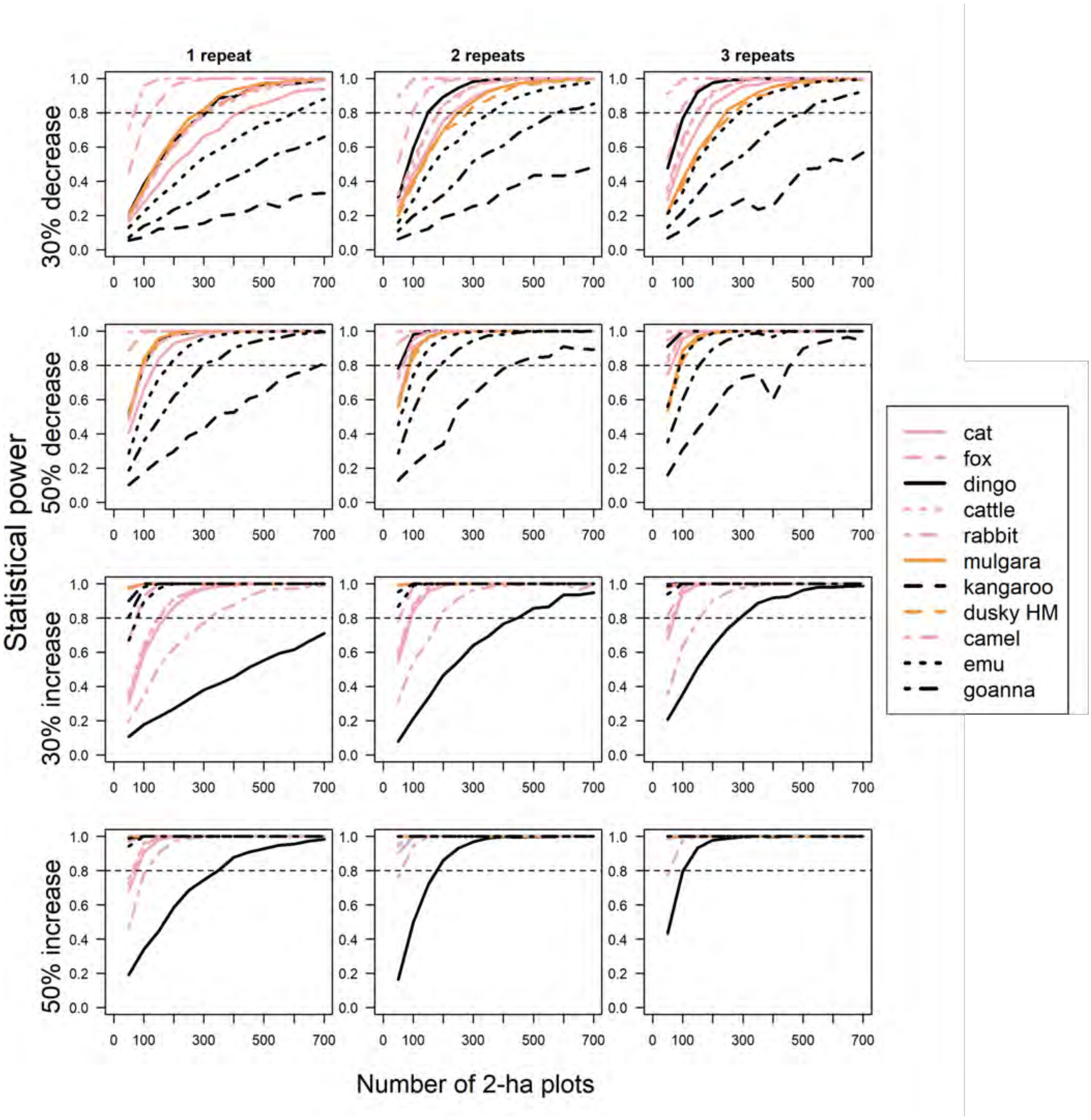


Figure 21: Statistical power (y-axis) to detect occupancy trends in 11 species over 15 years depending on the number of 2-ha plots surveyed each year (x-axis), the magnitude of change we aim to detect (30% or 50%), the direction of change (increasing or decreasing) and the number of within year repeat surveys (1-3). The dashed horizontal line represents 80% power.

9.2 Outputs – general findings

The general findings from the analysis were:

- Increasing the number of plots surveyed increases statistical power to detect change in occupancy. Increasing the number of times a plot is surveyed in a year (e.g., from one to two) also increases statistical power, but to a lesser extent.

- Reducing the survey frequency (from annually, to once every 2, 3 or more years) reduces statistical power, but may be compensated for by increasing the number of sites that are surveyed on each occasion.
- Less survey effort is needed to detect larger changes; for example, it requires less sites or fewer surveys to detect a 50% decline compared to a 30% decline in priority species occupancy.
- It is easier to detect increasing trends than decreasing trends when the starting occupancy estimates are closer to zero than to 1, this is because an increasing effect size results in a larger value than the same effect size that is decreasing.
- A subset of sites should be re-surveyed in the same year to estimate detectability; in practice re-surveying a small proportion of sites (as low as 10%) twice, is enough.
- If species are rarely detected, it's hard to design monitoring programs that have enough statistical power. You either need to survey a very large number of sites, or you should consider a different survey technique.
- Using the ensemble SDMs and the spatial prioritisation tool (Zonation) to locate sites, rather than relying on the pre-existing network of sites, increases the power to detect change in priority species. This matters less for common and widespread species, like the camel and the cat, but is very important for rarer, range-restricted species like crest-tailed mulgara.
- It is therefore important to decide which species are the priorities for monitoring during the design stage, because this decision affects where sites should be located. If we prioritised the location of sites for the two range-restricted species (dusky hopping mouse and crest-tailed mulgara), we will lose power for some the other species, unless we increase the number of sites in other localities.

9.3 Outputs - application for future monitoring in South Australia

The analysis showed that if groups and individuals collectively monitored 200 of the pre-existing sites every year (with at least 20 re-surveyed within the year to improve detectability), which is a similar effort to that used in past years, we could detect moderate declines (i.e. at least 30%) in six of the 11 priority species; and marked declines (i.e. at least 50%) in 10 of the 11 priority species. To increase the statistical power of detecting moderate declines for most of priority species, we should increase the number of sites that are surveyed.

If groups and individuals in South Australia repositioned their track-based monitoring sites according to the spatial prioritisation, the power to detect changes would increase across all species. If the spatial prioritisation targets the two species of conservation significance, our power to detect change in these species would increase, but it would decrease for some of the other species. We could compensate for this by adding more sites to the monitoring design to make sure all species are adequately covered (Figure 23).

An alternative to surveying every year, could be to reduce the survey frequency, whilst increasing the number of sites in the program. The most appropriate survey frequency will depend on factors not considered in our simulation. These include logistical constraints; the status of target species (i.e. it might be more important to monitor threatened species with small populations more often); generation length of target species; and how risk averse managers are to what could happen between survey events. In addition, monitoring frequency should be synchronised, if possible, with natural peaks and troughs in populations. This is particularly important in arid Australia, where rainfall drives 'boom-bust' population cycles, but may be challenging to plan due to the irregularity and random nature of such events.

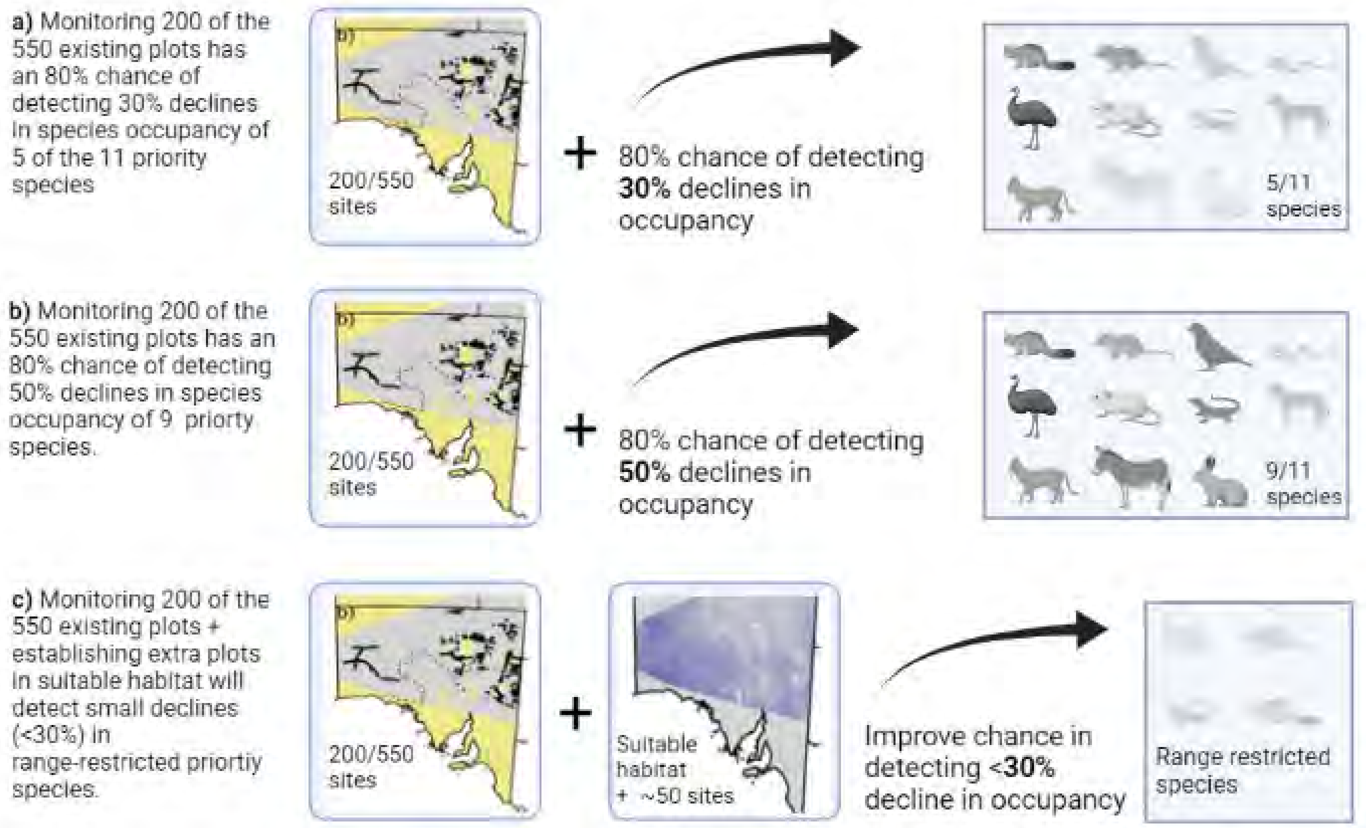


Figure 23: Examples of trade-offs in the monitoring design. Monitoring 200 of the 550 existing plots has an 80% chance of detecting 30% declines in species occupancy of 5 of the 11 species (panel a). This increased to 9 species if we relaxed our threshold to observe a 50% decline in occupancy (panel b). To detect small declines (<30%) in range-restricted species, then more of the existing 2-ha plot network should be surveyed and/or new plots should be established in areas with the highest predicted occupancy (panel c).

Some final considerations

We assumed the goal of monitoring was to detect trends in species occupancy, and not to understand factors driving changes in occupancy (fire or introduced species, for example). Landholders and groups might have their own, different objectives for 2-ha plot monitoring – for example, to track the effectiveness of management within their region. In this case, many plots within a small area could maximise what can be learnt about management effectiveness. If landholders are using fire to manage species, their plots could be stratified across fire histories and vegetation types within their region, so that monitoring not only meets the broader regional and national objectives of a detecting trends, but also answers local questions about management effectiveness. There are some fundamental principles common to all good monitoring programs.

- Set clear objectives (e.g., measure the distribution or abundance of a species over time, and learning how these attributes changes with fire management).
- Position sites to overlap with the distribution or potential distribution of priority species.
- Have enough resources (funding and people) secured for the length of time needed to detect changes in desert systems.
- Design the monitoring so it has adequate statistical power to detect a change (enough samples or surveys in one area repeated over time).
- Account for imperfect detection (thinking an animal is not present, when it was) by surveying a subsample of sites (10%) twice per year.

Section 10 – Improving future survey design and data collection

Key points:

- *We carried out a series of inter-related analyses on monitoring design and data collection, to support groups and individuals to carry out surveys that are optimal for their objectives, and to collect data efficiently and effectively.*
- *Working with the South Australian partners, we developed optimised designs for track-based monitoring in South Australia, finding that 200 sites are needed to have a high chance at detecting moderate to marked declines in the species of interest, with the placement of sites depending on the monitoring objective.*
- *We carried out a spatial analysis based to identify priority areas for expanding track-based surveys to support a national-scale monitoring program.*
- *Using a detailed dataset collect in the Maralinga Tjarutja Lands of the Alinytjara Wilurara NRM region of SA, we examined the drivers for variation in detectability across species, to advise on how many sites need to be revisited in a year, and how often, to estimate detectability reliably.*
- *Working with tracking experts, we surveyed the range of data collection templates in use, and produced a streamlined data collection sheet with core data fields that would support national monitoring. We finessed the data collection sheet after a field trial with APY land Management.*

9.1 Monitoring design

Like all biological surveys, track-based surveys need to be designed carefully to provide data that can be used to answer questions about species distributions, habitat preferences, trends or management effectiveness. The most appropriate monitoring design is influenced by how common species are, how easily their sign is detected, and the monitoring objective.

The AZM project carried out several analyses relevant for providing guidance on monitoring design. These were:

1) A detailed analysis to compare the statistical power of different monitoring designs for detecting changes in occupancy of animal populations. The analysis was based on data collected in SA, and species distribution maps developed from those data. It explored the optimal survey designs for achieving a range of potential objectives. For instance, to detect changes in species with small ranges, versus changes in species with large distributions, as well as the monitoring design required to detected small versus large changes in occupancy of those populations (See Section 9 for details).

2) An analysis to identify areas, aside from the 2 ha plot network that had already been sampled, that could be targeted in a nationally coordinated monitoring program across the deserts. This analysis was based on species distribution models built from the AZM National Dataset, augmented by data from the Atlas of Living Australia. The work showed that the existing 2 ha plot network already covers many regions of high predicted species richness. This is not surprising, given some 2-ha plot surveys have purposely targeted the known distributions of

threatened and range-restricted species such as the bilby and dusky hopping mouse. However, some species-rich regions outside of the existing 2-ha plot network are under-surveyed, such as the central and north-east regions of the project area (Figure 24).

3) An analysis of the drivers for variation in detectability, and the implications of this for the need to revisit sites, depending on the monitoring objective.

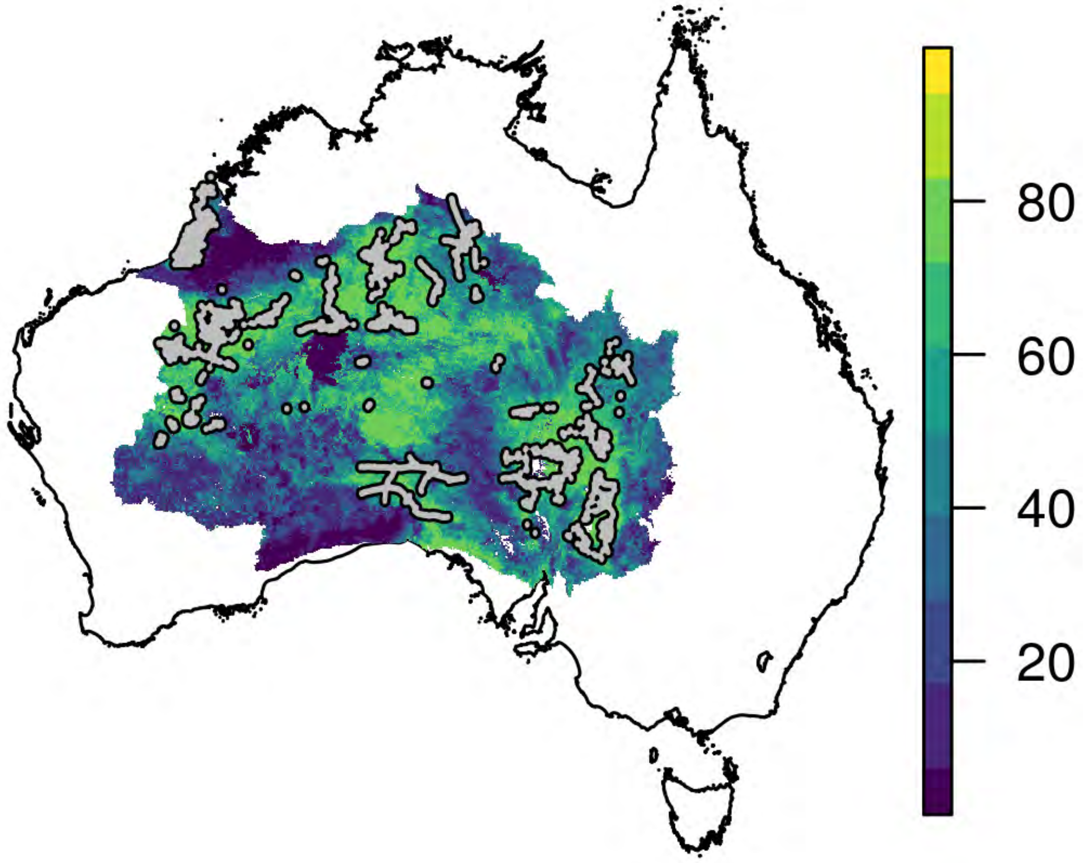


Figure 24. This map shows variation in species richness across the AZM project area, based on predictions from species distribution models developed for 26 desert species that are often detected, or are of high interest (threatened or culturally significant). The light grey colour shows the existing network of 2 ha plots with a 20 km buffer around each plot. Blue areas show regions with lowest species richness. Yellow areas represent the regions of highest expected species richness, and are the most suitable areas for new surveys outside of the grey buffered areas, to improve our knowledge of spatial and temporal patterns in species distributions.

All these analyses highlight that monitoring designs should be optimised for each context or objective, and may need expert input to design a robust monitoring plan with enough replicates and sites to achieve objectives. Nevertheless, based on the analyses briefly described above, we developed some broad guidelines to help groups and individuals improve the design of their track-based monitoring. The guidance includes some high-level rules-of-thumb for monitoring programs at local, regional and national scales.

For a monitoring program at the property or IPA scale, sampling 40 sites (from a set of about 80 sites) each year, split across the main habitat types, should pick up changes in the detections rates or occupancy of *the* more common species. If you increase the number of sites sampled in a year, you will have a greater chance of picking up change, especially if the change is small. If there are rare species that are targets for the survey, you may need extra sites clustered in the area or the preferred habitat where that species occurs. Groups and individuals could use the AZM SDM map output layers to determine where this may be on their Country/ study/ management area.

For a regional monitoring program, about 200 sites are needed to pick up moderate (~30%) declines for most species (based on analysis of South Australian data). These sites could be spread across several IPAs, national parks, and other properties, so that any one team is sampling only part of the whole set of sites.

For *a national monitoring program* that aims to track changes over time in medium-large mammals and larger reptiles and birds, based on the analysis of South Australian data, we estimate that at 400-600 sites are needed. Two hundred sites should be spread through the southern deserts, with 200 more sites in the northern deserts. In both north and south, additional sites should clustered within the ranges of key species with smaller distributions (such as great desert skink in the north, and dusky hopping mouse and crest-tailed mulgara in the south).

9.2 Data collection sheets

Track-based surveys are carried out to meet many objectives, and all could contribute to regional or national monitoring of threatened, feral and culturally significant species, if data are recorded reliably. There are several variations of track-based surveys being used across Australia, although the most common standardised method is a 2 ha plot survey (sometimes called a sign survey, track survey, 2 hectare plot, cybertracker survey or Tracks App survey). In the 2 ha plot survey, observers search a 2 ha area for signs of animal presence, ideally for a set period of time or effort. Transect searches – where a stretch of track is searched systematically, and timed searches, where trackers wander through an area in any direction searching for animal signs for a set amount of time, are also commonly used.

Over time, people have developed variations on track-based survey methods to fit with their monitoring objectives and local context. In addition, the type of data that people collect during surveys has changed, and people use several different data collection mechanisms, from paper datasheets to app-based systems.

Although the differences in method (2 ha plot vs transect) can be accommodated in analyses, any inconsistencies in data recording fields, and inconsistencies in data quality, can hinder the collation and interpretation of data across people and groups. Streamlining data collection to a core set of fields, with instructions on how to collect that information consistently, will make it possible to combine track-based data from many different groups and individuals. To that end, the Arid Zone Monitoring project worked with several tracking experts to design a data recording template that could be used nationally, regardless of the track-based survey method used. The streamlined data collection template contains core data fields that are relevant nationally, and that can be collected at a consistently high quality. Key conclusions from this work include:

- Any data fields that can be filled from other national spatial datasets, such as broad vegetation type, soil type, topography, can be omitted from a national data collection template.
- Any data fields that do not contribute to the survey objective can be omitted.
- Recording key attributes of the design and type of survey optimises the analysis potential. This includes recording whether detections were incidental, or made during standardised surveys, and if the latter, noting the method used is valuable.

- Data from transects along the road are valuable for detecting predators and larger herbivores, which often use roads to travel. However, it's important to keep the data from a 2 ha plot and a road transect separate, as they each introduce biases. A good compromise is to make sure the 2 ha plot is at least 30 m from the road, then survey an adjacent 100 m stretch of road separately, keeping the data clearly separated.
- Recording whether the surveys targeted one or a few species, or recorded all species, is important for identifying biases, and being able to recognise absence data as well as presence data, and thus allow different approaches to analysis.
- Training field surveyors in species identification from their sign, aging sign, and in filling out the data collection template is critical.
- The size of tracking teams often varies, but keeping tracking effort (the amount of search time across the team) consistent between surveys is important.
- Detectability of species signs varies between surveys, and is hard to estimate. Recording the tracking conditions can help understand detectability, but nothing can 'repair' collecting data in poor tracking conditions. If conditions are poor (e.g. high wind or rain), then defer the survey.

The new data collection sheet was trialed in surveys carried out by rangers and Traditional Owners working Aṉangu Pitjantjatjara Yankunytjatjara Land Management and the AZM project team, in May 2021.

Using sign to record animal presence (and absence) is prone to certain biases, but these biases can be managed by collecting data in good tracking conditions, identifying species and the age of sign correctly, and filling in the data collection sheet correctly. This work is a foundation step to support the development of a coordinated regional and national monitoring programs. The review of data collection templates also informed the manipulation and analysis of existing data that was being carried out in other components of the Arid Zone Monitoring project.

To download further guidance, and data collection templates, and database templates, see list of relevant documents listed in Appendix 3.

Survey on Antara-Sandy Bore IPA. Image: S. Legge.

Section 11 – Reporting back

Key points:

- *The project has been a collaboration between diverse partners with different objectives, and different reporting needs from the project. The project team therefore adapted many of the outputs on a group by group basis, and shared results back with partners via workshops and online meetings.*
- *A key reporting requirement was that some information was designed to be publicly available, and other outputs were shared solely with the data provider, to maintain data confidentiality provisions.*

The Arid Zone Monitoring project has involved a diverse array of partners, interested in different sorts of project outputs, and with different preferences for receiving those outputs. Some Indigenous ranger groups wanted to see map displays of the work they had achieved to date, to discuss how they could use track-based monitoring most effectively in their own programs, and also to see how their work fitted in with the regional or national effort. The project team worked with ranger groups individually, showing them the outputs most relevant to them, in a form most appropriate for them, and often iterating those outputs based on feedback received. The interactions mostly occurred via online meetings, due to COVID-related travel disruptions. Ranger team coordinators and land council staff played a key role facilitating these conversations, or even having them on behalf of the project. Other partners, including researchers, were potentially more interested in the scientific aspects of analysis and monitoring design, and were more heavily involved with the preparation of manuscripts for science journals.

In addition, some outputs were designed to become publicly available, whilst others were designed to only be available for individual data providers (typically involving species location information at high spatial resolution).

11.1 List of outputs

The main outputs from the project are listed below:

- AZM Project Report: describing the project development, the details of the database collation, and summaries of the main outputs (here).
- AZM Project Summary: a much shorter report, for a broad audience, including only the main graphical summaries (maps, graphs) from the AZM National Dataset.
- Species Profiles: summarising information on each species in the AZM National Database (detections, detection rates, habitat suitability models), and also providing information that may be useful for future surveys (a description of the animal, its habitat, and its tracks, scats and other sign). The species profiles can be downloaded from the web, and multiple copies of complete sets have been provided to all Indigenous Ranger groups in the project.
- Guidance for monitoring design: presenting rules of thumb to help people decide on the number of sites, where to position them, and how often to sample them. The guidance was based on a series of technical analyses of existing data (at property-scale, regional scale, and national scale); these analyses are being published, and should be available during 2022.

- **Guidance for data collection**: providing a core data collection template that supports future data collation by ensuring key meta data are collected, and data quality is consistent. This guidance was based on a review of existing data collection templates carried out by a working group of tracking experts.
- We also created an **interactive website (www.AridZoneMonitoring.org.au)**, built on a ShinyApp, that presents the key map and graph outputs from the project, allows viewers to explore the temporal and spatial patterns of data in the AZM National Dataset in a way that maintains data confidentiality (i.e. the precise locations of individual species detections cannot be discerned), and contains links for downloading species profiles, design and data collection guidance.

For Indigenous Ranger groups privately (i.e. not publicly available): Maps highlighting their data contribution to the National Dataset; detection rates for species on their Country; a map series showing the specific detection locations of species on Country; and their curated data as an excel file.

Workshop with Rangers and Traditional Owners hosted by APY Land Management, Umuwa. Image: S. Legge

Section 12 – Conclusions and next steps?

Key points:

- *The project has:*
    - *Established that a large volume of track-based data has been collected and that it is possible to collate these data despite considerable heterogeneity in survey objectives and data collection methods;*
    - *Demonstrated that the collated data can be used to describe species distributions, build species habitat suitability models, and investigate temporal trends if collected appropriately;*
    - *Carried out analyses to scope future regional and nationally scaled monitoring programs for medium-large desert animals;*
    - *Provided guidance on future monitoring design and data collection to project partners;*
    - *Shown that it is possible to build a large and diverse partnership that produces useable data compilations and analyses whilst respecting the Intellectual Property and diverse interests of the partners.*
- *With this foundation in place, the next step is to work with project partners to shape phase two of the project, which could aim to establish a national and collaborative monitoring program, based on a partnership between a lead Indigenous organisation, universities, governments, and NGOs.*

12.1 Conclusions: did the project achieve its objectives?

We briefly review the progress of the AZM project against each of the five project objectives.

1. Develop approaches to collating multiple, diverse datasets into a national dataset.

This objective was successfully achieved; the process also enabled us to identify potential improvements for future survey design and data collection, such as clarifying which metadata should be recorded for every survey, as well as which core data fields are essential.

2. Investigate the value of this national dataset for describing species distributions, correlates of occurrence, changes over time, and other spatio-temporal patterns.

The collated dataset augmented knowledge about species distributions (e.g. uncovering records outside the previously recognised distribution of some species), could be used to create habitat suitability models, and contained valuable information on the spatial and temporal variation in detection rates for some species. The collated dataset also revealed which species are most suitable for track-based monitoring approaches, and which less so. Parts of the dataset were suitable for detailed trend analyses, including looking at the effects of management and other covariates. Where the dataset was not suitable for trend analyses, we were able to provide advice to partners about the importance of revisiting sites if describing changes over time was a key objective for their monitoring program.

3. Identify the requirements (in terms of sampling effort and design) of using track-based monitoring to track species distributions and trends at a national scale.

By using a rich dataset from South Australia in a spatially explicit power analysis, and in an analysis of drivers of detectability, we were able to devise rules-of-thumb for how key design elements including the number, location and sampling frequency of sites should vary according to the monitoring objective. Based on this work, we estimate that 400-600 sites could form the basis for a national monitoring program. We also explored several property-scale datasets, revealing that changes in species occupancy (at that scale) due to variation in environmental and other co-variates can be detected from a survey effort of 40-70 sites, totaling about two weeks each year.

4. Improve the value of future track-based monitoring, by providing guidance to collaborators on sample design for differing objectives, key data fields, and where training in data collection might enhance data quality.

We produced guidance on monitoring design to fulfil a range of monitoring objectives, and for different scales (local, regional, national). We worked with tracking experts to review existing data collection templates and identify the core data fields that should be retained in a national data collection template, which data fields should be filled with existing spatial datasets, and which data fields could be omitted. This work also highlighted the data fields for which clear guidance and training are required to ensure consistency of quality.

5. Showcase the work being carried out by many groups across the arid zone.

The project has clearly documented the enormous contribution that people make towards collective knowledge of desert fauna. In particular, the contribution of Indigenous rangers and Traditional Owners towards collective knowledge, especially in the last 20 years with the growth of the funded ranger programs, is immense. Much of this survey and monitoring effort is part of broader programs to look after Country, involving cultural aspects as well as the biodiversity aspects.

The project clearly highlights the potential for enhancing the existing effort through funding and partnership models that respect the agency of individual partners to set their own survey objectives, and yet support those partners to contribute to a collective effort such as a national monitoring program for medium to large desert fauna.

12.2 Next steps?

The AZM Project has been a highly successful proof-of-concept. The project has established that a large volume of track-based data has been collected, that it is possible to collate these data despite considerable heterogeneity in survey objectives and data collection methods. The project has demonstrated that the collated data has value for describing species distributions and building species habitat suitability models, and that it can be used to investigate temporal trends if collected appropriately, and thus also used to inform, and report on, management. Finally, and most importantly, the project has shown that it is possible to build a large and diverse partnership, that produces useable data compilations and analyses whilst respecting the Intellectual Property and diverse interests of the partners.

With this foundation in place, the next step is to work with project partners to shape phase two of the project. As well as supporting individual partners to design surveys to meet their local objectives, a key element of the next phase would be to establish a national monitoring program, based on selecting survey sites across the deserts that:

- optimise the chance of detecting changes in occupancy and detection rates of key species (these are likely to be a mix of widespread and localised native species, as well as feral species);
- are shared between participating groups, so everyone can contribute;
- are aligned with the local objectives for each participating group (including cultural objectives);
- are near tracks, so that access is feasible;
- are revisited at least twice every five years.

From analyses carried out in the AZM Project, we estimate that 400-600 sites spread around the arid zone would be required for a national monitoring program. Given that the current AZM National Dataset is built on the shared data from 37 data providers, and notwithstanding that a few data providers have operated in overlapping geographic areas, this suggests that each partner would need to sample 10-20 sites, which is highly achievable. However, more sites will be needed if partners have additional objectives that they want to see built in (e.g. if understanding property-scale trends was considered important; or if detecting a smaller change in occupancy of a priority species was considered important). Such variations are expected, so the overall network of monitoring sites may exceed 600.

To be sustainable, such a program would need funding for the field survey component, so that surveys can be built into ranger, state agency, NGO workplans, and researcher schedules. The program would need a coordinator to nurture the collaboration and be a conduit for data flow, internal and external communication and connection; and a skilled analyst to curate, analyse and report, and to provide ongoing statistical support to project partners to optimise their own survey programs. As well as handling the new data coming in, the existing dataset still has substantial potential for further analyses. It would also make sense to engage a database designer to automate parts of the data collation and reporting process, so that partners could upload new data and generate reports for their local area as well as at larger scales, using a password-protected pathway so that data confidentially is maintained.

Finally, the Arid Zone Monitoring Project was carried out by university researchers working closely with data providers. Most of the project area is under direct management by Traditional Owners (Figure 1), and Indigenous Rangers and Traditional Owners contribute more data than any other data provider type (Figure 5). In large areas of the desert, they are the only data provider. It would therefore be appropriate if the next phase of the project was led or co-led by an Indigenous organisation that represented desert Traditional Owners, with project objectives that are co-developed by all project partners. The project coordinator should be employed directly by that organisation, and a partnership with a university could support the inclusion of sound scientific expertise into the project. In addition, a steering committee made up of representatives from the main data provider types could act as another conduit for information flow between project partners and the core project team (Figure 25).

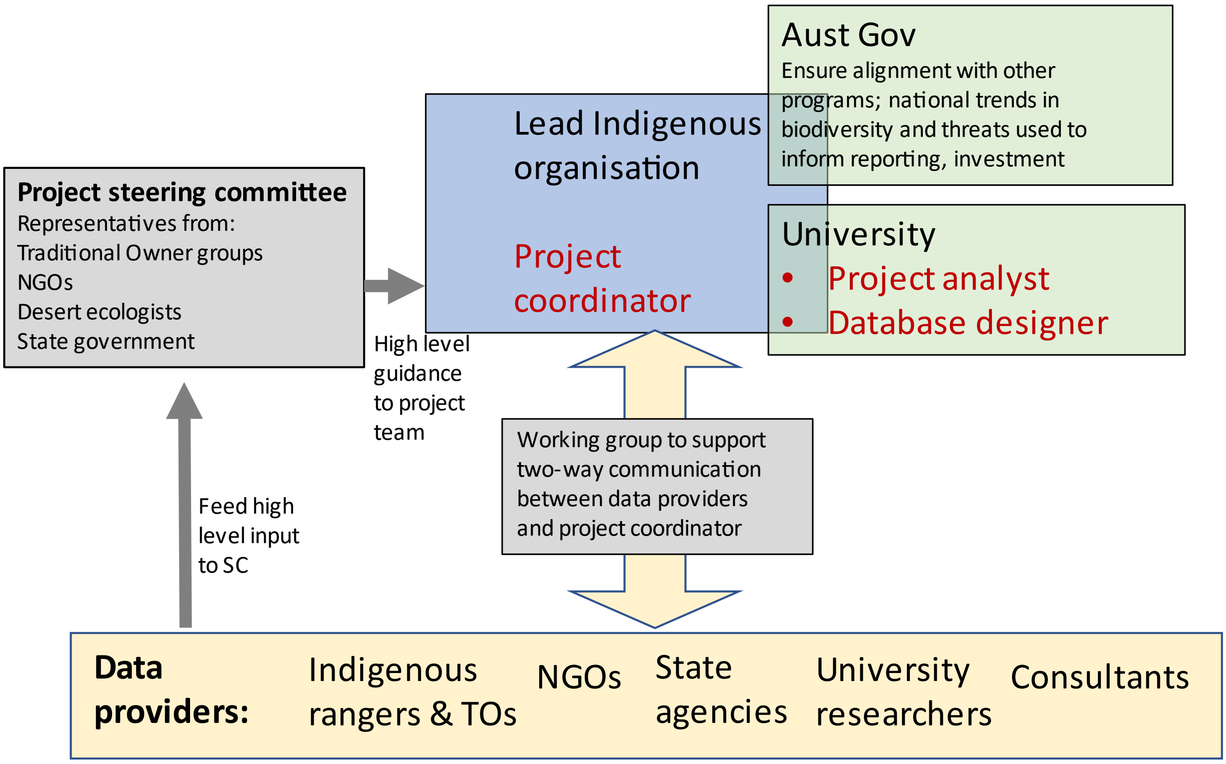


Figure 25. Schematic of a possible governance structure for a new version of the Arid Zone Monitoring project, led by an Indigenous organisation, involving a partnership with a university, and informed by a representative steering committee.

Yukultji Napangati, Kiwirrkurra Rangers, looking for tracks. Image: J. Dielenberg.

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Appendix 1 – Rationalising record naming across datasets

Naming conventions for species detected varied across and within data providers. One of the key data manipulation steps was to bring a consistent naming convention to the input datasets (Table S1.1). We re-classified every record to a species, or the lowest taxonomic level possible if the species was unknown or unclear. In a few cases, we grouped species that are ecologically similar and could be easily misidentified (e.g. *Ctenotus* spp.). For taxonomic and common names, we used the Australian Faunal Directory (https://biodiversity.org.au/afd/), and some recent updates to reptile taxonomy summarised in Chapple et al (2019), or recently published papers that revise taxonomy in specific groups, such as Melville et al (2019).

We omitted records from datasets using unsuitable survey methods, such as trapping with specialised equipment (Table S1.2), and records with erroneous or missing spatial data (Table S2.3)

Table S1.1. The assigned common name, assigned species name (or genus or group name, if applicable), against all the alternative versions of this assigned name in the provided datasets. Notes about changes to names, and data enhancement, are in the final column. Records based on specialised surveys (which were omitted from the AZM National Dataset) are presented separately, in part (b) of the table.

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
Native mammals			
Agile wallaby	*Notamacropus agilis*	*"Wallaby.Agile","Macropus.agilis","agile","Agile.wallaby","Notamacropus .agilis"*	
Brush-tailed mulgara	*Dasycercus blythii*	*"Mulgara","Dasycercus.blythi", "Dasycercus"*	*Detections of mulgara from the north-western part of Australia were renamed as D. blythii*
Central pebble-mound mouse	*Pseudomys johnsoni*	*"Pebblemound.mouse","Central.Pebble-mound.Mouse","Pseudomys.johnsoni"*	Renamed one record south of current distribution as *Pseudomys sp.*
Common brushtail possum	*Trichosurus vulpecula*	*"Brushtail.possum" ,"Common.Brushtail.Possum","Brushtail.possum"*	
Crest-tailed mulgara	*Dasycercus cristicauda*	*"Dasycercus.cristicauda","Dasycercus.cristicauda","Ampurta"*	*Detections of mulgara from south-eastern Australia were renamed as D. cristicauda. "Crest-tailed.Mulgara.(Ampurta)","Ampurta"), "Mulgara","Crest.Mulgara","Dasycercus.sp.","Dasycercus.sp",*
Dingo	*Canis familiaris lupus*	*"dog","feral.dog","Feral.dog","Feral.Dog","Feral.Dog,.Dingo", "Canis.sp.","Canis.familiaris","Canis.lupus.sp.","Canis.lupus","Canis.lupus .dingo", "Canis.lupus","Canis.lupus.dingo","Dingo","DIngo","Dingo/Dog","Dingo/*	*"Dog" records renamed to dingo.*

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
		wild.dog","Dog/Dingo", "Canis.lupus.familiaris, Canis lupus dingo or hybrids","Canis.lupus.sp.","Canislupis.dingo","dingo"	
Dusky hopping mouse	*Notomys fuscus*	*"Notomys.fuscus",*	*Plotted records of Notomys sp. and sought expert opinion on likely species given distributions. The records in Queensland and the NE quadrant of South Australia were determined to be dusky hopping mice (N. fuscus). "Notomys.sp."*
Euro	*Osphranter robustus*	*Euro,"euro","Macropus.robustus","Osphranter","Osphranter.robustus" Macropus.fuliginosus"*	
Fat-tailed dunnart	*Sminthopsis crassicaudata*	*"Fat-tailed.Dunnart"*	
Fat-tailed pseudantechinus	*Pseudantechinus macdonnellensis*	*"Fat-tailed.Pseudantechinus"*	
Forrest's short-tailed mouse	*Leggadina forresti*	*"Central.Short-tailed.Mouse (Forrest's Mouse)"*	
Golden bandicoot	*Isoodon auratus*	*"golden.bandicoot","Golden.bandicoot","Golden.Bandicoot","Golden. bandicoot?","Golden.Bandicoot?", "golden.bandicoot?.(photo)"*	
Greater bilby	*Macrotis lagotis*	*"Very.old.3 weeks old bilby.","Bilby?","bilby","Bilby","Great.Bilby","Macrotis.lagotis","Mankarr"*	*Detections from inside introduced mammal exclosure excluded. N= 18 Records omitted*
Kowari	*Dasyuroides byrnei*	*"Dasyuroides.byrnei"*	
Long-haired rat	*Rattus villosissimus*	*"Long-haired.Rat.(Plague Rat)","Rattus.villosissimus","Long-haired.Rat","Long-Haired.Rat","Long-haireed.Rat","Longg-haired.Rat","Leong-haired.Rat","Long-haired.rat", "Other.small.mammal Long-haired Rat","Leong-haired.Rat","Other.small.mammal Long-haired Rat", "Rat","Rattus.sp."*	
Northern nail-tail wallaby	*Onychogalea unguifera*	*"northern.nailtail","Nail-tail.wallaby","Northern.Nailtail","northern.nailtail.wallaby", "Northern.Nailtail.Wallaby","Onychogalea.unguifera","Wallaby.Northern.Nailtail"*	
Northern marsupial mole	*Notoryctes caurinus*	*"marsupialmole","Marsupial.mole","marsupial.mole","Marsupial.Mole"*	Renamed detections of moles from northern Australia *Notorycytes caurinus.*
Plains mouse	*Pseudomys australis*	*"Plains.mouse","Plains.Rat"*	
Red kangaroo	*Osphranter rufus*	*"Osphranter.rufus","Macropus.rufus","Red.kangaroo","Kangaroo.Red", "red.kangaroo","Red.Kangaroo","redkang","redkangaroo"*	
Sandy inland mouse	*Pseudomys hermannsburgensis*	*"Sandy.Inland.Mouse","Pseudomys.hermannsburgensis"*	

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
Short-beaked echidna	*Tachyglossus aculeatus*	*"Tachyglossus.sp.","Short-beaked.Echidna","Tachyglossus.aculeatus","echida","echidna","Echidna","Echinda"*	
Southern hairy-nosed wombat	*Lasiorhinus latifrons*	*"Southern.Hairy-nosed.Wombat"*	
Southern marsupial mole	*Notorycytes typhlops*	*"Southern.Marsupial.Mole (Itjaritjara)", "Notoryctes.sp.", "Notoryctes.typhlops", "Notoryctes"*	Renamed detections of Notorycytes sp. from southern Australia as *Notorycytes typhlops.*
Spectacled hare-wallaby	*Lagorchestes conspicillatus*	*"Lagostrophus.fasciatus","Lagorchestes.conspicillatus","spectacled.hare-wallaby","Spectacled.hare-wallaby", "Spectacled.Hare-wallaby","spectacled.hare.wallaby","Wallaby.-.Spectacled Hare"*	
Spinifex hopping mouse	*Notomys alexis*	*"Notomys.alexis", "Spinifex.hopping.mouse"*	*Plotted records of Notomys sp. and sought expert opinion on likely species given distributions. Renamed all records that were not located in the NE quadrant of South Australia as Spinifex Hopping Mice (N. alexis)."hopping.mouse", "hopping-mouse","Hopping.Mouse", "Hopping.mouse","Notomys sp." ," Hopping.Mouse","Spinifex.Hopping-mouse","Spinifex.hopping.mouse","Spinifex.Hopping.Mouse", "Hopping.mouse","hoppingmouse",*
Warru	*Petrogale lateralis centralis*	*"Black-footed.Rock-wallaby","Black-flanked.Wallaby","Petrogale.lateralis.subsp. (MacDonnell Ranges)","Petrogale.sp.","Rock.wallaby", "black-footed.rock-wallaby","Petrogale.lateralis"*	*"Rock wallaby" rename to Petrogale lateralis centralis. "Petrogale.lateralis.lateralis (McDonnell Ranges race)","Black-footed.Rock-wallaby","Black-footed.rock-wallaby",*
Yellow-footed rock-wallaby	Petrogale xanthopus	"Yellow-footed.Rock-wallaby"	
Genera			
Dunnart	*Sminthopsis sp*	*"Sminthopsis.sp."*	
Large macropod	*Macropus/Osphranter sp*	*"Kangaroo","Western.Grey.Kangaroo","western.grey.kangaroo", "greykangaroo","Kangaroo.W.Grey", "Western.grey.kangaroo", "wallaby", "macropod","kangaroo","Kangaroo","Kangaroo.-.unknown","Kangaroos","large.macropod.(red orEuro)","Macropus.sp.","Macropod.(wallaby/kangaroo)","Wallaby.-.unknown"*	Western Grey Kangaroo records north of Broome renamed as *M. robustus.* Records from south of Broome renamed as *Macropus/Osphranter sp.*
Pseudomys sp	*Pseudomys sp*	*"Pseudomys.sp."*	
Group			
Bat	Bat	"White-striped.Free-tailed.Bat","Bat"	

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
Medium large mammal	Mammal	"Large-sized.mammal","Medium-sized.mammal.species"	
Native rodent	Native rodent	"Rock.Rat", "Rodent", "Small.rodent"	One detection record renamed to native rodent.
Small mammal	Small mammal	"Could.be.mulgara","Rodent","DASYURIDAE.sp.","Small.mouse","rodent ","Small.mammal.sp.","Small.mammal.species","Small.mammal..other.", "small.mouse","Small.Mouse", "Dunnart/Mouse","Other.small.mammal","Little.mouse","mouse","Mouse","Mouse.-.non hopping", "Other.mice/dunnarts","other.mouse","Rodents","rodentsmalldasy","small.mammal","Small.Mammal","Small.rodent"	
Introduced mammal			
Camel	*Camelus dromedarius*	*"One-humped.Camel.(Dromedary, Arabian Camel)","Camelus.sp.","Camel","Camelus.dromedarius","camel","One-humped.Camel"*	
Cat	*Felis catus*	*"Felis.catus","cat","Cat","Feliscatus","Felix.catus"*	
Cow	*Bos taurus*	*"Cattle","European.cattle","Bos.sp.","Cattle","cattle","Bos.taurus","Bos.taurus/Bos.indicus","Bostaurus","bullock","cow","Cow"*	
Donkey	*Equus asinus*	*"Donkey.(Feral.Donkey)","Donkey","Equus.asinus","donkey","Donkey","Equus.africanus.asinus","Equus.caballus","Equusafricanus"*	
European red fox	*Vulpes vulpes*	*"Vulpes.vulpes","Fox","fox"*	
Goat	*Capra hircus*	*"Goat.(Feral.Goat)","Capra.hircus"*	
Horse	*Equus caballus*	*"Horse.(Brumby)","Equus.sp.","Equus.caballus","horse","Horse","Horse/donkey"*	
House mouse	*Mus musculus*	*"House.Mouse"*	
Pig	*Sus scrofa*	*"Pig","Sus.scrofa","pig","Susscrofa","pigs"*	
Rabbit	*Oryctolagus cuniculus*	*"Rabbit.(European.Rabbit)","Rabbit","Oryctolagus.cuniculus","rabbit","Rabbit"*	
Sheep	*Ovis aries*	*"Sheep.(Feral.Sheep)","Ovis.aries"*	
Birds			
Australian bustard	*Ardeotis australis*	*"bush.turkey","bushturkey","Ardeotis.australis","Australian.Bustard","Bird.-.Turkey (Bustard)","bustard","Bustard","Bush.Turkey","turkey","Turkey","Turley",*	
Bush stone-curlew	*Burhinus grallarius*	*"Curlew","Bush.Stone-curlew","Bush.stone.curlew","curlew","Curlew"*	
Emu	*Dromaius novaehollandiae*	*"Bird.(Emu)","EMU","eMU","Dromaius.novaehollandiae","Emu","Bird.-.Emu","emu"*	

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
Malleefowl	*Leipoa ocellata*	*"Malleefowl.x2","Malleefowl","malleefowl"*	*X1 record too far north out of distribution range- reclassifed into bird category. "Leipoa.ocellata",*
Group			
Bird	Bird	"Spinifex.Pigeon","grey.headed.honey eater","Quail_sitting_place","Quail_","Quail.camp","Quail-thrush","Magpie-lark","Little.button.quail","Crow","Button.quail","button.quail","Bronzewing","bronzewing","Birds", "Bird.(Quail)","Wedge-tailed.Eagle","water.birds","Variegated.Fairywren","Torresian.Crow","Todiramphus.pyrrhopygius","Taeniopygia.guttata", "Spotted.Nightjar", "Smicrornis.brevirostris","Rhipidura.leucophrys","Ptilotula.penicillata","Ptilotula.keartlandi","Petrochelidon.ariel","Pardalotus.striatus","Pardalotus.rubricatus","Painted.Buttonquail","Pachycephala.rufiventris","Ninox.novaeseelandiae","Milvus.migrans","Melopsittacus.undulatus","Melithreptus.gularis","Malurus.leucopterus","Malurus.lamberti","Lophochroa.leadbeateri","Little.Crow","Little.Buttonquail","Lichmera.indistincta","Lalage.tricolor","Hamirostra.melanosternon","Great.Cormorant","Gibberbird","Geopelia.cuneata","Gavicalis.virescens","Falco.berigora","Eyrean.Grasswren","Elanus.axillaris","Eastern.Barn.Owl","Dicaeum.hirundinaceum","Cuculus.pallidus","crows","Colluricincla.harmonica","Circus.assimilis","Cinclorhamphus.cruralis","Chrysococcyx.basalis","Chestnut-backed.Quailthrush.(Chestnut Quailthrush)","Certhionyx.variegatus","Calamanthus.campestris","Black-tailed.Nativehen","Black-faced.Woodswallow","Bird_sm","Barnardius.zoniarus","Banded.Lapwing","Australian.Raven","Artamus.personatus","Artamus.minor","Artamus.cinereus","Aquila.audax","Anas.gracilis","Aegotheles.cristatus","Bird","Accipiter.cirrocephalus","AVES.sp.","AVES.sp.","Aves.sp.","Large.bird","small.bird","Small.bird", "Small.birds","Small.parrot","raptor","Raptor","Flock.Pigeon","Corvus.sp.", "Neopsephotus.bourkii","Epthianura.tricolor","pigeon","Pigeon","Melanodryas.cucullata","Pomatostomus.sp.","Amytornis.goyderi","Amytornis.sp.", "Bird.-.Curlew Mulywurah","Bird.-.Hopping","Bird.(hopping)","Bird.-.Quail","Bird.-.Walking","Burhinus.grallarius","Button.Quail","Cinclosoma.sp.","Corvus.sp.","Coucal","crow_magpie","Epthianura.tricolor","Eurostopodus.argus","Flock.Pigeon","Large.bird","Melanodryas.cucullata","Neopsephotus.bourkii","Other.-.type	

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
		pheasant","Other.bird","PHASIANIDAE","Pomatostomus.sp.","princess.parrot","Ptilonorhynchus.nuchalis","quail","Quail","Small.parrot","Water.bird","Zebra.Finch","button-quail"	
Reptiles			
Black-headed monitor	*Varanus tristis*	*"Varanus.tristis","V.tristis"*	
Burton's legless lizard	*Lialis burtonis*	*"Lialis.burtonis"*	
Central bearded dragon	*Pogona vitticeps*	*"Bearded.Dragon","Bearded.dragon","bearded.dragon","Pogona.vitticeps", "Central.Bearded.Dragon"*	
Central military dragon	*Ctenophorus isolepis*	*"Military_Lizard","Military_Dragon_?", "Military_Dragon","Military_dragon","military_dragon","Military.Lizard"," Military.Dragon.?", "military_dragon","Military_dragon","Military.dragon","Military.Dragon"," Ctenophorus.isolepis"*	
Central netted dragon	*Ctenophorus nuchalis*	*"Ctenophorus.nuchalis", "Central.Netted.Dragon"*	
Central pebble dragon	*Tympanocryptis sp*	*"Pebble_Dragon","Pebble.Dragon","Tympanocryptis.centralis", "Tympanocryptis.sp."*	
Centralian blue-tongue	*Tiliqua multifasciata*	*"Blue.touge.lizard","blue-tongue","Blue-tongue","blue.tongue","Blue.tongue","Blue.tongued.lizard","bluetongue", "Bluetongue","Bue-tongue","Lizard.-.Bluetongue Ngalyaka","Tiliqua.sp.","Tiliquasp.","Blue_Tongue_Lizard" ,"Blue_tongue_Lizard","Blue_Tongue","Blue.Tongue.Lizard","Blue.tongue.Lizard" , "Blue.tongue.lizard","blue.tongue.lizard", "Blue.Tongue","Centralian.Blue-tongue","Tiliqua.multifasciata"*	
Common knob-tailed gecko	*Nephrurus levis*	*"Nephrurus.sp.","Common.Knob-tailed.Gecko"*	
Crested dragon	*Ctenophorus cristatus*	*"Crested.Dragon"*	
Desert skink	*Liopholis inornata*	*"Gidgee.Skink","Desert.Skink"*	
Gould's goanna	*Varanus gouldii*	*"Juvenile.sand.goanna","Bungarra","Varanus.gouldii","Goulds.Goanna"," sand.goanna","Sand.goanna","Sand.Goanna","Sand.goanna.(yellow, small)","Sand.Goanna/Gould's.Goanna"*	
Great desert skink	*Liopholis kintorei*	*"greatdesertskink","Tjakura","Egernia.kintorei","great.desert.skink","Great.Desert.Skink","Liopholis.kintorei","Lizard.-.Great Desert Skink","tjalapa"*	*record in the south of SA; and records in the NE of SA; are mis-identified, they are most likely L. inornata, and have been so re-named.*
Lally's two-line dragon	*Diporiphora lalliae*	*"Diporiphora.lalliae"*	
Long-nosed dragon	*Gowidon longirostris*	*"Lophognathus.longirostris"*	
Macquarie river turtle	*Emydura macquarii*	*"Macquarie.River.Turtle"*	

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
Merten's water monitor	*Varanus mertensi*	*"water.goanna"*	
Mulga snake	*Pseudechis australis*	*"Mulga_Snake","Mulga.Snake","King.Brown.Snake (Mulga Snake)","Mulga.snake","Mulga/brown.snake","Pseudechis.australis"*	
Night skink	*Liopholis striata*	*"Egernia.striata","E.striata","Liopholis.striata","night.skink","Night.skink"," Night.Skink"*	
Painted dragon	*Ctenophorus pictus*	*"Painted.Dragon"*	
Perentie	*Varanus giganteus*	*"Perenti","Parenti","Goanna/Perentie","Perentie","Perentie.(black,.cheeky goanna)","Varanus.giganteus","perentie"*	
Reticulated whip snake	*Demansia psammophis*	*"Demansia.psammophis"*	Renamed to Demansia reticulata
Ringed brown snake	*Pseudonaja modesta*	*"Pseudonaja.modesta"*	
Shingle-back	*Tiliqua rugosa*	*"Sleepy.lizard","Bobtail","Sleepy.Lizard","Tiliqua.rugosa","Shingleback"*	
Short-tailed pygmy monitor	*Varanus brevicauda*	*"Desert.Pygmy.Goanna","V.eremius"*	
Spiny-tailed monitor	*Varanus acanthurus*	*"Ridge-tailed.Monitor","Varanus.acanthurus","V.acanthurus","spiney.tail.goana","Spiny-tailed.Goanna","Spiny.tailed.monitor","varanus.acanthurus"*	
Stimson's python	*Antaresia stimsoni*	*"Stimson's.python","stimsons.python"*	
Thorny devil	*Moloch horridus*	*"Thorn.devil","Thorny_devil","Thorny_Devil","Thorny_devil","thorny_devil","mountaindevil","Mountain_devil","Mountain.devil.- Photographed","Mountain.Devil","Mountain.devil","Devil","Moloch.horridus","Lizard.-.thorny devil","thorny.devil","Thorny.Devil"*	
Tree dtella	*Gehyra variegata*	*"Tree.Dtella"*	
Western beaked gecko	*Rhynchoedura ornata*	"Beaked.Gecko"	
Western bearded-dragon	*Pogona minor*	*"Pogona.sp."*	
Western blue-tongue	*Tiliqua occipitalis*	*"Western.Bluetongue"*	
Western brown snake	*Pseudonaja mengdeni*	*"Western.Brown.Snake","Western.Brown.Snake"*	
Woma python	*Aspidites ramsayi*	*"Aspidites.melanocephalus","Black-headed.python","woma.python"*	
Yellow-spotted monitor	*Varanus panoptes*	*"Floodplain.monitor","Varanus.panoptes"*	
Genera			
Blind snake	*Anilios sp*	*"Blind.Snake","Centralian.Blind.Snake"*	*rename to Anilios sp. (blind snake)- record of Centralian blind snake is out of range; should be either enderotus or bituberculatus*
Ctenotus sp	*Ctenotus sp*	*"Skink","Ctenotus_sp","Ctenotus_sp(lined)","Eastern.Desert.Ctenotus"," Ctenotus.calurus", "Ctenotus.pantherinus",*	

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Changes/ Comments
		"Lizard_(Ctenotus_sp)","Stripy.Lizard.Ctenotus sp","Ctenotus.sp","Ctenotus.sp.(lined)", "Ctenotus_pantherinus"	
Egernia sp	*Egernia* sp	*"Egernia.sp."*	
Goanna	*Varanus* sp	*"Goanna","Varanus_sp_(hand_capture)","Varanus.sp.(hand capture)","goanna","Goanna","kalawurru","goannas","Varanus.sp.","Goanna","goanna","Goannas", "Varanus.sp.","Varanus","Small_Goanna,","Small_Goanna","Small_Goanna","small.varanid","Small.Goanna","Goanna.(small)","Lizard.-.Goannasmall","Lizard.-.Goanna Small", "Varanus.sp..(small)","Goanna.(large)","Goanna.(yellow,.large)","V..panoptes/giganteus","Lizard.-.Goanna large","Varanus.panoptes.or Varanus giganteus", "Varanus.sp..(large)"*	
Legless lizard	Legless lizard	"Legless_Lizard","Legless.Lizard", "legless.lizard"	
Sand sliders	*Lerista* sp	*"Sandslider","Eastern.Two-toed.Slider","Sand.slider.(Lerista)","Lerista.sp."*	
Group			
Dragon	Agamidae	"Unidentified_Dragon","unidentified_Dragon","Unidentified.Dragon","unidentified.Dragon","small.dragon","Dragon.lizard","dragon","Dragon","Agamidae.sp.","AGAMIDAE.sp.","Dragon.Lizard")	
Gecko	Gekkonidae	"Gekkonidae.sp.","GEKKONIDAE.sp.","Gecko.(dark.coloured)", "S.stenodactylus"	
Small reptile	Reptile sp	"Lizzard","Unidentified_Lizard","Unidentified.Lizard","Small_Lizard","Small.Lizard","Lizard","REPTILIA.sp.","Reptilia.sp.","Small.lizard","small.reptile","little.lizard","Little.lizard","lizard","Lizard","Lizard.-.medium","Lizard.-.small", "Lizard.(medium)","Lizard.(small)","other.lizard","Other.lizard","Other.reptile","small-lizard","small.lizard","Small.lizard"	
Snake	Snake	"Fresh.snake","Two_Snake","Snakes","Snake.v.small","python","Large.Snake","Medium.snake","Python","sanke","SERPENTES","Small.snake","snake","Snake","Snake.-.Python Kalurrjawa","Snake.-.Unknown","snake.(elapid)","Snake.Wiril","Small.Snake"	
Frog			
Frog	Anuran	"frog","Frog", "Notaden.sp."	
Invertebrate			
Invertebrate	Arthropoda	"Scorpion","Crab","hermit.crab","Hermit.crab","Insect","Invertebrate","inverts","Scorpion","spider"	

Table S1.2. List of records from specialised survey data collection - species, group or genera highlighted in blue were only recorded in surveys using specialised equipment, or were deemed erroneous, and so were entirely omitted from the AZM National Dataset. The assigned common name, assigned species name (or genus or group name, if applicable), against all the alternative versions of this assigned name in the provided datasets. Notes regarding changes to names, and data enhancement, are in the final column. Data from blank rows in "AZM data provider range of names for species, genera or species groups" column are provided in Table 9a.

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Records omitted/ Comments
ative mammal			
Agile wallaby	*Notamacropus agilis*		"Agile.Wallaby",
Burrowing bettong	*Bettongia lesueur*	"Burrowing Bettong",	Wrong classification, there are no bettongs persisting at unfenced sites. Omitted.
Brush-tailed mulgara	*Dasycercus blythii*		"?.Mulgara","mulgara", "Mulgara/Ampurta"),
Common brushtail possum	*Trichosurus vulpecula*		"Trichosurus.vulpecula"
Crest-tailed mulgara	*Dasycercus cristicauda*		"Crest-tailed.Mulgara.(Ampurta)","Ampurta"), "Mulgara","Crest.Mulgara","Dasycercus.sp.","Dasycercus.sp",
Desert mouse	*Pseudomys desertor*	"Pseudomys desertor",	
Dingo	*Canis familiaris lupus*		"Dog/dingo", "Canis.lupus.familiaris,.Canis.lupus dingo or hybrids","Canis dingo","Canis.dingo",
Dusky hopping mouse	*Notomys fuscus*		"Notomys.sp."
Euro	*Osphranter robustus*		"Macropus.(Osphranter).robustus",
Fat-tailed pseudantechinus	*Pseudantechinus macdonnellensis*		"Pseudantechinus.macdonnellensis",
Greater bilby	*Macrotis lagotis*		"Greater.Bilby"- detections from inside introduced mammal exclosure excluded . *N= 18 Records omitted .*
Greater stick-nest rat	Leporillus conditor	"stick-nest.rats","Leporillus.sp."	Detection records- detected outside of their known distribution or detected inside introduced mammal exclosure.
Lesser hairy-footed dunnart	*Sminthopsis youngsoni*	"Sminthopsis youngsoni",	
Long-haired rat	*Rattus villosissimus*		"Rat.Long.haired"
Ningaui	*Ningaui ridei*	"Ningaui rydei",	
Northern nail-tail wallaby	*Onychogalea unguifera*		"Northern.nail-tail.wallaby",
Plains mouse	*Pseudomys australis*		"Rat.Plains",
Red kangaroo	*Osphranter rufus*		"Macropus.(Osphranter).rufus",
Southern hairy-nosed wombat	*Lasiorhinus latifrons*		"Lasiorhinus.latifrons",
Striped-faced dunnart	*Sminthopsis macroura*	"Sminthopsis.youngsoni"	

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Records omitted/ Comments
Warru	*Petrogale lateralis centralis*		"Petrogale.lateralis.lateralis (McDonnell Ranges race)","Black-footed.Rock-wallaby","Black-footed.rock-wallaby",
Genera			
Pseudomys sp	*Pseudomys sp*		"Pseudomys sp."
Group			
Bat	Bat	"White-striped.Free-tailed.Bat","Bat"	"Austronomus.australis",
Introduced mammal			
House mouse	*Mus musculus*		"Mus.musculus"
Bird			
Malleefowl	*Leipoa ocellata*		"Leipoa.ocellata",
Group			
Bird	Bird		"Oreoica.gutturalis","Ocyphaps.lophotes","Nankeen.Kestrel", "Falco.hypoleucos","Falco.cenchroides", "Epthianura.aurifrons","Merops.ornatus","Manorina.flavigula","Malurus.sp.","Malurus.melanocephalus","Grallina.cyanoleuca","Coracina.novaehollandiae","Cincloramphus.mathewsi","Cacatua.sanguinea","Ardea.pacifica","Aphelocephala.leucopsis","Anthus.novaeseelandiae",,"Accipitergentilis","Pomatostomus.temporalis","Falco.longipennis",
Reptile			
Blue-lined dragon	*Diporiphora winneckei*	"Diporiphora winneckei",	
Broad-banded sand-swimmer	*Eremiascincus richardsonii*	"Eremiascincus richardsonii",	
Bynoe's gecko	*Heteronotia bynoei*	"Heteronotia binoei",	
Central military dragon	*Ctenophorus isolepis*		"Military.dragon.(burrow)"),
Centralian blue-tongue	*Tiliqua multifasciata*		"Skink.Blue.tongue.lizard"
Common dwarf skink	*Menetia greyii*	"Menetia greyii",	
Common knob-tailed gecko	*Nephrurus levis*		"Nephrurus.levis"
Desert skink	*Liopholis inornata*		"Liopholis.inornata",
Excitable delma	*Delma tincta*	"Delma tincta",	
Fat-tailed gecko	*Diplodactylus conspicillatus*	"Diplodactylus conspicillatus",	
Goanna	*Varanus* sp		Goanna.Short.tailed.monitor=c("Varanus.brevicauda", "short.tailed.monitor"),
Great desert skink	*Liopholis kintorei*		record in the south of SA; and records in the NE of SA; are mis-identified, they are most likely L. inornate, and have been so re-named.
Lined firetail Skink	*Morethia ruficauda*	"Morethia ruficauda",	
Liopholis sp	*Liopholis sp*	"Liopholis sp ",	Renamed northern Egernia species record to Liopholis sp.

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Records omitted/ Comments
Little spotted snake	*Suta punctata*	"Suta punctata",	
Narrow-banded sand-swimmer	*Eremiascincus fasciolatus*	"Eremiascincus fasciolatus",	
Narrow-banded shovel-nosed snake	*Brachyurophus fasciolatus*	"Simoselaps fasciolatus",	
Northern spiny-tailed gecko	*Strophurus ciliaris*	"Strophurus ciliaris",	
Ornate soil-crevice skink	*Notoscincus ornatus*	"Notoscincus ornatus",	
Pilbara dtella	*Gehyra pilbara*	"Gehyra pilbara",	
Purplish dtella	*Gehyra purpurascens*	"Gehyra purpurascens",	
Pygmy desert monitor	*Varanus eremius*	"Varanus eremius",	
Ringed brown snake	*Pseudonaja modesta*		"Pseudonaja.modesta ", "Ringed brown snake","Ringed.brown.snake",
Sand-plain gecko	*Lucasium stenodactylum*	"Lucasium stenodactylum",	
Short-tailed pygmy monitor	*Varanus brevicauda*	"Varanus brevicauda", "short tailed monitor",	
Southern phasmid gecko	*Strophurus jeanae*	"Strophurus jeanae",	
Striped-faced dunnart	*Sminthopsis macroura*	"Sminthopsis macroura",	
Tree delta	*Gehyra variegata*	"Gehyra variegata",	
Unbanded delma	*Delma butleri*	"Delma haroldi",	
Western beaked gecko	*Rhynchoedura ornata*		"Rhynchoedura.ornata",
Western bearded dragon	*Pogona minor*		"Pogona.minor"
Western blue-tongue	*Tiliqua occipitalis*		"Tiliqua.occipitalis",
Western brown Snake	*Pseudonaja mengdeni*		"Pseudonaja.nuchalis"
Western chestnut mouse	*Pseudomys nanus*	"Pseudomys nanus",	
Western soil-crevice skink	*Proablepharus reginae*	"Proablepharus reginae",	
Woma python	*Aspidites ramsayi*		"Aspidites.ramsayi", "Black.headed.python",
Yellow-sided two-line dragon	*Diporiphora magna*	"Diporiphora magna",	
Genera			

Assigned common name	Assigned species name (or genus name, or group name)	AZM data provider range of names for species, genera or species groups	Records omitted/ Comments
Ctenotus sp	*Ctenotus* sp		"Ctenotus.decaneurus","Ctenotus.grandis","Ctenotus.greeri","Ctenotus.hanloni","Ctenotus.helenae","Ctenotus.leonhardii","Ctenotus.piankai","Ctenotus.robustus","Ctenotus.schomburgkii","Ctenotus.sp.","Ctenotus.tanamiensis", "Skink.spp." "Skink.pantherinus"),Skink.Western.soil.crevice=c("Proablepharus.reginae"
Legless lizard	Legless lizard		"Legless.Lizard.spp","Sand.slider","Lerista.labialis","Lerista.taeniata","Lerista.bipes"
Sand slider	*Lerista sp*	"Sandslider","Eastern Two-toed Slider","Sand slider (Lerista","Lerista sp ", "Lerista taeniata","Lerista bipes",	
Group			
Snake	Snake sp		"Two.Snakes.together"
Frog	Anuran		"Notaden.nichollsi","Cyclorana.australis","Cyclorana.cultripes","Uperoleia.micromeles","Neobatrachus.aquilonius","Platyplectrum.spenceri"
Unidentifiable			
Unidentifiable sp	*NA*	"Snow.leopard","Unknown (small elongate guna","Smb","Other animal","Other (list in next section","Bird or lizard not sure took pictures","Other","Unidentified sp ", "Unidentified sp ", "", "Unidentified sp ", "Small bird, Scorpion","Small birds, Scorpion", "Small species", "Other mammal", "Jululka", "emu and bilby",	Records omitted as detection was unidentified

Table S1.3. Details of records in each contributed dataset that were omitted from the dataset because of inaccuracies in the spatial information for records, which could not be corrected. The dataset ID is the unique dataset identifier in the AZM National Dataset.

Data Provider	Details of inaccuracies in spatial information within datasets. (Blank cells mean no issues noticed).	Dataset place	Dataset ID
Northern Territory			
AWC Newhaven		Newhaven Wildlife Sanctuary	15
(CLC) Anangu Luritjiku Rangers	18 points plotting north of jurisdiction – omitted.	Papunya, Katiti Petermann IPA	45
(CLC) Angas Downs IPA Rangers		Angas Downs IPA	39
(CLC) Anmattyerr Rangers and Illeuwurru TOs		Illeuwurru, Ti-Tree	35
(CLC) Kaltukatjara Rangers		Docker River, Katiti Petermann IPA	40
(CLC) Ltyentye Apurte Rangers		Santa Teresa	41
(CLC) Muru Warinyi Ankkul Rangers	15 datapoints plotting far north outside range - omitted.	Tennant Creek	53
			52
			34
			37
			47
			38
(CLC) Muru Warinyi Ankkul Rangers and North Tanami Rangers		Lajamanu, Tennant Creek	54
(CLC) North Tanami Rangers		Lajamanu	55
			46
(CLC) Tjakura Rangers		Katiti Petermann IPA	44
(CLC) Warlpiri Nyirripi Rangers	Spatial data for some records not provided	South Tanami IPA	42
(CLC) Warlpiri Willowra Rangers			36
(CLC) Warlpiri Yuendumu Rangers			43
Tanami RBM	1 bettong record omitted.	Tanami Desert	31
Tom Newsome		Tanami Desert	30
Queensland			
Save the Bilby	Some spatial data not provided	Southeast Qld	32
South Australia			
Ellen Ryan Colton and APY Land Management		APY Lands	25
Arid Recovery		Arid Recovery Reserve	28
Joe Benshemesh and AW NRM		Alinytjara Wilurara NRM region	27

Data Provider	Details of inaccuracies in spatial information within datasets. (Blank cells mean no issues noticed).	Dataset place	Dataset ID
AWC Kalamurina		Kalamurina Wildlife Sanctuary	14
AW NRM and Rick Southgate		Alinytjara Wilurara NRM region	62
SA Government		Northeast SA (Ampurta surveys 2006)	5
		Northeast SA (Ampurta surveys 2013)	3
		Statewide (BDBSA)	24
		Northeast SA (Dusky Hopping Mouse surveys 2012)	1
		Northeast SA (Dusky Hopping Mouse surveys 2018)	4
		Quinyambie (2008)	8
		Quinyambie (2015)	2
		Simpson and Tirari Deserts	6
		Simpson Desert and other locations	7
		Simpson Desert	9
		Strezlecki Desert	10
		Strezlecki Desert	12
Western Australia			
Birriliburu Rangers, Mungarlu Ngurrarankatja Rirraunkatja AC	13 points projecting to Perth WA - outside AZM study area - omitted. 1 point- recorded as "snow Leopard" – omitted.	Birriliburu IPA	50
Kanyirninpa Jukurrpa		Martu	58
Karajarri Lands Trust Association	11 data points are too far north; 1 datapoint plotting into the sea - omitted.	Karajarri IPA	60
Kiwirrkurra Rangers and TOs		Kiwirrkurra IPA	20
	One point plotting very far west of other survey points – omitted.		48
Ngaanyatjarra Council		Ngaanyatjarra	49
	Points plotting outside Australia (because spatial data not provided) - omitted.		57
Ngurrara Rangers, Yanunijarra AC		Ngurrara	26
Ngururrpa Rangers and TOs		Ngururrpa IPA	22
Nigel Jackett		Nita Downs	19
Nyikina Mangala Rangers, Walalakoo AC	50 points plotting outside Australia - omitted.	Nyikina Mangala	61
Nyul Nyul Rangers		Dampier Peninsula	21
Nyumba Buru Yawuru	5 points plotting outside of Australia (in the ocean) – omitted.	Dampier Peninsula	11

Data Provider	Details of inaccuracies in spatial information within datasets. (Blank cells mean no issues noticed).	Dataset place	Dataset ID
Paruku Rangers, Tjurabalan AC		Paruku IPA	59
Sheffield Resources		Mt Jowlaenga, Dampier Peninsula	23
WA DBCA and Yawuru Country Managers, Karajarri Rangers, Nyangumarta Rangers		La Grange area	17
WA Main Roads		Dampier Peninsula	18
			33
Wiluna Rangers, Tarlka Matuwa Piarku AC	11 points plotting outside Australia – omitted.	Matuwa Kurrara Kurrara	16

Appendix 2 – Species groups

Overall, 18% of records were made to genus, family or higher level, rather than to species level, but the proportion of records that were not made to species varied among birds, reptiles, mammals and reptiles. To explore this further, we created a hierarchy with up three species group levels to aggregate detections. The group levels were based on a combination of taxonomy, size, and whether the species in the group were native or introduced (for instance: Crest-tailed mulgara: dasyurid; small-medium mammal; mammal) (Table S2.1).

By creating these groups, we were also able to consider detection data that was only made to the group level, and thus take another look at how detections were distributed across classes and other higher level groups. For example, a record called 'snake' could be included here (as 'snake' and also as 'reptile') even though it could not contribute to any analyses based on species (Table S2.2; Figures S2.1; S2.2).

Table S2.1. Species group hierarchy in the AZM National Dataset.

Common name	Scientific name	Subgroup 2	Subgroup 3
Native mammals			
Agile wallaby	*Notamacropus agilis*	Large mammal	Large macropod
Brush-tailed mulgara	*Dasycercus blythii*	Small medium mammal	Dasyurid
Central pebble-mound mouse	*Pseudomys johnsoni*	Small medium mammal	Rodent
Central short-tailed mouse	*Leggadina forresti*	Small medium mammal	Rodent
Common brushtail possum	*Trichosurus vulpecula*	Small medium mammal	Possum
Crest-tailed mulgara	*Dasycercus cristicauda*	Small medium mammal	Dasyurid
Dingo	*Canis familiaris lupus*	Large mammal	Large carnivore
Dusky hopping mouse	*Notomys fuscus*	Small medium mammal	Rodent
Euro	*Osphranter robustus*	Large mammal	Large macropod
Fat-tailed dunnart	*Sminthopsis crassicaudata*	Small medium mammal	Dasyurid
Fat-tailed pseudantechinus	*Pseudantechinus macdonnellensis*	Small medium mammal	Dasyurid
Golden bandicoot	*Isoodon auratus*	Small medium mammal	Bandicoot-Bilby
Greater bilby	*Macrotis lagotis*	Small medium mammal	Bandicoot-Bilby
Kowari	*Dasyuroides byrnei*	Small medium mammal	Dasyurid
Long-haired rat	*Rattus villosissimus*	Small medium mammal	Rodent
Northern marsupial mole	*Notoryctes caurinus*	Small medium mammal	Mole

Common name	Scientific name	Subgroup 2	Subgroup 3
Northern nail-tail wallaby	*Onychogalea unguifera*	Small medium mammal	Small macropod
Plains mouse	*Pseudomys australis*	Small medium mammal	Rodent
Red kangaroo	*Osphranter rufus*	Large mammal	Large macropod
Sandy inland mouse	*Pseudomys hermannsburgensis*	Small medium mammal	Rodent
Short-beaked echidna	*Tachyglossus aculeatus*	Small medium mammal	Monotreme
Southern hairy-nosed wombat	*Lasiorhinus latifrons*	Large mammal	Wombat
Southern marsupial mole	*Notorycytes typhlops*	Small medium mammal	Marsupial mole
Spectacled hare-wallaby	*Lagorchestes conspicillatus*	Small medium mammal	Small macropod
Spinifex hopping mouse	*Notomys alexis*	Small medium mammal	Rodent
Warru	*Petrogale lateralis centralis*	Small medium mammal	Small macropod
Yellow-footed rock-wallaby	*Petrogale xanthopus*	Small medium mammal	Small macropod
Native mammals identified to genera			
Dunnart	*Sminthopsis sp*	Small medium mammal	Dasyurid
Large macropod	*Macropus/Osphranter sp*	Large mammal	Large macropod
Pseudomys sp	*Pseudomys sp*	Small medium mammal	Rodent
Native mammals identified to group			
Bat	Bat	Bat	Bat
Medium large mammal	Mammal	Large mammal	
Native rodent	Native rodent	Small medium mammal	Rodent
Small mammal	Small mammal	Small medium mammal	
Introduced mammal			
Camel	*Camelus dromedarius*	Introduced herbivore	Introduced large herbivore
Cat	*Felis catus*	Introduced predator	
Cow	*Bos taurus*	Introduced herbivore	Introduced large herbivore
Donkey	*Equus asinus*	Introduced herbivore	Introduced large herbivore
European red fox	*Vulpes vulpes*	Introduced predator	
Goat	*Capra hircus*	Introduced herbivore	Introduced large herbivore
Horse	*Equus caballus*	Introduced herbivore	Introduced large herbivore
House mouse	*Mus musculus*	Introduced rodent	

Common name	Scientific name	Subgroup 2	Subgroup 3
Pig	*Sus scrofa*	Introduced herbivore	Introduced large herbivore
Rabbit	*Oryctolagus cuniculus*	Introduced herbivore	Introduced small herbivore
Sheep	*Ovis aries*	Introduced herbivore	Introduced large herbivore
Birds			
Australian bustard	*Ardeotis australis*	Medium bird	
Bush stone-curlew	*Burhinus grallarius*	Medium bird	
Emu	*Dromaius novaehollandiae*	Large bird	
Malleefowl	*Leipoa ocellata*	Medium bird	
Bird identified to group			
Bird	Bird	Small bird	
Reptiles			
Black-headed monitor	*Varanus tristis*	Medium reptile	Medium goanna
Burton's legless lizard	*Lialis burtonis*	Small reptile	Legless lizard
Central bearded dragon	*Pogona vitticeps*	Medium reptile	Medium dragon
Central military dragon	*Ctenophorus isolepis*	Medium reptile	Medium dragon
Central netted dragon	*Ctenophorus nuchalis*	Medium reptile	Medium dragon
Central pebble dragon	*Tympanocryptis sp*	Medium reptile	Medium dragon
Centralian blue-tongue	*Tiliqua multifasciata*	Medium reptile	Medium skink
Common knob-tailed gecko	*Nephrurus levis*	Small reptile	Gecko
Crested dragon	*Ctenophorus cristatus*	Medium reptile	Medium dragon
Desert skink	*Liopholis inornata*	Medium reptile	Medium skink
Gould's goanna	*Varanus gouldii*	Large reptile	Large goanna
Great desert skink	*Liopholis kintorei*	Medium reptile	Medium skink
Lally's two-line dragon	*Diporiphora lalliae*	Medium reptile	Medium dragon
Long-nosed dragon	*Gowidon longirostris*	Medium reptile	Medium dragon
Macquarie river turtle	*Emydura macquarii*	Small reptile	
Merten's water monitor	*Varanus mertensi*	Large reptile	Large goanna
Mulga snake	*Pseudechis.australis*	Large reptile	Large snake
Night skink	*Liopholis striata*	Medium reptile	Medium skink
Painted dragon	*Ctenophorus pictus*	Medium reptile	Medium dragon
Perentie	*Varanus giganteus*	Large reptile	Large goanna
Reticulated whip snake	*Demansia reticulata*	Medium reptile	Medium snake
Ringed brown Snake	*Pseudonaja modesta*	Medium reptile	Medium snake
Shingle-back	*Tiliqua rugosa*	Medium reptile	Medium skink
Short-tailed pygmy monitor	*Varanus brevicauda*	Medium reptile	Medium goanna
Spiny-tailed monitor	*Varanus acanthurus*	Large reptile	Large goanna
Stimson's python	*Antaresia stimsoni*	Medium reptile	Medium snake
Thorny devil	*Moloch horridus*	Medium reptile	Medium dragon
Tree dtella	*Gehyra variegata*	Small reptile	Gecko
Western beaked gecko	*Rhynchoedura ornata*	Small reptile	Gecko

Common name	Scientific name	Subgroup 2	Subgroup 3
Western bearded-dragon	*Pogona minor*	Medium reptile	Medium dragon
Western blue-tongue	*Tiliqua occipitalis*	Medium reptile	Medium skink
Western brown snake	*Pseudonaja mengdeni*	Large reptile	Large snake
Woma python	*Aspidites ramsayi*	Large reptile	Large snake
Yellow-spotted monitor	*Varanus panoptes*	Large reptile	Large goanna
Reptiles identified to genera			
Blind snake	*Anilios sp*	Small reptile	Blind snake
Ctenotus sp	*Ctenotus sp*	Small reptile	Small skink
Egernia sp	*Egernia sp*	Medium reptile	Medium skink
Goanna	*Varanus sp*	Large reptile	Large goanna
Legless lizard	Legless lizard	Small reptile	Legless lizard
Sand sliders	*Lerista sp*	Small reptile	Small skink
Reptiles identified to group			
Dragon	Agamidae	Small reptile	Small dragon
Gecko	Gekkonidae	Small reptile	Gecko
Small reptile	Reptile sp	Small reptile	
Snake	Snake	Medium reptile	Medium snake
Frog			
Frog	Anuran		
Invertebrate			
Invertebrate	Arthropoda		

Table S2.2. Table summarising the numbers of sites, site-visits and records for different subgroup detections in the AZM National dataset. Some species records were omitted from this summary, for example: Macquarie river turtle, unidentified small mammal, unidentified small reptile, and unidentified medium-large mammal. Data is also summarised in Fig S2.2.

Group (Class)	Subgroup 1	Subgroup 2	N. sites	N. site visits	N. records	Percentage % of records
Mammal			1888	4123	15,167	31.3
	Large mammal		1123	2799	8374	17.3
		Large macropod	411	*696*	3366	6.94
		Large carnivore	698	*2080*	4966	10.2
		Wombat	10	*15*	25	0.05
	Small medium mammal		765	1323	6790	14.0
		Bandicoot-Bilby	300	*459*	907	1.87
		Dasyurid	74	*134*	1056	2.18
		Marsupial mole	3	*6*	33	0.07
		Monotreme	53	*105*	348	0.72
		Possum	2	*2*	7	0.01
		Rodent	154	*382*	2731	5.63
		Small macropod	111	*124*	321	0.66
	Bat		1	1	3	0.01
Introduced mammal			2119	7731	21,380	44.1
	Introduced herbivore		1367	4832	13,907	28.7
		Introduced large herbivore	1044	*1573*	6869	14.2
		Introduced small herbivore	323	*3259*	7038	14.5
	Introduced rodent		1	1	5	0.01
	Introduced predator		752	2898	7468	15.4
Bird			720	1161	4711	9.71
	Large bird		335	479	1379	2.84
	Medium bird		286	501	2193	4.52
	Small bird		99	181	1139	2.35
Reptile			632	1792	7125	14.7
	Large reptile		369	1157	3547	7.31
		Large goanna	362	*1138*	3378	6.96
		Large snake	7	*19*	169	0.35
	Medium reptile		118	261	1532	3.16
		Medium dragon	3	*13*	193	0.40
		Medium goanna	1	*1*	8	0.02
		Medium skink	102	*211*	724	1.49
		Medium snake	13	*36*	607	1.25
	Small reptile		145	374	2046	4.22
		Blind snake	1	*1*	2	0.00

Group (Class)	Subgroup 1	Subgroup 2	N. sites	N. site visits	N. records	Percentage % of records
		Gecko	4	*4*	28	0.06
		Legless lizard	1	*1*	30	0.06
		Small dragon	9	*13*	168	0.35
		Small skink	10	*17*	208	0.43
Frog			2	2	28	0.06
Invertebrate			2	4	114	0.23
Total records in AZM National Dataset					48,525	

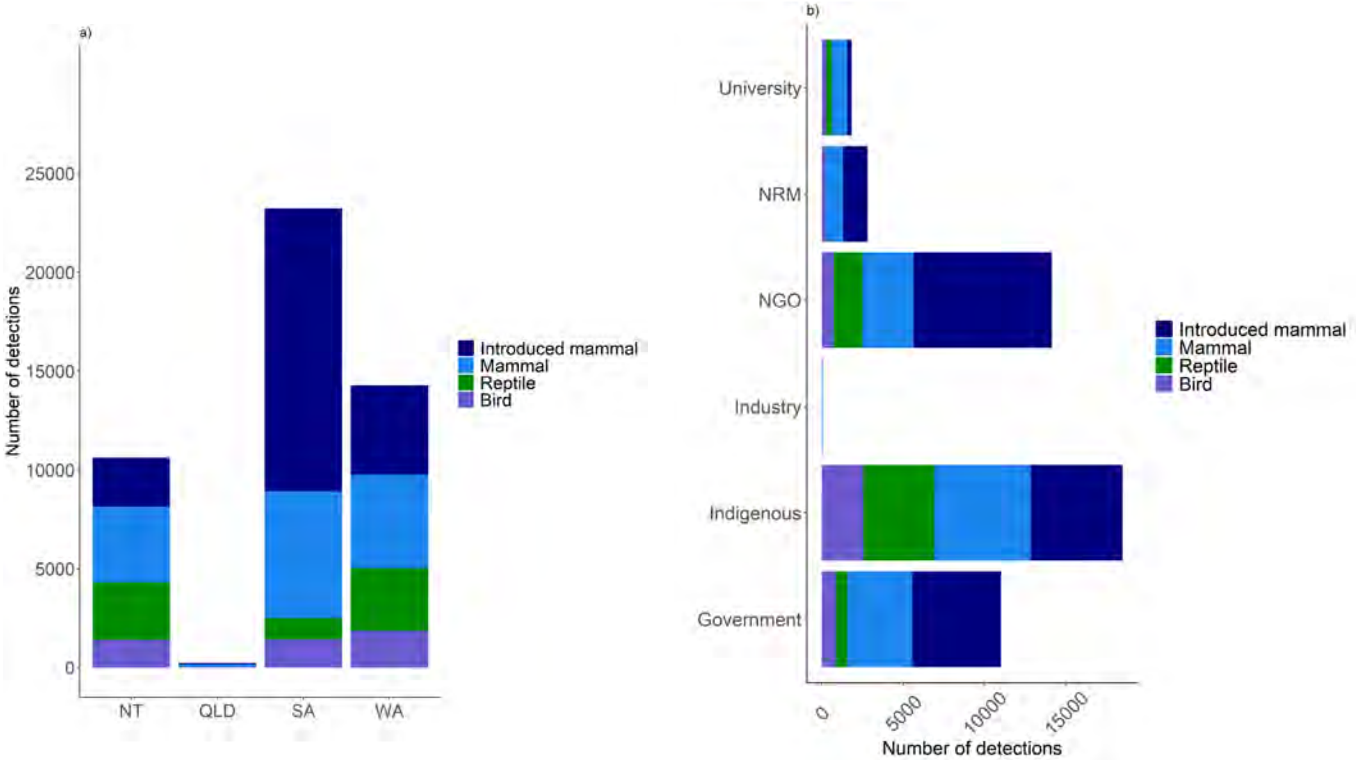

Figure S2.1. Records by class/type by a) jurisdiction; and b) data provider type, from the AZM National Dataset. Frog (N. records = 28) and invertebrate (N. records = 114) omitted.

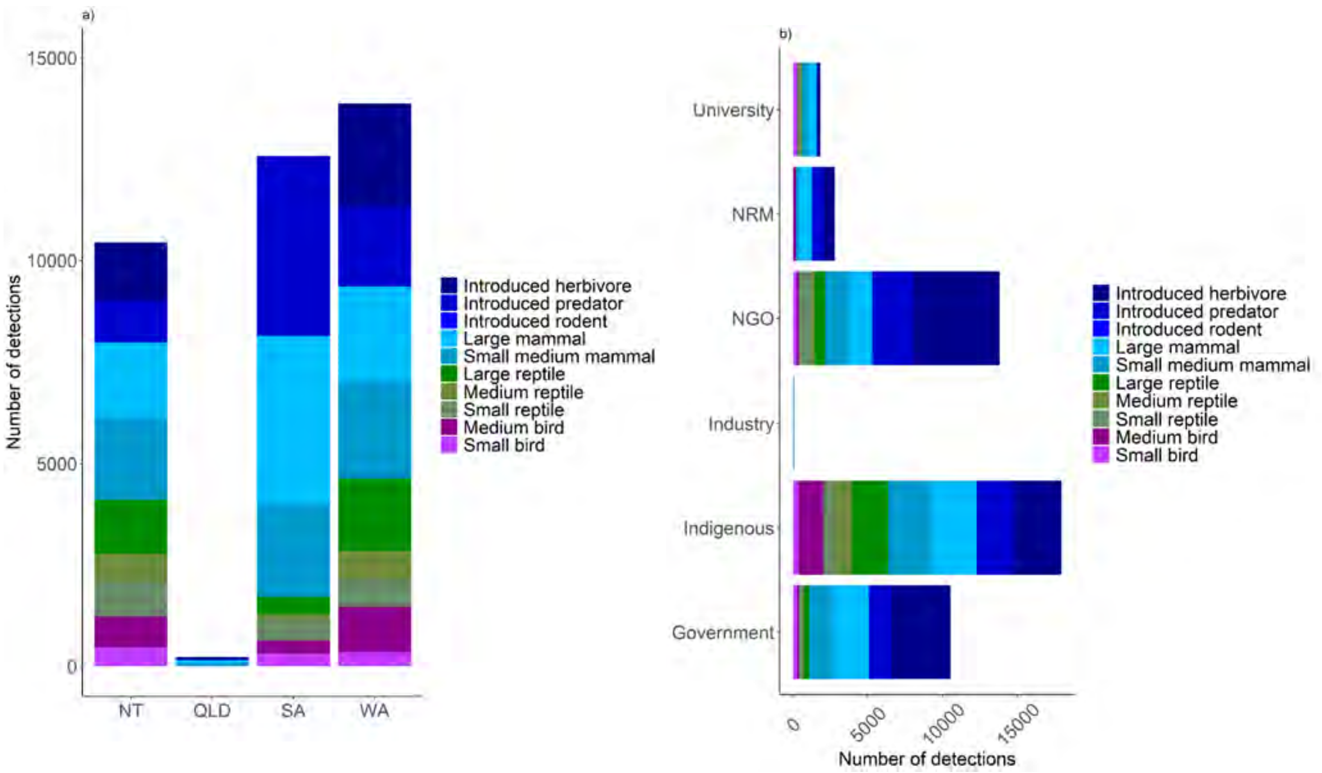

Figure S2.2. Aggregated subgroup 1 by a) jurisdiction; and b) data provider type from the AZM National Dataset. Frog (N. records = 28) and Invertebrate (N. records = 114) records omitted.

Table S2.3: Number of records of each species, arranged by Jurisdiction and Data provider within the AZM National Dataset. The group levels were based on a combination of taxonomy and identification to species, the full list of species / groupings are in Table S2.1.

Data provider	Native mammal		Native mammal groups		Introduced mammal		Native reptile		Native reptile groups		Native bird		Native bird groups		Frog		Invertebrate		Subtotal (N. records)
	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	
Northern Territory																			
AWC Newhaven	838	1.73	442	0.91	904	1.86	229	0.47	944	1.95	170	0.35	129	0.27					3656
CLC Anangu Luritjiku Rangers	8	0.02			10	0.02	4	0.01	1		2		1						26
CLC Angas Downs IPA Rangers					1						1								2
CLC Anmattyerr Rangers, Illeuwurru TOs	17	0.04	3	0.01	7	0.01	9	0.02	5	0.01	1								42
CLC Kaltukatjara Rangers	1				3	0.01	1		1										6
CLC Ltyentye Apurte Rangers	9	0.02			15	0.03	9	0.02	5	0.01	2						1		41
CLC Muru Warinyi Ankkul Rangers	575	1.18	35	0.07	390	0.8	96	0.2	144	0.3	195	0.4	18	0.04	3	0.01			1456
CLC North Tanami Rangers	32	0.07			40	0.08	84	0.17	6	0.01	16	0.03	2		3	0.01			183
CLC Tjakuṟa Rangers	2		1		7	0.01	3	0.01	3	0.01	1								17
CLC Warlpiri Nyirripi Rangers	75	0.15	8	0.02	96	0.2	85	0.18	26	0.05	18	0.04	1		2				311
CLC Warlpiri Willowra Rangers	128	0.26	4	0.01	162	0.33	58	0.12	56	0.12	60	0.12	10	0.02					478
CLC Warlpiri Yuendumu Rangers	11	0.02			29	0.06	9	0.02	9	0.02	8	0.02	1						67
Tanami RBM	721	1.49	26	0.05	602	1.24	574	1.18	197	0.41	417	0.86	68	0.14	10	0.02			2615

Data provider	Native mammal		Native mammal groups		Introduced mammal		Native reptile		Native reptile groups		Native bird		Native bird groups		Frog		Invertebrate		Subtotal (N. records)
	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	
Tom Newsome	677	1.4	252	0.52	202	0.42			328	0.68	48	0.1	240	0.49					1747
Queensland																			
Save the Bilby	116	0.24	30	0.06	78	0.16					17	0.04							241
South Australia																			
Arid Recovery	594	1.22	145	0.3	6540	13.48	1				168	0.35							7448
AW NRM and Rick Southgate	594	1.22	155	0.32	1007	2.08					109	0.22							1865
AWC Kalamurina	787	1.62	197	0.41	980	2.02	3	0.01	575	1.18	126	0.26	128	0.26	2		17	0.04	2815
Ellen Ryan Colton and APY Land Management	27	0.06	3	0.01	48	0.1			3	0.01			2						83
Joe Benshemesh and AW NRM	269	0.55	63	0.13	506	1.04	5	0.01			117	0.24							960
SA Government	2839	5.85	759	1.56	5227	10.77	258	0.53	225	0.46	582	1.2	190	0.39			30	0.06	10110
Western Australia																			
Birriliburu Rangers Mungarlu Ngurrarankatja Rirraunkatja AC	215	0.44	103	0.21	344	0.71	61	0.13	129	0.27	134	0.28	10	0.02			1		997
Kanyirninpa Jukurrpa	1799	3.71	150	0.31	1964	4.05	621	1.28	538	1.11	722	1.49	28	0.06					5822
Karajarri Lands Trust Association	50	0.1	10	0.02	35	0.07			42	0.09	15	0.03							152
Kiwirrkurra Rangers and TOs	260	0.54	10	0.02	449	0.93	132	0.27	134	0.28	130	0.27	4	0.01	2				1121

Data provider	Native mammal		Native mammal groups		Introduced mammal		Native reptile		Native reptile groups		Native bird		Native bird groups		Frog		Invertebrate		Subtotal (N. records)
	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	N. records	% all records	
Ngaanyatjarra Council	88	0.18			5	0.01	97	0.2			1								191
Ngurrara Rangers Yanunijarra AC	4	0.01			8	0.02			18	0.04	1		2				1		34
Ngururrpa Rangers and TOs	148	0.3	22	0.05	182	0.38	29	0.06	30	0.06	95	0.2							506
Nigel Jackett	1		4	0.01	17	0.04			4	0.01	1								27
Nyikina Mangala Rangers Walalakoo AC	25	0.05			3	0.01													28
Nyul Nyul Rangers	22	0.05	1		35	0.07			18	0.04	3	0.01							79
Nyumba Buru Yawuru	23	0.05	1		15	0.03	1		18	0.04			2						60
Paruku Rangers Tjurabalan AC	3	0.01																	3
Sheffield Resources	36	0.07																	36
WA DBCA and Yawuru Country Managers Karajarri Rangers Nyangumarta Rangers	560	1.15	121	0.25	803	1.65	18	0.04	616	1.27	153	0.32	181	0.37	6	0.01	5	0.01	2463
WA Main Roads	320	0.66	83	0.17	218	0.45			207	0.43	19	0.04	94	0.19			57	0.12	998
Wiluna Rangers Tarlka Matuwa Piarku AC	464	0.96	206	0.42	443	0.91	147	0.3	309	0.64	240	0.49	28	0.06			2		1839
Grand Total	12338	25.43	2834	5.84	21375	44.05	2534	5.22	4591	9.46	3572	7.36	1139	2.35	28	0.06	114	0.23	48525

Appendix 3 – Other outputs

AZM website: www.AridZoneMonitoring.org.au

Project outputs are available from the TSR Hub website. They include:

Reports

- AZM Project Report (this document)
- AZM Project Summary
- APY Lands field trip report

Monitoring design guidance

- AZM Monitoring design for track-based surveys
- AZM Summary-Designing a monitoring program for South Australia
- Detailed example of how to design a regional monitoring program
- Detailed example of the design of a national monitoring program
- Detailed analysis of features that affect detectability

Data collection guidance and templates

- AZM Report perspectives on tracking data
- AZM Data recording sheet and instructions
- AZM Data entry templates

Species profiles (animal factsheets)

NATIVE MAMMALS
Macropods (small to large)

- Mala (rufous hare-wallaby)
- Pututjurru (brush-tailed bettong, woylie)
- Spectacled hare-wallaby
- Northern nailtail wallaby
- Warru (black-footed rock-wallaby)
- Agile wallaby
- Large kangaroos (red kangaroo, grey kangaroo, euro)

Other mammals (small to large)

- Hopping mice
- Kowari
- Other small mammals
- Marsupial moles
- Brush-tailed mulgara
- Crest-tailed mulgara
- Short-beaked echidna
- Minkajurru (golden bandicoot)
- Greater bilby
- Southern hairy-nosed wombat
- Dingo

INTRODUCED MAMMALS (small to large)

- Rabbit
- Cat
- Fox
- Goat

- Donkey and horse
- Cow
- Camel

BIRDS (small to large)
- Bush stone-curlew
- Malleefowl
- Australian bustard
- Emu
- Birds

REPTILES (small to large)
- Small reptiles
- Dragons
- Thorny devil
- Large skinks
- Tjakura (great desert skink)
- Centralian blue tongue lizard
- Shingleback (bobtail, sleepy lizard)
- Small goannas
- Gould's goanna (sand goanna)
- Perentie
- Yellow-spotted monitor
- Large snakes

OTHER GROUPS
- Invertebrates
- Frogs

See you soon. Image: Nico Rakotopare