Mornington – Marion Downs – Tableland Wildlife Sanctuary

Ecohealth Report 2021

australian wildlife conservancy

Summary

Australian Wildlife Conservancy (AWC) has implemented an Ecological Health Monitoring Program (Ecohealth) across Mornington and Marion Downs Wildlife Sanctuaries and Tableland Partnership Area (MMDT) to measure the changes in the status and trend of conservation assets and threats to those assets. Metrics from the program are reported in annual Ecohealth Reports and Scorecards. This is the Ecohealth Report for 2021. Values of metrics derived in this report were based on data collected during surveys carried out in 2021, with reference to historical surveys from 2004 – 2020. The complete set of metrics and their values are summarised in the accompanying Ecohealth Scorecard.

In implementing the Ecohealth program in 2021, AWC conducted 5,440 camera trap nights 6,151 live trap nights, 110 bird surveys and 886 km of aerial surveys. Ecohealth surveys in 2021 detected 21 mammals, 48 reptiles, 112 birds and 18 amphibians out of a possible 53 mammals (6 introduced), 111 reptiles, 212 birds, 23 amphibians, known or likely to occur on MMDT. Guilds were assessed with surveys such as Standard Live Trapping and Standard Bird surveys. Targeted monitoring occurred for Northern Quoll (*Dasyurus hallucatus*), Purple-crowned Fairy-wren (*Malurus coronatus*), Northern Brown Bandicoot (*Isoodon macrourus*) and Spectacled Hare-wallaby (*Lagorchestes conspicillatus*).

The above average wet season of 2020-2021 (1,082 mm) following two consecutive below average wet seasons is likely to be a key driver in patterns of abundance and occupancy detected on Ecohealth surveys across MMDT in 2021. In particular, the population estimate for Purple-crowned Fairy-wren has increased by 142% compared with 2020 estimates. The arrival of cane toads on MMDT in 2016-2017 and two years of below average rainfall caused a dramatic decline in the abundance and occupancy of Northern Quolls, a trend continued this year. Only one quoll was detected on camera at the long-term survey site of Sir John Gorge.

Populations of small lowland reptiles increased considerably in 2021, likely due to increased rainfall or warmer than average temperatures during 2021. The small lowland mammal guild abundance and richness, however, remained stable in 2021, continuing to be at levels well-below longer term values (2004-2016), potentially due to a delayed response to rainfall. One exception for small mammals was the Long-tailed Planigale (*Planigale ingrami*), which had an increase in abundance by 147% compared with 2019 survey results. Savanna bird guild richness increased in 2021, possibly driven by higher rainfall supporting more fruiting and flowering plant species and water sources.

The Feral Herbivore Aerial Surveys, which direct intensive and targeted land management efforts for destocking ecologically sensitive areas on MMDT, recorded similar numbers of cattle compared with the prior year; long term trend inferences are less reliable due to a recent change in experimental design but appear to be lower in recent years. Fire regimes have improved markedly on MMDT since AWC management, and encouragingly, all fire metrics derived from the 2021 fire program shifted in a positive direction relative to both the pre-management and AWC management baselines. In particular, a reduction in late dry season fire, an increase in area of long-unburnt vegetation and decline in mean distance to unburnt vegetation over various time scales was recorded. These changes to vegetation age improves habitat availability for ground-dwelling mammals and birds that forage in recently burnt areas and shelter in long-unburnt vegetation.

For several indicators, results from surveys in previous years (2004 – 2020) provide data for comparison. For others, 2021 was the first year of survey, or methods remain in development. Further data collection over the next few years will be important for teasing out the changes in abundance and occupancy of wildlife from climatic effects and the impact of cane toads. Comparisons of climate with historical data and future surveys will provide valuable data on the ecological condition following an above average wet season, as well as, important direction for the development of future conservation land management to optimise the outcomes for MMDT's native wildlife.

Contents

Introduction 1
Mornington, Marion Downs Wildlife Sanctuaries and Tableland Partnership Area 1
Climate and weather summary 4
Methods 5
Monitoring and evaluation framework 5
Threatened and iconic species 5
Assemblages 5
Indicators and metrics 6
Survey types and history 9
Survey design and methods 10
Threatened and iconic species 10
Assemblages 14
Threats 17
Analysis methods 18
Results 20
Threatened and iconic species 20
Northern Quoll 20
Northern Brown Bandicoot 21
Spectacled Hare-wallaby 23
Purple-crowned Fairy-wren 24
Gouldian Finch 24
Assemblages 25
Mammals 25
Reptiles 27
Birds 28
Vegetation surveys 29
Threat indicators 30
Feral Herbivores 30
Fire 31
Discussion 34
Acknowledgments 35
References 36
Appendices 38
Appendix 1. Survey Methods 38
Targeted surveys 38

Document citation: Lowe K, Cameron S, Wauchope M, Pierson J, Joseph L, Kanowski J (2022) Mornington, Marion Downs and Tableland Ecohealth Report for 2021. Australian Wildlife Conservancy, Perth, WA.

Introduction

Australian Wildlife Conservancy (AWC) currently owns, manages, or works in partnerships across 31 properties in Australia, covering almost 6.5 million hectares, to implement our mission: *the effective conservation of Australian wildlife and their habitats*. AWC relies on information provided by an integrated program of monitoring and research to measure progress in meeting its mission and to improve conservation outcomes.

AWC's Ecohealth Monitoring Program has been designed to measure and report on the status and trends of species, ecological processes and threats on each of these properties (Kanowski et al. 2018). Data from the monitoring program are used to address the following broad questions relevant to our mission:

- 'are species persisting on a property?',
- 'are habitats being maintained?'
- 'are threats below ecologically-significant thresholds?'

For threatened and iconic species, including reintroduced species, AWC's monitoring program aims to obtain more detailed information related to their conservation management, for example data on survival, recruitment, condition, distribution and/or population size.

The structure of the Ecohealth Program is as follows. AWC's Monitoring and Evaluation framework provides guidance on the development of the Ecohealth Monitoring Plans for each property managed by AWC: these plans describe the conservation values and assets of each property, the threats to these assets, and the monitoring program that will be used to track their status and trend, and to evaluate outcomes. Annual survey plans and schedules are developed to implement these plans. The outcomes of these surveys are presented in annual Ecohealth Reports and summary Ecohealth Scorecards.

This document is one of a series of annual Ecohealth Reports for Mornington and Marion Downs Sanctuaries and Tableland Partnership Area (referred to here as MMDT). It draws on surveys conducted during 2021 to report on the status and trends of the Ecohealth indicators. The companion Ecohealth Scorecard presents the indicators and their metrics in a summary format.

Mornington, Marion Downs Wildlife Sanctuaries and Tableland Partnership Area

The Mornington and Marion Downs Wildlife Sanctuaries and Tableland Partnership Area (MMDT) are located in the Central Kimberley and are 320,994 ha, 256,811 ha and 308,302 ha, respectively in extent, totalling a continuous 886,107 ha (Figure 1).

The Central Kimberley Bioregion encompasses the lower half of the Kimberley Basin, an ancient landscape created by marine sedimentation and volcanic activity almost two billion years ago, and the subsequent buckling and folding of these rocks units as the Kimberley plate collided with the Northern Australian plate. This tectonic activity formed the spectacular Wunaamin Miliwundi Ranges in the south of the bioregion.

The long and varied geological history of the Central Kimberley has resulted in a complex patterning of soils, which support a diverse array of woodlands and savannas. Combined with this, a north-south rainfall gradient (from 900 mm/year to 500 mm/year) drives a general cline of vegetation from taller open woodlands in the north, to very sparse, low savannas at the southern edge of the bioregion, just before the transition to the inland deserts. The fauna in the bioregion reflects this diversity, having elements of both monsoon savanna fauna as well as arid zone fauna. A third element is high levels of endemism, occurring neither in the deserts nor the savannas outside the region.

Prior to colonization by Europeans, the Kimberley was managed for hunting and traditional purposes for tens of thousands of years, particularly with the use of traditional burning practices (Vigilante 2001, Vigilante and Bowman 2004). In 1916, the Glenroy Pastoral Company took up pastoral leases over what is now MMDT (which are still under pastoral lease), and the land was managed primarily for cattle production for much of the twentieth century. Mornington and Marion Downs and Tableland represent Australia's largest privately managed conservation area (with 320,994 ha, 256,811 ha and 308,302 ha respectively, including stock routes). Mornington was acquired by AWC in 2001 and has had an active land management and science

program since 2004. Marion Downs was acquired in 2007, and in 2012 AWC entered into partnership with the Yulmbu Aboriginal Corporation to manage Tableland Partnership Area.

MMDT includes 23 ecosystem types, with 11 broad vegetation types, the most dominant being low Eucalypt savanna woodland with mixed grasses (Figure 2). A diverse array of plants and vegetation types occur on MMDT, including at least 1,000 plant species, which form a wide variety of plant associations. The great diversity of plants and mosaic of vegetation types is likely due to the climate and complex underlying geology and resulting differences in soil characteristics.

Marion Downs and the northern section of Mornington are dominated by low tree savanna woodland, characterized by Scarlet Gum (*Eucalyptus phoenicea*) and *E. ferruginea* over the hard spinifex (*Triodia pungens*). Snappy gum (*E. brevifolia*) and spinifex (*Triodia spp*.) is common on rocky areas of central and southern Mornington, while Darwin box (*E. tectifica*) and mixed grassland is typical in the deeper volcanic soils of the valleys. Along watercourses, galleries of Paperbark (i.e. *Melaleuca argentea* and *M. leucadendra*), Leichardt tree (*Nauclea orientalis*), and *Pandanus spiralis* and *P. aquaticus* represent an important habitat of high diversity.

On MMDT there is a combined 422 terrestrial and aquatic vertebrate species known or likely to occur, 53 of which are mammals (6 introduced), 212 birds, 111 reptiles and 23 amphibians. Eighteen species are considered threatened either under federal (Environment Protection and Biodiversity Conservation [EPBC] Act 1999) or state (WA Biodiversity Conservation Act 2016) legislation.

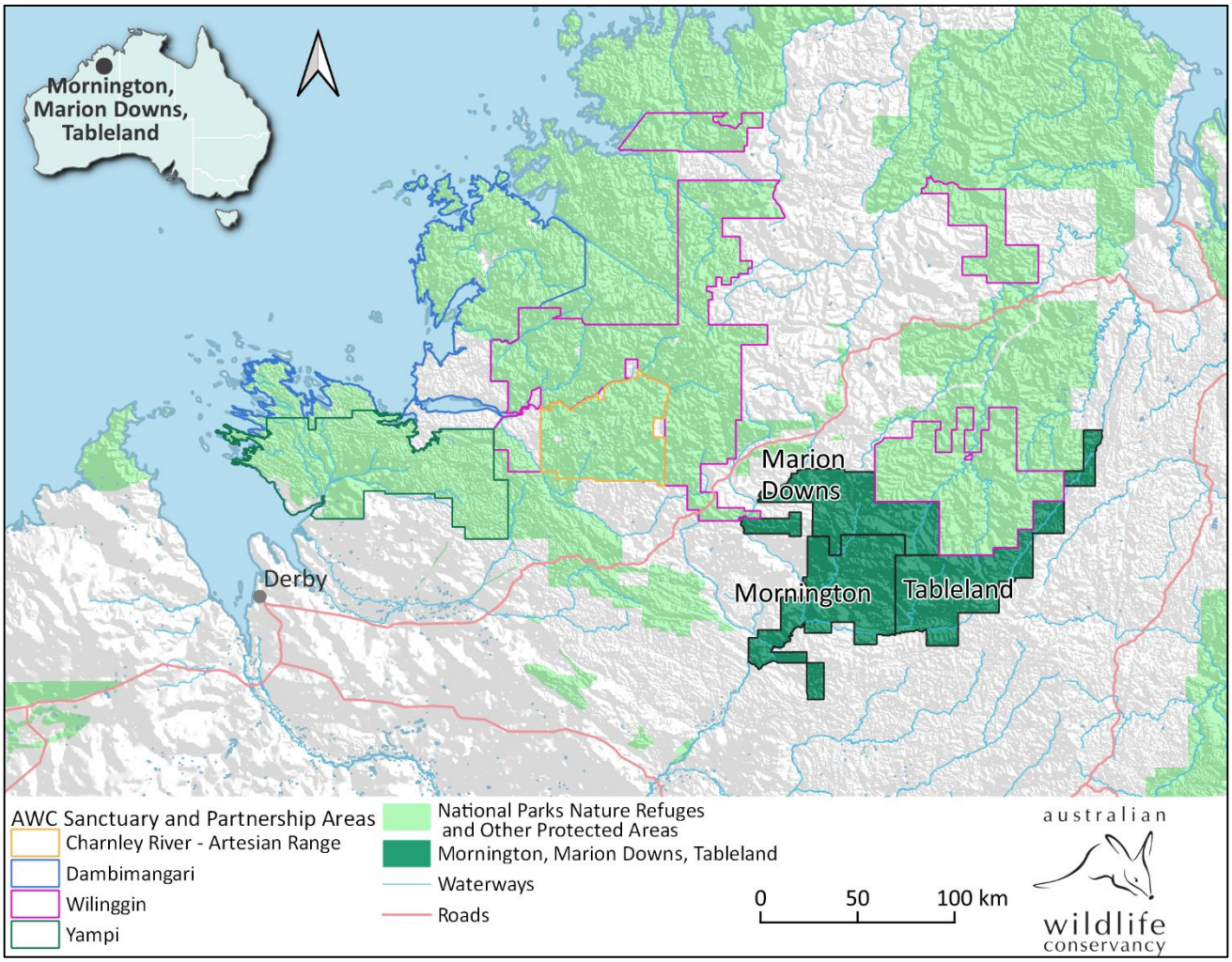


Figure 1. Location and regional context of Mornington, Marion Downs Wildlife Sanctuaries and Tableland Partnership Area, with reference to other AWC Sanctuary and Partnership Areas in the Kimberley, WA. Mornington resides on Bunuba and Kija Country, Marion Downs on Wilinggin Country and Tableland on Kija Country - AWC acknowledges the Bunuba, Kija and Ngarinyin People, the Traditional Custodians of the land.

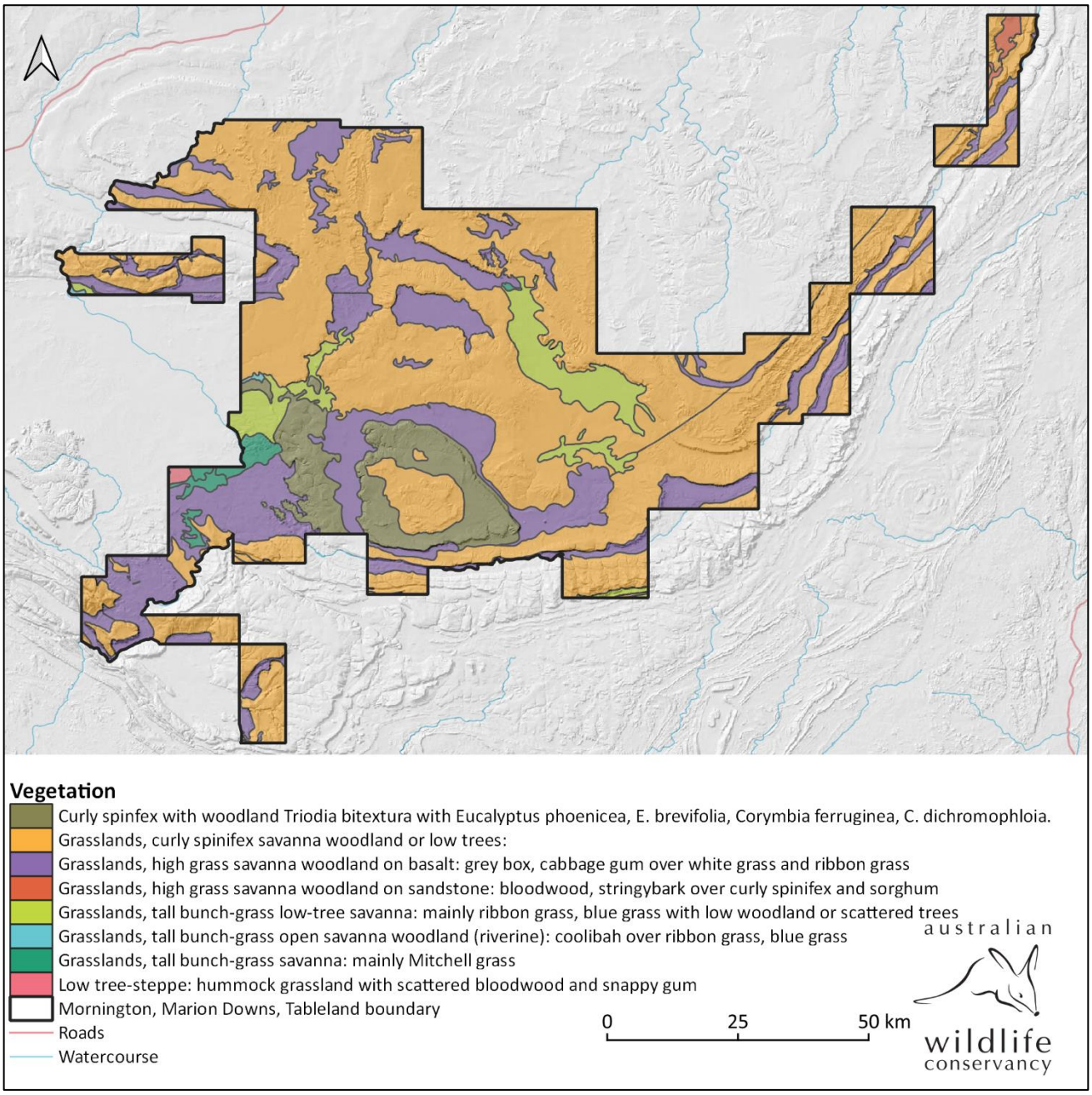


Figure 2. Extent and distribution of broad vegetation types on Mornington and Marion Downs Wildlife Sanctuaries and Tableland Partnership Area.

Climate and weather summary

MMDT is located in tropical Australia and is characterised by distinct wet and dry seasons, with rainfall concentrated in the 6 months from November to April. Rainfall is a major driver of ecological processes in the region and the 2020-2021 wet season was wetter than average, with 1,082 mm of rainfall received compared to the long-term wet season mean of 874 mm (data from nearby Mount House BoM weather station 3098) (BOM 2021). This was substantially higher than the previous 2019-2020 and 2018-2019 wet seasons with 433 mm and 791 mm recorded, respectively (Figure 3). The end of 2020 saw a typical onset to the 2020-2021 wet season, followed by the wettest December 2020 on record for Mornington operations base with large and persistent monsoonal lows (Figure 4). Some unexpected rain was also experienced in June 2021, occurring during Standard Live Trapping Surveys. Higher than average monthly maximum temperatures were recorded in 2021, particularly in July and August, which was during Standard Live Trapping Surveys (Figure 5).

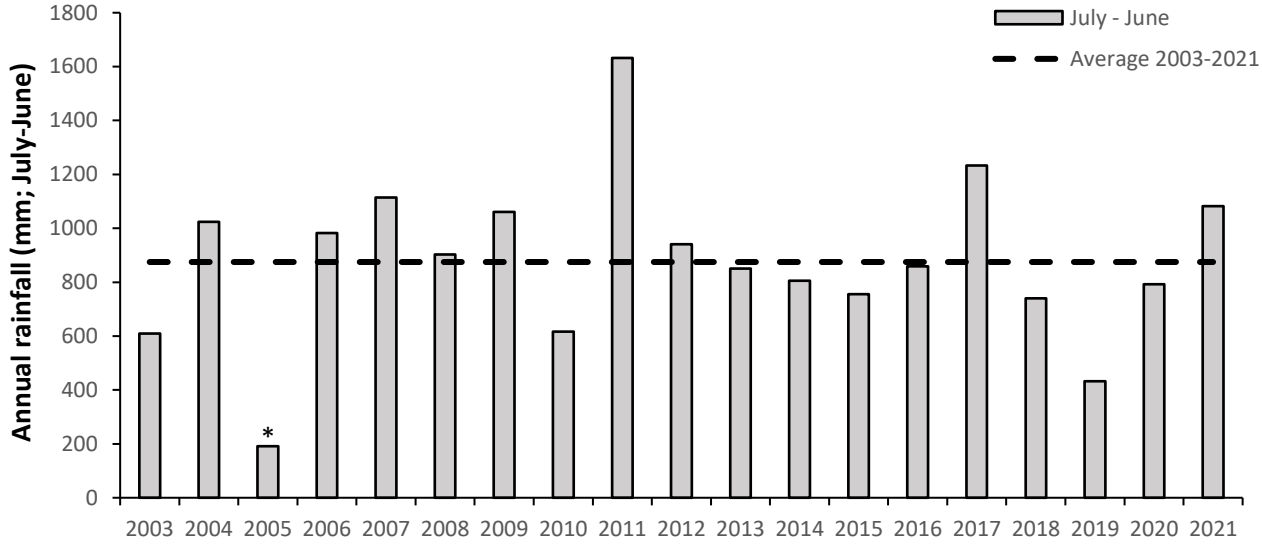


Figure 3. Annual rainfall (July-June) on Mornington, Marion Downs and Tableland from 2003 – 2021. Dashed line = average rainfall from 2003 – 2021 (July-June) (BOM 2021). Source: Bureau of Meteorology weather station 3098. *December data for 2005 is not available, and therefore annual rainfall is not accurately represented.

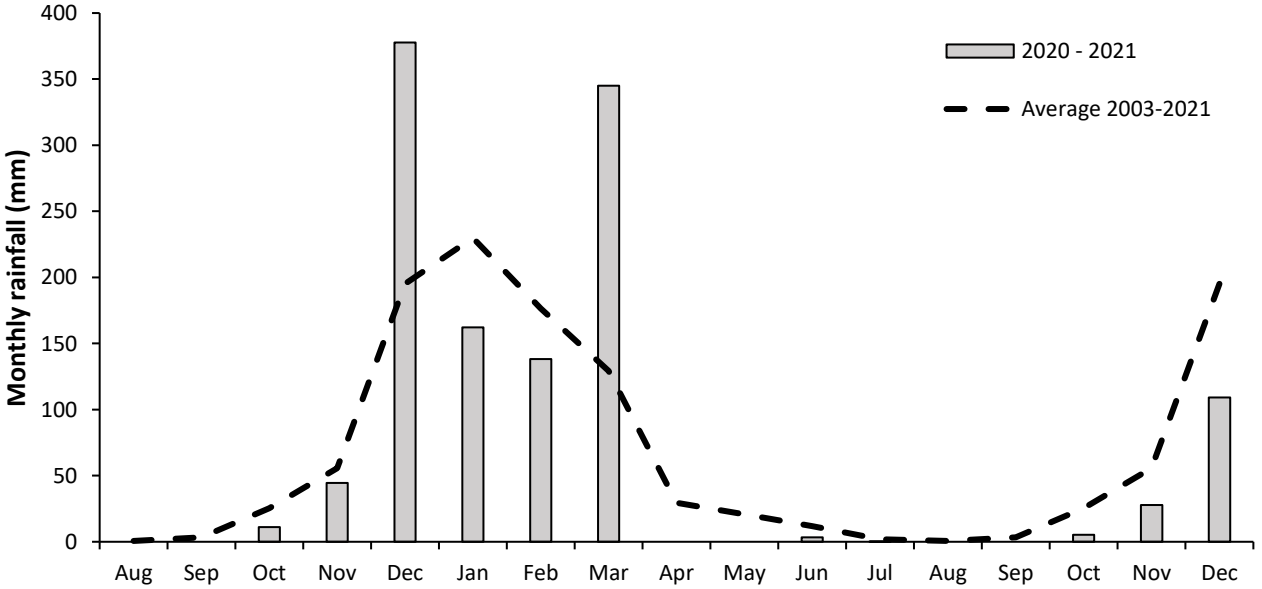


Figure 4. Monthly rainfall for Mornington, Marion Downs and Tableland, for August 2020-December 2021 compared to the long-term average (2003-2021). Source: Bureau of Meteorology weather station 3098 (BOM 2021).

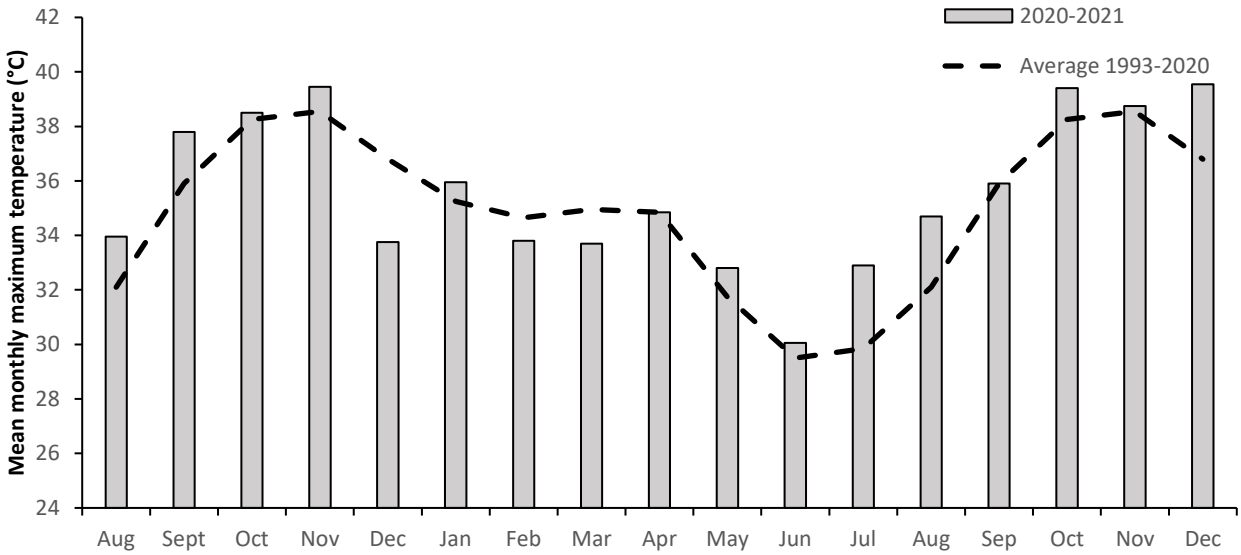


Figure 5. Mean monthly maximum temperature (°C) for Mornington, Marion Downs and Tableland from July 2020-December 2021 with historic data for reference (1993 - 2020). Source: mean monthly maximum temperatures from Mt Elizabeth Station (BOM 001018) and Fitzroy Crossing Aerodrome (BOM 003093) as they are to the north and south of MMDT (BOM 2021).

Methods

Monitoring and evaluation framework

MMDT's Ecohealth Monitoring Program has been designed to measure and report on the status and trends of selected biodiversity and threat indicators on the property, using metrics derived from data collected through a series of purpose-designed surveys. Where possible, outcomes will be evaluated against performance criteria relevant to each species, guild or assemblage.

Key threatened and iconic vertebrates

The Ecohealth program is focused on species of high conservation value, including threatened and 'iconic' species (e.g., regional endemics, species with high public profile and other species of conservation importance because of the role they play in an ecosystem, etc). Where relevant, reintroduced species are also in this category.

Monitoring programs for reintroduced species in the establishment phase (i.e., within 5-10 years of establishment) are typically set out in a *Translocation Proposal*, along with success criteria to evaluate outcomes around survival, recruitment, population size, etc.

AWC will develop *Population Management Plans* to underpin management of long-established populations of reintroduced species, to ensure early detection of any serious issues that arise, and to trigger timely responses. These plans will specify a monitoring and evaluation program (e.g., Berry et al. 2021).

AWC will aim to develop *Conservation Plans* for the remaining (extant) threatened and iconic species, with similar objectives to Population Management Plans. These plans will specify metrics to monitor outcomes for target species against nominated performance criteria.

Assemblages and surveillance species

AWC's mission involves the conservation of all native wildlife, not only threatened or reintroduced species. For this reason, AWC's monitoring program extends to surveillance monitoring of faunal assemblages (mammals, birds, reptiles, frogs). The monitoring program aims to address questions relevant to the conservation of assemblages.

At the most basic level, the program seeks to establish whether all species that are known to occur on the property are still persisting on the property (i.e., 'are all species present?').

With increasing information, the monitoring program can address more detailed questions relating to conservation of assemblages, such as 'have species maintained their distributions or abundance?' However, the boom/ bust conditions of most Australian environments can lead to large variations in the numbers of individuals in a population and the habitats or sites occupied by a species – these variations may not necessarily be informative in relation to the conservation of a species at a property over the long term.

AWC is currently working on developing an evaluation framework for surveillance monitoring of faunal assemblages. At present, we will continue to present data on a range of metrics relating to indicator species and guilds.

Indicators and metrics

On MMDT, 37 biodiversity (species and guilds) indicators have been selected for monitoring (Table 1). Seventeen of these indicators are reported on in this 2021 Ecohealth report, including 5 related to threatened and iconic species, and the remainder to surveillance monitoring of faunal assemblages, individual species, and vegetation.

Threat metrics are selected to monitor the status and trends of introduced weeds, predators and herbivores, and fire regimes. Ten threat indicators have been selected for monitoring, 4 of which were reported on in this report (Table 2).

Table 1. Biodiversity indicators and metrics for Mornington, Marion Downs and Tableland (MMDT). All surveys occurred across MMDT unless otherwise specified. *Not surveyed in 2021.

Key threatened and iconic vertebrates

Indicator	Survey name	Survey method	Metric/s
Mammals			
Northern Quoll (*Dasyurus hallucatus*)	Rocky Gorge Camera Survey, Sir John Gorge Northern Quoll Camera Survey, Sir John Gorge Northern Quoll Live Trapping	Camera traps, Live trapping	Abundance, occupancy
Northern Brown Bandicoot (*Isoodon macrourus*)	Bandicoot Camera Survey – southern Mornington only, Standard Live Trapping	Camera traps, Live trapping	Activity, abundance, occupancy
Spectacled Hare-wallaby (*Lagorchestes conspicillatus*)	Spectacled Hare-wallaby Targeted Survey	Camera traps	Activity, occupancy
Birds			
Purple-crowned Fairy-wren (*Malurus coronatus*)	Purple-crowned Fairy-wren Targeted Survey – southern Mornington only	Mist netting, Observations	Population estimate, density
Gouldian Finch (*Erythrura gouldiae*)*	Gouldian Finch Waterhole survey – southern Mornington only	Observational and acoustic	Abundance, occupancy

Vertebrate assemblages and surveillance species

Indicator	Survey name	Survey method	Metric/s
Mammals			
Assemblage richness	Standard Live Trapping, Rocky Gorge Camera Array, incidentals	Various	Number of species
Small lowland mammals			
Assemblage richness	Standard Live Trapping, incidentals	Live trapping	Number of species
Small lowland mammal guild (dasyurids, rodents)	Standard Live Trapping	Live trapping	Abundance, richness
Long-tailed Planigale (*Planigale ingrami*)	Standard Live Trapping	Live trapping	Abundance, occupancy
Common Planigale (*Planigale maculata*)	Standard Live Trapping	Live trapping	Abundance, occupancy

Indicator	Survey name	Survey method	Metric/s
Delicate Mouse (*Pseudomys delicatulus*)	Standard Live Trapping	Live trapping	Abundance, occupancy
Western Chestnut Mouse (*Pseudomys nanus*)	Standard Live Trapping	Live trapping	Abundance, occupancy
Pale Field Rat (*Rattus tunneyi*)	Standard Live Trapping	Live trapping	Abundance, occupancy
Small-medium rocky mammals			
Small rocky mammal guild (dasyurids, rodents)*	Rocky Gorge Camera Array	Camera traps	Activity, richness
Echidna (*Tachyglossus aculeatus*)*	Rocky Gorge Camera Array	Camera traps	Activity, occupancy
Ningbing False Antechinus (*Pseudantechinus ningbing*)*	Rocky Gorge Camera Array	Camera trap	Activity, occupancy
Common Rock Rat (*Zyzomys argurus*)*	Rocky Gorge Camera Array	Camera trap	Activity, occupancy
Macropods			
Large macropod guild (*Macropus agilis, M. antilopinus, M. robustus, Onychogalea unguifera*)*	TBD	Methods in development	Abundance, Richness
Short-eared Rock Wallaby (*Petrogale brachyotis*)*	Rocky Gorge Camera Array	Camera traps	Activity, occupancy
Arboreal mammals			
Savanna Glider (*Petaurus ariel*)*	Arboreal camera array (*under development*)	Camera traps	Activity, occupancy
Northern Brushtail Possum (*Trichosurus vulpecula arnhemensis)**	Arboreal camera array (*under development*)	Camera traps	Activity, occupancy
Reptiles			
Assemblage richness	Standard Live Trapping, Large Reptile Camera Survey, Rocky Gorge Camera Array, Freshwater Crocodiles Spotlighting Survey, incidentals	Various	Number of species
Small lowland reptile guild (skinks, dragons, geckos, flap-footed lizards, small snakes)	Standard Live Trapping	Live trapping	Abundance, richness
Rock monitor guild (*Varanus glebopalma, V. glauerti, V. acanthurus*)*	Rocky Gorge Camera Array, Large Reptile Camera Survey – Mornington only	Camera traps	Abundance, occupancy
Water monitor guild (*Varanus mitchelli, V. mertensi*)*	Rocky Gorge Camera Array, Large Reptile Camera Survey – Mornington only	Camera traps	Abundance, occupancy
Northern Blue-tongue Skink (*Tiliqua scincoides*)*	Large Reptile Camera Survey – Mornington only	Camera traps	Abundance, occupancy
Yellow Spotted Monitor (*Varanus panoptes*)*	Large Reptile Camera Survey – Mornington only	Camera traps	Abundance, occupancy
Freshwater Crocodile (*Crocodylus johnstoni*)*	Freshwater Crocodile Spotlighting Survey – Mornington only Freshwater Crocodile Aerial Survey – Mornington only	Visual Survey	Density
Birds			
Assemblage richness	Standard Bird Surveys, Waterhole Surveys, incidentals	Various	Number of species
Savanna diurnal bird guild	Standard Bird Surveys	Observational and acoustic	Abundance, richness
Granivorous bird guild*	Waterhole Surveys – Mornington only	Observational and acoustic	Abundance, richness

Vegetation indicators and surveillance species

Indicator	Survey name	Survey method	Metric/s
Leaf litter extent	Standard Vegetation Survey	Transect point measurement (every 1 m, 300 m per site)	Density (% points surveyed)
Vegetation ground cover	Standard Vegetation Survey	Transect point measurement (every 1 m, 300 m per site)	Density (% points surveyed)
Total groundcover extent	Standard Vegetation Survey	Transect point measurement (every 1 m, 300 m per site)	Density (% points surveyed)
Canopy cover	Standard Vegetation Survey	Transect point measurement (every 1 m, 300 m per site))	Density (% points surveyed)
Woody debris	Standard Vegetation Survey	Transect records per 100 m (continuous)	Density (records per 100 m)
Mountain White Gum (*Eucalyptus mooreana*)*	TBD	Methods under development	TBD

Table 2. Threat indicators and metrics for Mornington, Marion Downs and Tableland (MMDT). All surveys occurred across MMDT unless otherwise specified. *Not surveyed in 2021.

Indicator	Survey name/ methods	Metric/s	Performance criteria
Pest animals			
Feral cat (*Felis catus*)*	Predator Camera Array (*under redesign*)	Abundance, Occupancy	In development
Feral cattle (*Bos taurus, B. indica*)	Feral Herbivore Aerial Surveys	Density (/km)	In development
Horse (*Equus caballus*)	Aerial Herbivore Surveys	Density (/km)	In development
Donkey (*Equus asinus*)	Feral Herbivore Aerial Surveys	Density (/km)	In development
Pig (*Sus scrofa*)*	*Methods under development*		In development
Cane toad (*Rhinella marina*)*	Rocky Gorge Camera Array, Large Reptile Camera Survey – Mornington only	Occupancy	In development
Weeds			
Grader Grass (*Themeda quadrivalvis*)*	Weed Surveys (*under development)*	Extent of infestation (categorised by distribution)	In development
Parkinsonia (*Parkinsonia aculeata*)*	Weed Surveys (*under development)*	Extent of infestation (categorised by distribution)	In development
Other weeds (rubber bush, butterfly pea and stylo)*	Weed Surveys (*under development)*	Plants treated, Person Hours	In development
Fire			
Fire	Remote sensing (data compared to baseline and AWC management average)	Extent/area burnt (EDS, LDS, long unburnt) Modal frequency Distance to unburnt/long unburnt	Reduce the extent and frequency of LDS wildfires, increase long unburnt vegetation, decrease distance to unburnt/long unburnt vegetation (relative to baseline)

Survey types and history

To report on the biodiversity and threat indicators, our survey teams conduct a variety of surveys repeated on a schedule of 1-5 years, as required to obtain timely information on each indicator.

For threatened and iconic species, a range of targeted surveys include:

- Sir John Gorge Northern Quoll Survey: Camera and Live Trapping*
- Northern Brown Bandicoot Camera Array*
- Spectacled Hare-wallaby Camera Array
- Purple-crowned Fairy-wren Targeted Survey
- Gouldian Finch Waterhole Survey

**Note that some threatened and iconic species are also assessed by general surveillance monitoring surveys listed below (Table 3).*

For surveillance monitoring of assemblages, these surveys include:

- Standard Live Trapping
- Rocky Gorge Camera Array
- Standard Bird Survey
- Standard Vegetation Survey
- Predator Camera Array

To specifically monitor threats, a range of surveys are used, including:

- Feral Herbivore Aerial Survey
- Predator Camera Array

Eight of the established Ecohealth surveys were conducted on MMDT in 2021. Below is a list of surveys reported upon in this Ecohealth Report (Table 3). The Fire Scar Analysis has been completed using satellite data from 2000 (1 year prior to acquisition) to 2021. The methodology is described and results of these surveys and computations are reported on in this document.

Table 3. Survey history and effort for Ecohealth surveys on Mornington, Marion Downs and Tableland (MMDT) reported on in this report. TN = Trap nights.

Survey name	Effort (2021)	Description/comment	Previous surveys
Sir John Gorge Northern Quolls Camera Array	260 TN	20 cameras at one site spaced 100 m apart for 14 TN. In 2021, cameras deployed for 13 nights.	2020 – 240 TN 2019 – 600 TN 2018 – 600 TN
Sir John Gorge Northern Quolls Live Trapping	140 TN	20 cage and 20 Elliot traps for 4 nights. In 2021, traps were deployed for 4 nights (south side) and for 3 nights (north side) (20 traps total each side). Historical effort has been inconsistent in timing and effort.	2020 - 160 TN 2019 – 688 TN 2017 – 300 TN 2016 – 256 TN 2015 – 862 TN 2014 – 901 TN 2013 – 716 TN 2012 – 857 TN 2011 – 816 TN
Northern Brown Bandicoot Camera Array	2,380 TN	90 cameras across 18 sites (5 cameras per site) for 28 TN each spaced 50 m apart. 17 sites surveyed in 2021.	2020 – 2,520 TN 2019 – 377 TN (trial cameras)
Spectacled Hare-wallaby Camera Array	2,800 TN	100 cameras across 10 sites (10 cameras per site) spaced 200 m apart. In 2021, reduced to 5 cameras per site (50 cameras) and 50 cameras at 1 site (population grid) spaced 300 m apart, for 28 TN.	2020 – 2,800 TN 2019 – 285 TN (surveillance trial) 2018 – 900 TN (exploratory)
Purple-crowned Fairy-wren Targeted Surveys	30 kms	15 km survey area. Biannual census conducted over several weeks by Monash University.	2005-2021 – 30 kms

Survey name	Effort (2021)	Description/comment	Previous surveys
Gouldian Finch Waterhole Survey – southern Mornington	0	Survey of granivorous birds (including Gouldian Finch) at waterholes. Surveyed on 5 mornings along 5 watercourses.	2019 – 107 waterholes 2018 – 119 waterholes 2017 – 79 waterholes 2016 – 106 waterholes 2015 – 102 waterholes 2014 – 91 waterholes 2013 – 92 waterholes 2012 – 92 waterholes 2011 – 113 waterholes 2009 – 93 waterholes 2008 – 103 waterholes 2007 – 150 waterholes 2006 – 148 waterholes 2005 – 94 waterholes
Standard Live Trapping	51 sites, 6,011 TN	62 trapping sites each surveyed with 8 pitfall, 20 Elliot, 4 cage and 8 funnel traps. Stratified across 4 habitat types. Each site was trapped for 3 consecutive nights. In 2021, 51 sites were surveyed.	2019 – 7,759 TN; 65 sites 2018 – 7,371 TN; 62 sites 2017 – 7,610 TN; 64 sites 2016 – 8,581 TN; 86 sites 2015 – 7,858 TN; 66 sites 2014 – 7,511 TN; 63 sites 2013 – 7,483 TN; 63 sites 2012 – 7,726 TN; 68 sites 2011 – 6,568 TN; 62 sites 2010 – 9,853 TN; 83 sites 2009 – 9,907 TN; 84 sites 2008 – 6,192 TN; 54 sites 2007 – 5,254 TN; 55 sites 2006 – 6,302 TN; 54 sites 2005 – 5,256 TN; 42 sites 2004 – 2,880 TN; 20 sites
Standard Bird Survey	110 bird surveys	2-ha 20 min surveys at 51 Standard Live Trapping sites, once per day replicated on 2-3 mornings.	2019 – 62 sites, 179 surveys 2018 – 62 sites, 177 surveys 2004 – 2014 (average of 60 sites surveyed twice per year)
Vegetation Structure Survey	51 plots	300 point-measurements of ground and canopy cover surveyed at 51 Standard Live Trapping site. New method and transects were established in 2021.	2019 – 62 sites (100 point-measurements 2018 – 62 sites (100 point-measurements
Feral Herbivore Aerial Survey	880 km transect	Aerial survey over both stocked and destocked areas. New standardised flight path implemented since 2020.	2020-2021, 880 km of new standardised flight path 2018-2019, 1,200-1,300 km of creek lines and rivers 2009-2017 (variable lengths, creek lines and rivers; Table 9)

Survey design and methods

Targeted threatened and iconic species surveys

Sir John Gorge Northern Quoll Camera Survey

Targeted camera trapping for Northern Quoll at Sir John Gorge began in 2018 and consists of 20 cameras operating prior to live trapping. Cameras were deployed along 1 km on the north and south side of the Martuwarra (Fitzroy) River at Sir John Gorge for 13 nights in July 2021, totalling 260 trap nights. Cameras were set to standard AWC Kimberley specifications – 5 images per trigger, RapidfireTM mode, no delay between triggers, and high sensitivity. Cameras were baited with peanut butter, oats and mackerel, and set at approximately 1 m off the ground, facing down on a 45° angle to facilitate individual quoll identification based on dorsal spot patterns.

Sir John Gorge Northern Quoll Live Trapping Survey

Targeted live trapping for Northern Quolls (*Dasyurus hallucatus*) has been conducted annually in southern Mornington since 2011 (excluding 2018) at a single study site, Sir John Gorge. Historically, live trapping was conducted multiple times throughout the year, however, since 2019, surveys have been conducted annually, in July. The Northern Quoll Live Trapping Survey was conducted at Sir John Gorge in late July over 4 nights. A total of 20 cage traps and 20 Elliot traps were deployed alternating in a transect on both the north and south side of the river (20 traps total each side), with traps spaced approximately 40 m apart and operational for 4 nights (noting that only the south side of the river was trapped on the fourth night in 2021). Traps were set and baited with a ball of peanut butter, oats and mackerel in the late afternoon and checked early each morning. Traps on the fourth night were baited with chum to increase capture potential.

Northern Brown Bandicoot Camera Survey

Bandicoots are omnivorous ground-dwelling critical weight range mammals and historically two species were reported to potentially occur on MMDT: Northern Brown (*Isoodon macrourus*) and Golden Bandicoots (*I. auratus*). DNA analysis has since revealed only Northern Brown Bandicoots have been detected on MMDT. The detection of the Northern Brown Bandicoot on MMDT has been consistent with what is currently known about their habitat preferences, which includes positive associations with dense ground cover vegetation (Strahan 1995, Southgate et al. 1996), low predator densities and high seasonal rainfall (Radford et al. 2014). Records on MMDT have predominantly come from densely vegetated Sandseep and Riparian habitats.

A targeted Bandicoot Camera Survey was established across 18 sites in 2020, where sites were in clusters of 3 with each locality being at least 1 km apart (Figure 6), following a smaller trial camera array in 2019 on southern Mornington. In May 2021, camera traps were deployed at 17 sites, 5 cameras per site spaced 50 m apart for 28 TN (totalling 2,380 trap nights) within Sandseep and Riparian habitats (Figure 6). Cameras were set to standard AWC Kimberley specifications - 5 images per trigger, RapidfireTM mode, no delay between triggers, and high sensitivity. Cameras were baited with peanut butter, oats and mackerel, and set at approximately 1 m off the ground, facing down on a 45° angle. Site 16 was not surveyed in 2021 due to logistical restrictions.

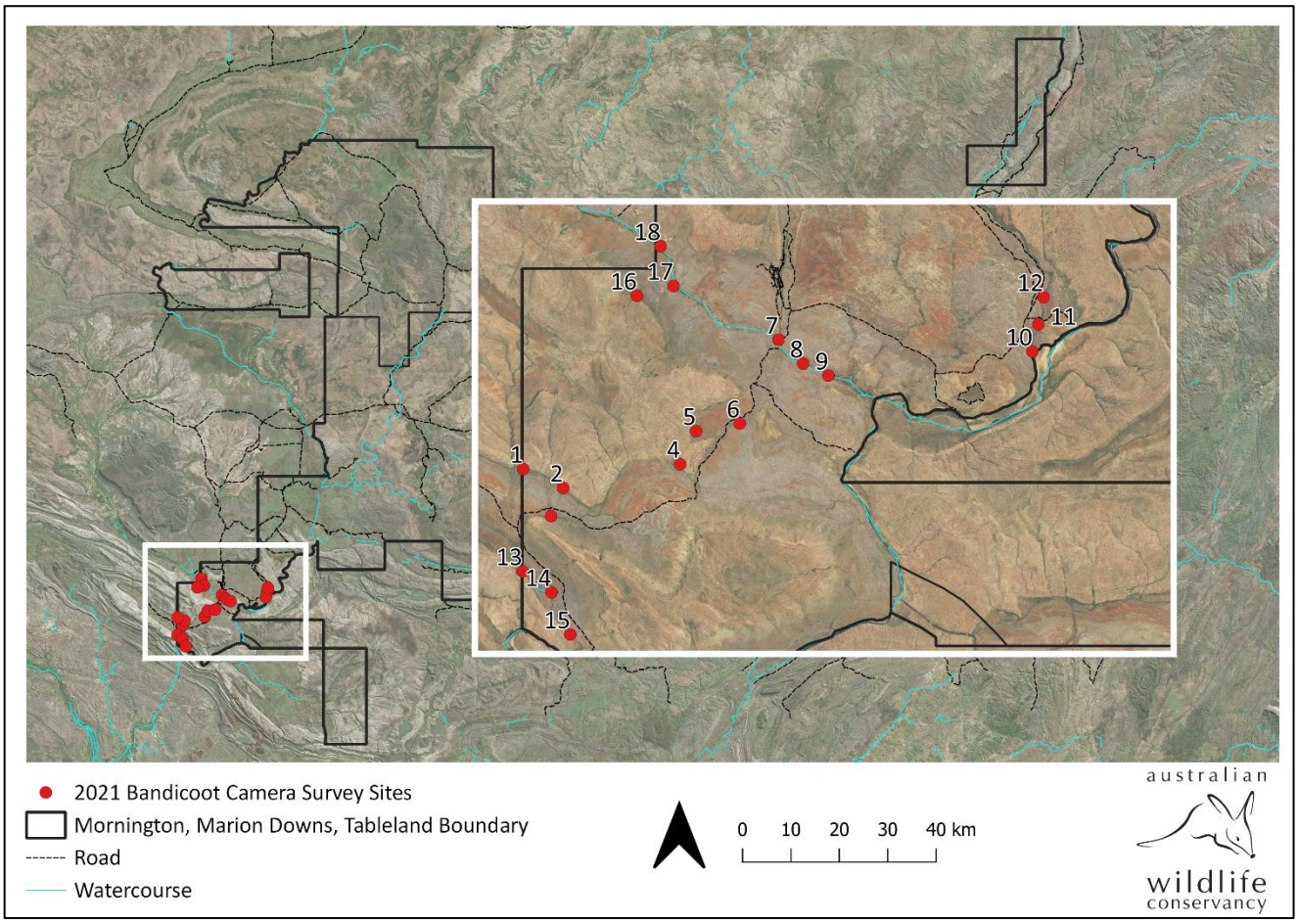


Figure 6. Northern Brown Bandicoot Camera Survey, 17 of 18 sites were surveyed in 2021, distributed across the southern Mornington landscape in Riparian and Sandseep habitats.

Spectacled Hare-wallaby Camera Array

Targeted Spectacled Hare-wallaby (*Lagorchestes conspicillatus)* surveys on Tableland began in 2018 with selected exploratory sites based on incidental sightings of the species in 2014. In June 2018 and 2019, 45 cameras spaced 100 m apart were deployed for 20 nights (900 trap nights) and 19 cameras for 15 nights (285 trap nights), respectively. Camera locations were selected based on close proximately to creek lines and vegetation that was 1-2 years post fire. In June 2020, the array was expanded to include some of north-east Mornington with 100 cameras spread across 10 sites. Sites were a minimum of 2 km apart and each contained 10 cameras spaced 100 m apart operational for 28 days (2,800 trap nights). The site spacing aimed to provide suitable spatial coverage, given the home range of SHW is estimated to be between 10-180 hectares (McCosker 1997, Woinarski et al. 2014).

In June 2021, 5 cameras were placed 200 m apart at each of the same 10 sites as 2020 to continue to monitor the population at a large scale (Figure 7). An additional large camera grid ('population grid'; 5 cameras per row with 10 rows) covered the area with the most historical detections to determine the population extent at this locality (Figure 7). In total, 100 cameras were set for 28 days in 2021 (2,800 trap nights). Cameras were baited with peanut butter and oats in a contained bait canister or smeared on a rock or suitable log. Cameras were mounted on trees 1.5-2 m from the bait on a 45° angle and were set to standard AWC Kimberley specifications - 5 images per trigger, RapidfireTM mode, no delay between triggers, and high sensitivity.

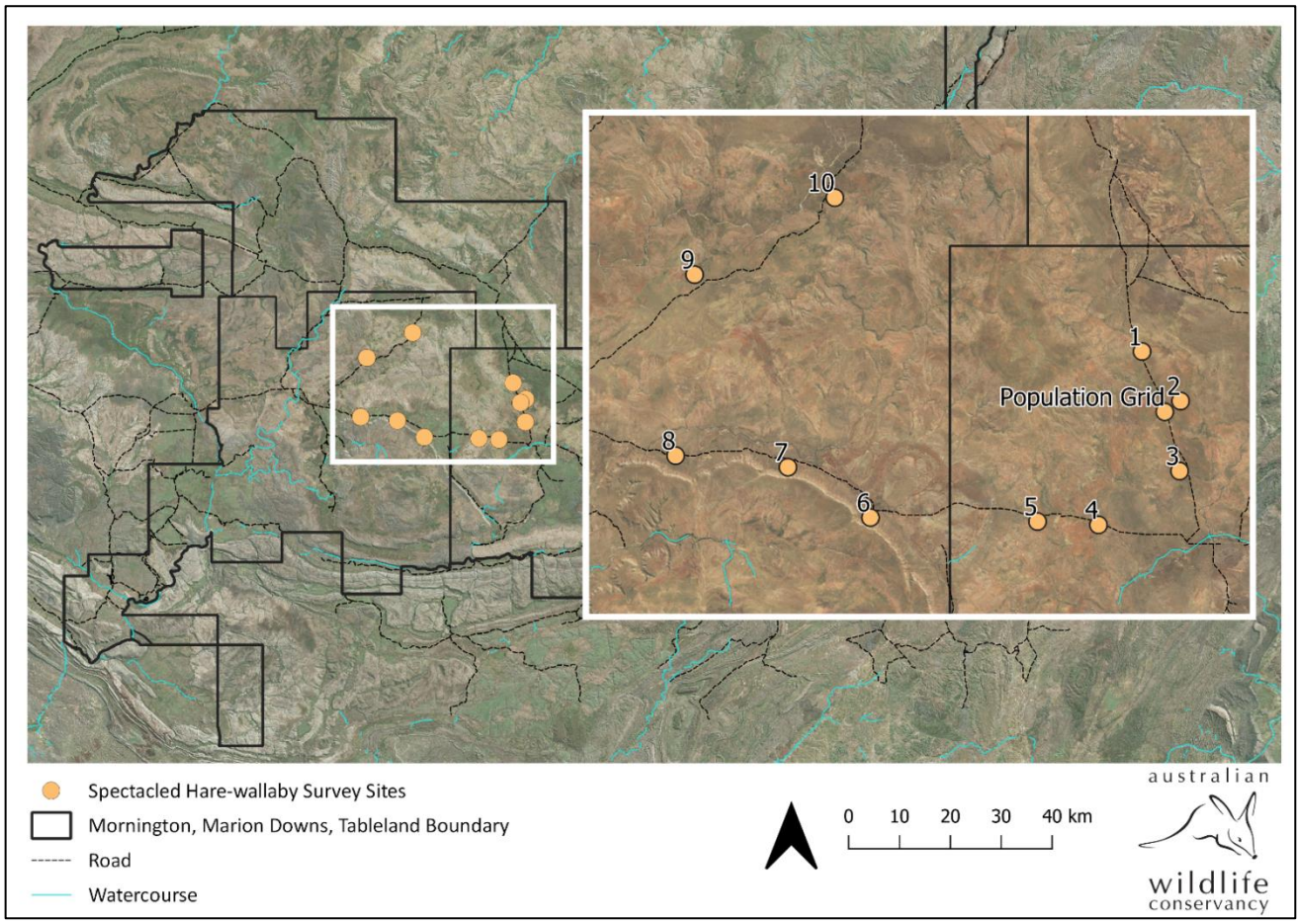


Figure 7. Spectacled Hare-wallaby Camera Array on Mornington and Tableland in 2021 (10 sites with 5 cameras per site, with a Population Grid consisting of 50 cameras).

Purple-crowned Fairy-wren Targeted Survey

The Purple-crowned Fairy-wren (*Malurus coronatus*) project is led by Professor Anne Peters of Monash University and is conducted in collaboration with AWC. In 2021, the fieldwork was run by Dr. Niki Teunissen. Since 2005, the population has been monitored year-round. Since 2011, monitoring has occurred twice annually (May-June and November) with the aim of both tracking the population at Annie Creek and Adcock River in response to ongoing land management to protect riparian habitat and investigating aspects of their ecology and social interactions to better understand this threatened species. All individuals within the focus area, one 15 km-stretch of Annie Creek and the Adcock River on Mornington, are individually marked and (re)sighted, identifying and recording territories during each census. This census, replicated since 2005, generates biannual population estimates.

Gouldian Finch Waterhole Survey

In 2018 and 2019, Gouldian Finch (*Erythrura gouldiae*) and other granivorous birds were surveyed in September (late dry season) at selected waterholes on southern Mornington, northern Mornington and Marion Downs. Southern Mornington has been surveyed for Gouldian Finch and other bird species since 2005 (excluding 2010). Northern Mornington surveys have been conducted from 2008-2018 (excluding 2010 and 2017) while Marion Downs was only surveyed in 2018. Only long-term data from southern Mornington are presented in this report.

For southern Mornington, available water within ~80 km of waterway was mapped the week prior to surveys. All possible drinking spots were marked on a GPS and given a rank between 1-5 based on suitability for Gouldian Finch (where 1 is low suitability and 5 is high). Waterholes were chosen based on high rankings and the number of observers available. In 2021, 107 waterholes were surveyed over 5 days in the order of Upper Annie Creek, Lower Annie and Termite Creeks, Adcock River, Fitzroy Bluff (River) and Roy Creek. Alteration to the order has occurred in some years but, in all cases, one morning of survey is spent in each area.

For each waterhole, birds are observed and counted for 2 hours on one morning between 5.30 - 7.30 am. All birds that drink from the waterhole are counted and identified to species. Sampling effort changes year to

year due to uncontrollable annual changes in water availability, suitable drinking holes, and the number of waterholes that can be surveyed with the given number of observers. Note that exact waterhole locations are not repeatable year to year.

Surveillance surveys

Standard Live Trapping Survey

A total of 62 Standardised Live Trapping monitoring sites were selected across MMDT in 2018 to monitor small lowland mammal and reptile assemblages (Figure 8). These 62 sites are a subset of 186 sites that were initially set-up (2004-2016) to examine the long-term ecological impacts of fire and grazing on assemblages (Legge et al. 2004). The sites are restricted to landscapes suitable for pitfall traps and sites have been spread out across MMDT, as much as practical. The selected 62 sites encompass several vegetation types, but for simplicity in analyses, are classified into 4 habitat types: Blacksoil, Riparian, Sandseep and Woodland (Table 4). Recently, this extensive (13 years, 9,000 km^2) dataset was analysed by Legge et al. (2019). This dataset forms a substantial comparative dataset (2004 – 2016) from which to monitor trends in the abundance, species richness and occupancy of small lowland mammals and reptiles across MMDT. Only data from the same 62 sites are used for trend comparisons. Surveys have been conducted annually since 2004 and biennially since 2019.

In 2021, from early-May to late-July, 51 (of the 62) sites were sampled across the 4 main habitat types: Blacksoil (n = 12), Riparian (n = 14), Sandseep (n = 13) and Woodland (n = 12; Figure 8). Eleven sites were not sampled in 2021 due to increased rainfall, causing logistical and accessibility limitations.

Each Standard Live Trapping site is a quarter-hectare (50 m x 50 m) plot containing 20 Elliot traps, 4 medium-sized cage traps, and 4 x 20 m drift fences, each containing 2 pitfall traps and 2 funnel traps (Figure 9). Riparian sites are deployed differently to keep within the riparian habitat, which is more linear and narrow in configuration (20 m x 80 m; Figure 9). Elliot and cage traps were baited with the standard bait of peanut butter, oat and mackerel, and only opened overnight (dusk till dawn). Funnel and pitfall traps were left open continuously. Sites were checked twice each day, each morning and evening and once in the morning on the third day of sampling (resulting in 3 morning and 2 evening checks for each site). Every animal trapped was identified to species level (when possible), and sex, age, weight and breeding status for mammals and snout-vent length (SVL) for reptiles was recorded. Animals were temporarily marked with a non-toxic permanent marker either on the ear (mammals) or on their underside (reptiles), to track recaptures. Amphibians were not marked.

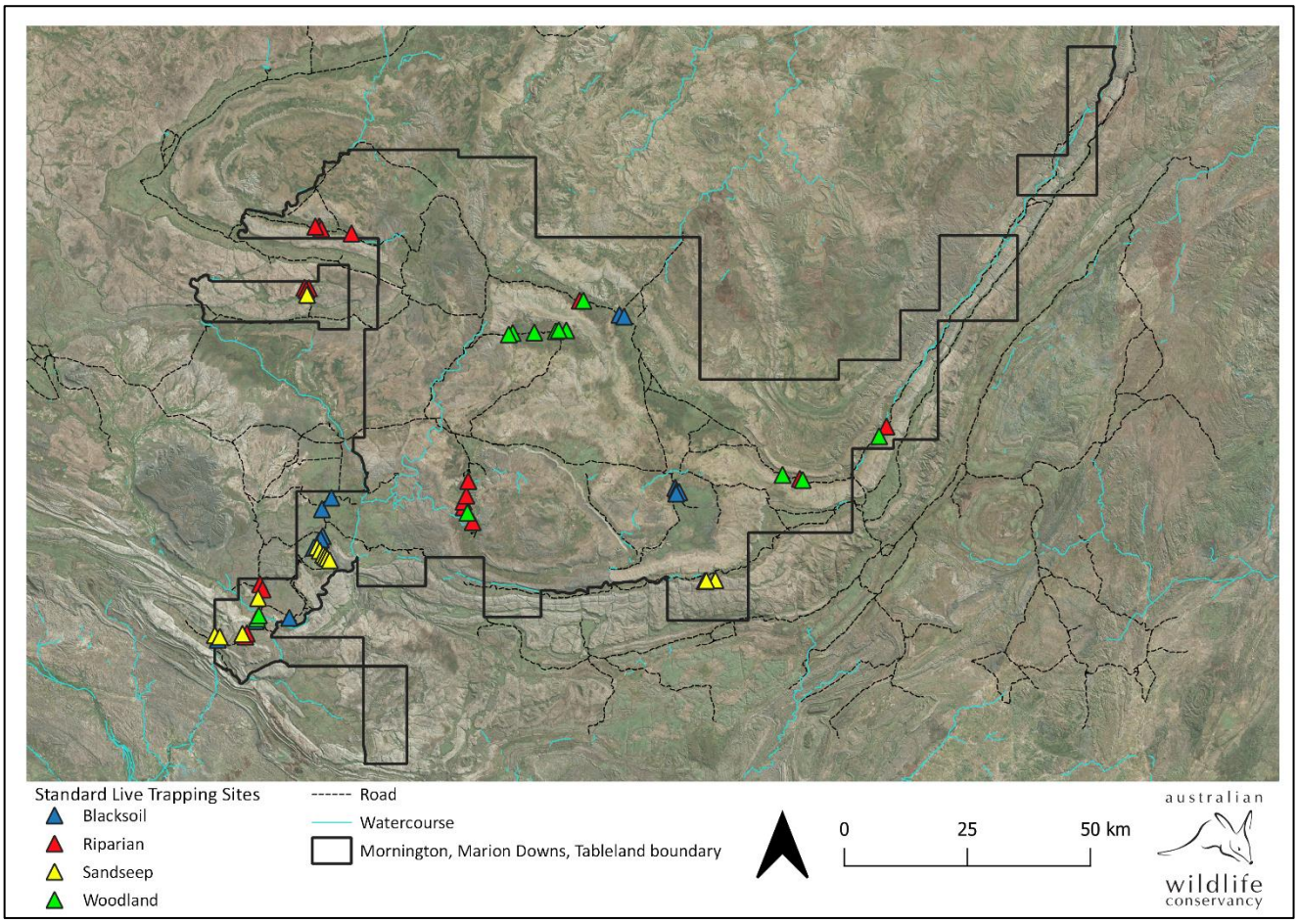


Figure 8. Location of 62 Standard Live Trapping sites across the four habitat types on Mornington, Marion Downs and Tableland. Blacksoil (n = 16), Riparian (n = 19), Sandseep (n = 14) and Woodland (n = 13). Fifty-one of the sites were sampled in 2021.

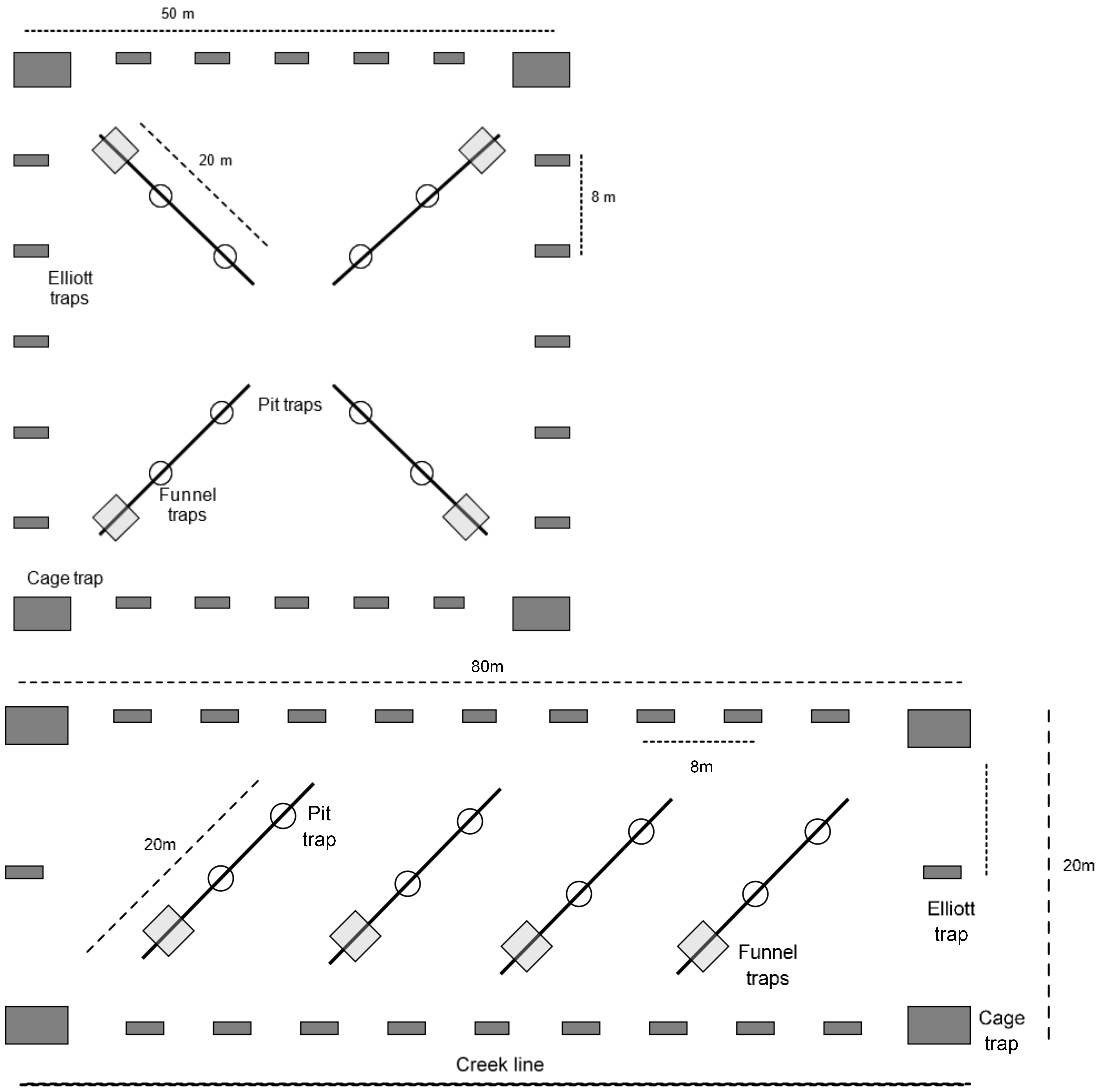


Figure 9. Site schematic for Standard Live Trapping sites (top) and Riparian habitat sites (bottom). Each site is 50 x 50 m (20 x 80 m for Riparian), with 4 cage traps, 20 Elliot traps, 8 pitfall traps and 8 funnel traps.

Table 4. Description of Standard Live Trapping site stratification (habitat type) across Mornington, Marion Downs and Tableland.

Category	Description	No. of sites in 2021
Blacksoil	Volcanic-derived blacksoil grasslands with few/no trees on cracking clay soils. Typically dominated by perennial grasses and specialised forbs and shrubs such as *Vachellia suberosa*.	12
Riparian	Riparian vegetation along waterways on alluvium soils. Typically, with *Melaleuca/Lophostemon/Ficus/Terminalia overstorey, Pandanus/Sesbania* midstory and often with dense grassy ground layer.	14
Sandseep	Periodically inundated sandy soils at the base of sandstone ranges. Typically dominated by *Grevillea/Acacia/Banksia* overstorey and matted *Chrysopogon/Triodia* ground layer.	13
Woodland	Tropical savanna woodlands with a Eucalyptus-dominated tree layer and a grassy understorey. Woodland soils vary from skeletal rocky soils, red and grey clays, to sandy alluvial valleys. May be simple with *Eucalyptus tectifica* overstorey and *Sehima nervosum* ground layer, or complex with *Eucalyptus miniata/Corymbia* overstorey, a wide range of fruiting mid-storey trees and a diverse ground layer.	12
Total		**51**

Standard Bird Survey

Each of the 51 Standard Live Trapping site was surveyed for lowland diurnal birds concurrent to live trapping on 2 – 3 consecutive mornings. The Standard Live Trapping sites have been surveyed in this standardised manner since 2004 annually until 2014 then again from 2018-2021. A total of 110 Standard Bird Surveys were conducted in 2021. Surveys were conducted during the dawn chorus and consisted of a 20-minute observation of a 2-ha area around the survey site. Standard Bird Surveys are known to have a strong observer bias, so the number of observers each year were limited and rotated evenly, and observer name always recorded. Notes were also taken on weather and site conditions, such as significant flowering or fruiting events.

Vegetation Structure Survey

The Standard Vegetation Structure Survey was conducted at each of the 51 Standard Live Trapping sites using three 100 m transects set up within each site (Figure 8). At each 1 m point (300 measurement points per site), the type and height of ground cover was recorded (i.e. either bare soil, rock, leaf litter, elevated dead debris, woody debris, tussock, hummock, or vegetation <140 cm), as was the type and height of canopy cover (identified to genus) directly overhead for 1.4-6 m and >6 m. Any woody debris >2.5 cm diameter was recorded continuously along each transect, along with a site score for fire and cattle impact. The primary function of vegetation structure surveys is to provide covariates for interpreting Standard Live Trapping data, although, given the intention to repeat the vegetation surveys over a number of years, they may also give insight into vegetation structural changes occurring in major habitats on MMDT and responses to land management activities and environmental change.

Threat monitoring

Feral Herbivores Aerial Surveys

Large, introduced herbivores such as cattle, horses, donkeys, and omnivorous pigs are distributed over northern Australia, where they cause major damage to ecosystems and significantly alter biotic interactions (Woinarski and Ash 2002, Legge et al. 2011). At a landscape scale, feral herbivores have the ability to greatly reduce habitat availability, particularly in the ground layer, and interact with other major threatening processes, such as fire to further effect biodiversity (Legge et al. 2019). On MMDT, large feral herbivores represent one of the major threats to biodiversity. As such, their impact has been managed and monitored by AWC, with more than 40,000 hectares de-stocked since 2004.

The annual Feral Herbivore Aerial Survey was undertaken on the 5th and 6th of November 2021. Flight paths for Feral Herbivore Surveys and methods for calculating densities was altered in 2020, as historically flight paths targeted search effort along creek lines. The new flight path was designed to survey a representative sample of MMDT covering a range of cattle suitability classes and distances from water, rather than only along creek lines. The new method was designed to give a more accurate estimate of large feral mammal densities across MMDT. The 2021 survey was undertaken shortly before the feral herbivore cull and prior to significant rainfall on MMDT and covered approximately 880 km or 18,840 ha representing 2% of MMDT (Figure 10). The standard flight path is flown at a height of 100 m and a speed of 100 km/hr and covers landscapes of varied pastoral productivity and habitat. Four helicopter crew members (including one pilot) observed and recorded all cattle, pigs, horses, and donkeys seen (and pigs if detected), and noted whether they were inside or outside a 45° angle from vertical (this gives an 'inside' transect width of 200 m).

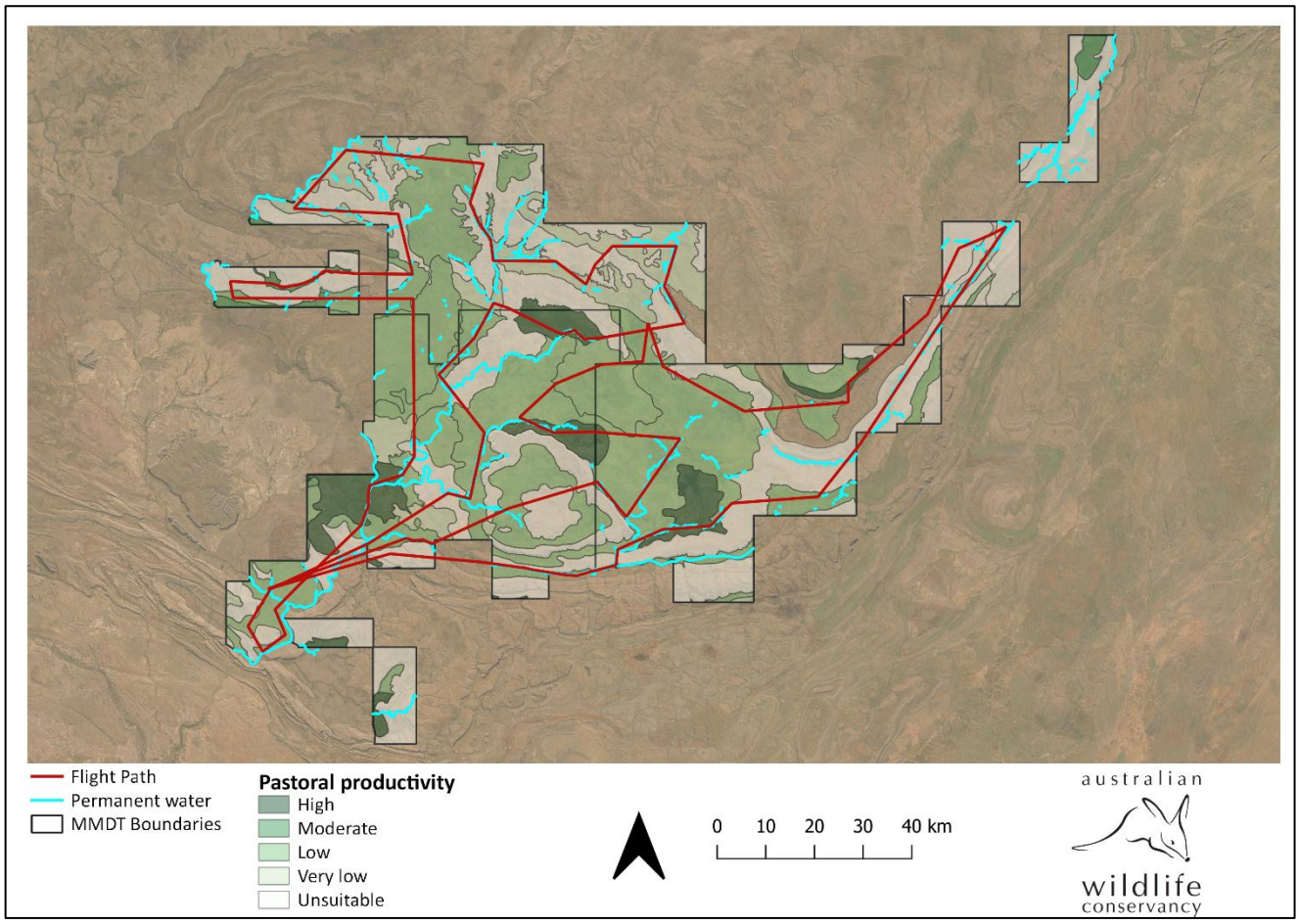


Figure 10. Feral Herbivore Aerial Survey flight path in 2021 on Mornington, Marion Downs and Tableland.

Fire Scar Analysis

Fire scar data were obtained for 2000 to 2021 from the North Australia Fire Information (NAFI) website. NAFI fire scars are based on hotspot and fire scar imagery collected by MODIS instruments on NASA's Terra and Aqua satellites, which provide coverage every 1 to 2 days at a resolution (for fire scars) of between 250 and 500 m. For each season, scars detected from January to June (inclusive) are typically attributed as "Early", whereas those detected July to December were attributed as "Late". All spatial manipulations for the analyses were carried out using ArcMap 10 with Spatial Analyst (Environmental System Research Institute Inc., Redlands, CA, USA). The analysis was semi-automated using Python scripting. Graphs were produced using Microsoft Excel (Millen et al. 2022).

Analysis methods

Most Ecohealth metrics are common across the indicator species and guilds for MMDT. Unless noted otherwise, the metrics are calculated as set out in Table 5.

Table 5. Metrics and associated calculations for Mornington, Marion Downs and Tableland.

Indicator	Metric	Survey data sources	Description	Analysis summary/calculation
Assemblage richness	Number of species	All surveys and incidental records	A measure of intactness for the whole sanctuary	The number of species detected on the sanctuary within the last 1-5 years is compared to the number of species listed as 'confirmed', 'very likely' or 'likely' on the sanctuary species list.
Purple-crowned Fairy-wren	Population estimate	Purple-crowned Fairy-wren Targeted Survey	Estimate of total number of individuals in the population	The population estimate for the Purple-crowned Fairy-wren is based on the total number of individuals sighted, which are all individually banded and identifiable.

Indicator	Metric	Survey data sources	Description	Analysis summary/calculation
Mammals, Reptiles Gouldian Finch	Occupancy	Standard Live Trapping Gouldian Finch Waterhole Survey Camera Trapping: Northern Quoll, Bandicoot, Spectacled Hare-wallaby	A measure of distribution; the proportion of sites where the species was recorded using a particular technique	For individual species: [Number of (appropriate) sites (or cameras) at which the species was detected or captured/number of sites surveyed] x 100 Survey site is waterhole for Gouldian Finch. For live trapping, incidentals and recaptured individuals were removed prior to analyses. Data from camera traps was derived from the specified survey time frame (i.e., any additional trap nights above the standardised total for each camera was removed prior to analyses).
Mammals, Reptiles, Gouldian Finch	Abundance	Standard Live Trapping Sir John Gorge Northern Quoll Camera and Live Trapping Gouldian Finch Waterhole Survey Camera traps (only when individuals are identified) e.g. Sir John	The number of individuals captured or observed in live trapping and waterhole surveys, respectively per 100 TN or per standard survey; and number of individuals identified for camera traps, if individuals can be identified. When individuals cannot be identified in camera trapping, a measure of activity is used – see Activity metric.	Per 100 trap nights (TN): For individual species: Calculate the average abundance (per 100 TN) for that species across all survey sites. Average of: (total number of individuals recorded at survey site / total number of trap nights at each survey site x 100). For Gouldian Finch is average number of birds per waterhole. For guilds: Calculate the average abundance (per 100 TN) of all individuals in the guild across all survey sites. Average of: (total number of individuals of the guild recorded at survey site / total number of trap nights at each survey site x 100). For live trapping, trap nights are only included where a trap type targets the indicator appropriately. For example, funnel trap nights are excluded for small rodents, and cage and Elliot traps are excluded for small reptiles. Only data from Elliot and cage traps are used for bandicoots, and only pitfall traps are used for planigales. Recaptures and incidental captures are excluded from analyses.
Savannah Birds Guild		Standard Bird Survey		Per standard survey: Calculate the no. individuals (abundance) observed per site, and average across all sites. Flyovers are excluded from analyses.
Northern Brown Bandicoot, Spectacled Hare-wallaby	Activity	Camera traps	A measure of activity associated with the number of detections or 'visits' per 100 trap nights (to account for survey effort). This metric does not account for multiple	Per 100 trap nights (TN): For individual species: Calculate the average visits (per 100 TN) for that species across all survey sites. Average of: (total number of individuals recorded at survey site / total number of trap nights at each survey site x 100).

Indicator	Metric	Survey data sources	Description	Analysis summary/calculation
			visits by the same individual (i.e., the majority of species cannot be identified to individual animals in camera trap images).	In a sequence of images of a single species, a single camera 'visit' is defined as occurring when there is at least a 5 min period between the species' last capture and subsequent image.
Guilds: Birds, Reptiles, Mammals	Richness	Standard Live Trapping Survey Standard Bird Survey	A measure of raw species diversity for indicator guilds; average number of species per site.	Total number of species captured per site averaged across all survey sites Average across all sites of: (Total the number of species within a guild detected across replicates (2 or 3 survey days) for each site). In situations where a species could not be identified to species level, it is assumed that it does not represent a separate species when congeners have already been counted for the purposes of calculating richness. For live trapping incidentals and recaptured individuals were removed prior to analyses. Flyovers are removed for bird analyses.
Feral herbivores	Density	Feral Herbivore Aerial Survey	The number of detections per unit distance or area (/km).	Total number of individuals detected/ distance flown.

Results

Threatened and iconic species

Northern Quoll

Sir John Gorge Northern Quoll Camera Survey

In 2021, 1 individual Northern Quoll was detected on 1 camera on the south side of the Martuwarra (Fitzroy) River on the Sir John Gorge Northern Quoll Camera Survey. The abundance of Northern Quolls at Sir John Gorge in 2021 was 0.38 (Table 6). Results from 2021 continue to highlight the significant decline in quoll abundance from 4.16 to 0.38 since this survey began in 2018. Note that cane toads (a major contributor to decline in populations of Northern Quolls) are known to have arrived at Mornington in the 2016-2017 wet season.

Table 6. Metrics for Sir John Gorge Northern Quoll Camera Survey from 2018 - 2021. MNKA = minimum number of individuals known alive, as identified from spot patterns.

Year	Trap Nights	Abundance (per 100 TN)	MNKA
2018	600	4.16	7
2019	600	7.83	2
2020	240	0.60	2
2021	**260**	**0.38**	**1**

Sir John Gorge Northern Quoll Live Trapping Survey

No Northern Quolls were captured at Sir John Gorge Northern Quoll Live Trapping Survey in 2021. This is a marked decline from a maximum 10.6 quolls per 100 trap-nights in 2013 (Figure 11). The arrival of cane toads (see orange line on Figure 11) combined with 2 below average rainfall years (2018-2019 and 2019-2020) likely accounts for the low capture rates in recent years. AWC will continue to closely monitor this site in the

coming years and investigate viable interventions under the development of the Conservation Management Plan for this threatened species.

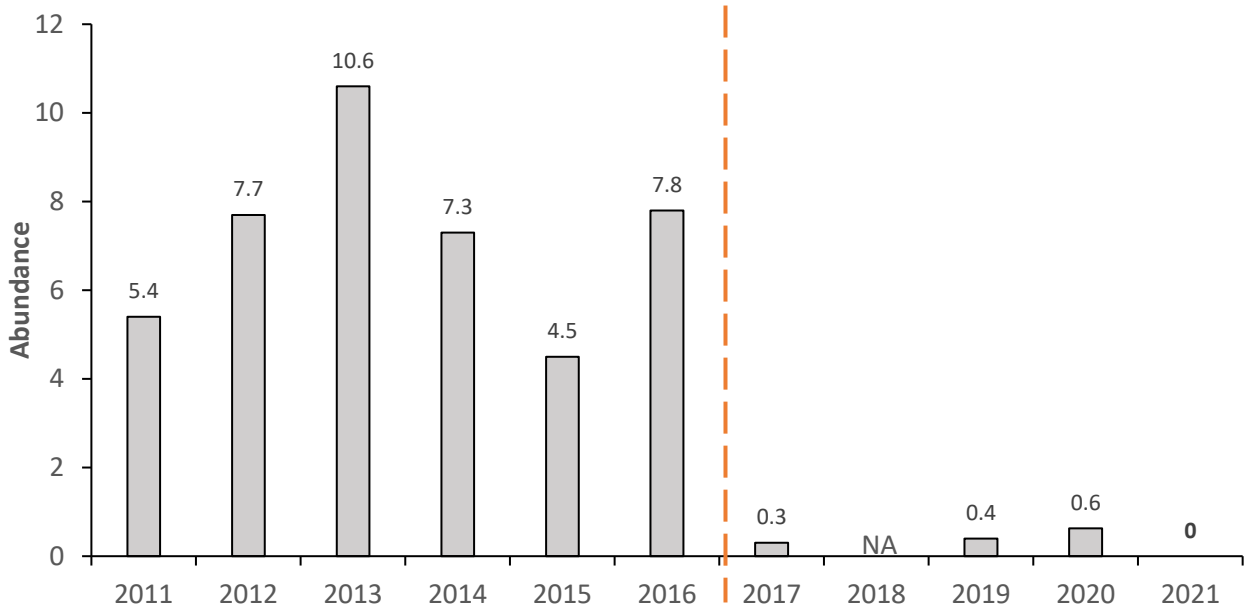


Figure 11. Northern Quoll abundance (individuals per 100 cage trap nights) from Northern Quoll Live Trapping Survey at Sir John Gorge from 2011-2021 (excluding 2018). Orange line indicates arrival of cane toads at the survey site (2016-2017). Note that cage trapping was undertaken in various months and multiple times in some years (Appendix 2), such that some of the variation in abundance may be influenced by life history and variation in quoll activity relative to timing of surveys.

Northern Brown Bandicoot

Northern Brown Bandicoot Camera Survey

Northern Brown Bandicoots increased in activity in 2021 to 4.75 (number of detections per 100 trap nights) compared to 0.32 in 2020. Bandicoots were detected at 3 of the 18 sites (see Figure 12), with an occupancy of 17.65%, increasing from an occupancy of 5.55% in 2020 where bandicoots were only detected at 1 site (Site 1 – see Figure 6). These sites are in the continuous Sandseep habitat along the southern edge of Mt Leake in southern Mornington. The increase in Northern Brown Bandicoot activity and occupancy in 2021 from 2020 may be a result of the above average 2020-2021 wet season.

Of note, from other camera surveys, is that bandicoots were detected for the first time on Tableland during the Spectacled Hare-wallaby Camera Array (Figure 12).

Table 7. Northern Brown Bandicoot Camera Surveys occupancy (%) and activity (detections per 100 trap nights) ± standard error for 2020 to 2021.

Year	Occupancy (%)	Activity (detections / 100 trap nights)
2020	5.55	0.32 ± 0.32
2021	**17.65**	**4.75 ± 3.16**

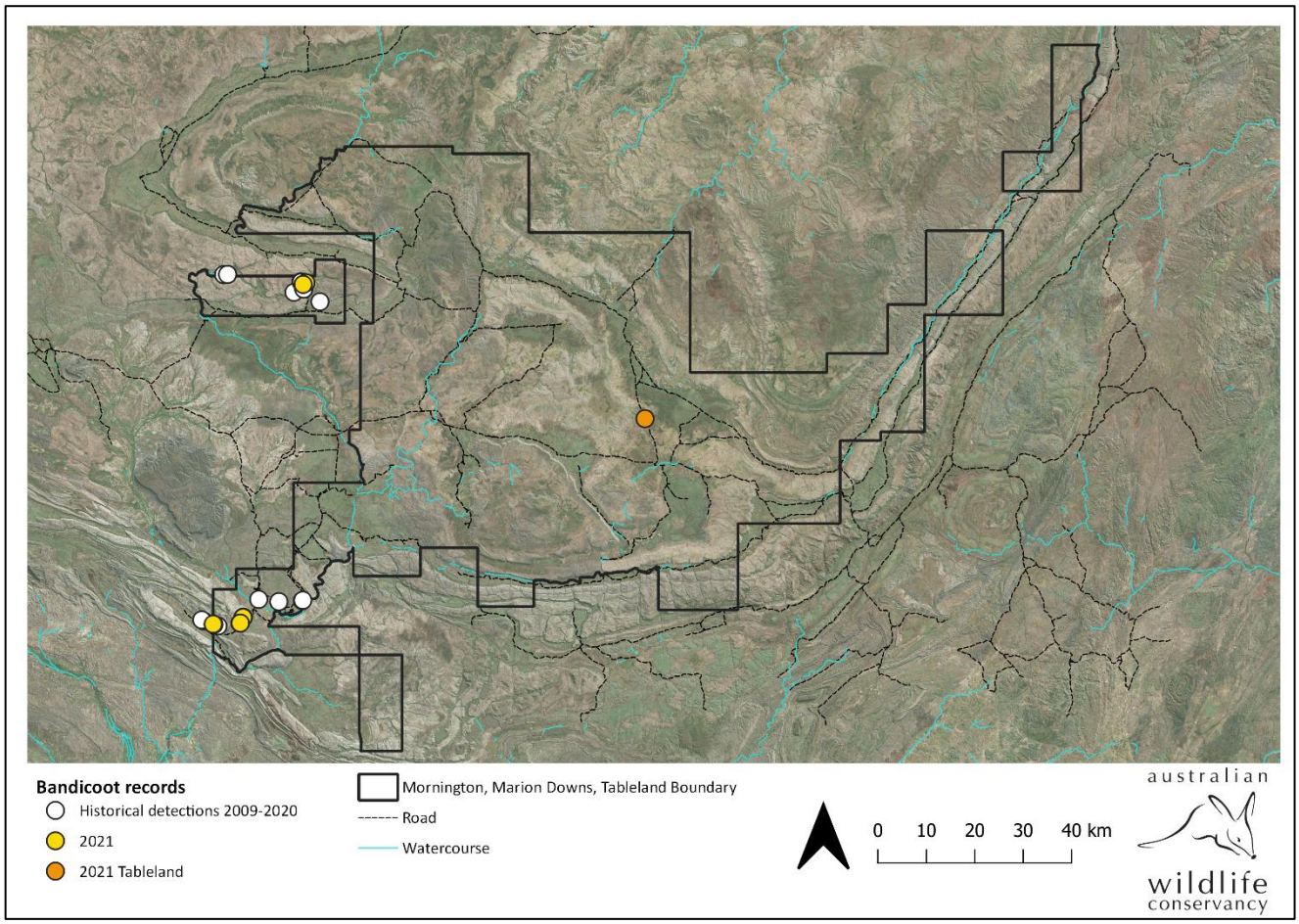


Figure 12. Northern Brown Bandicoot records from Mornington, Marion Downs and Tableland Standard Live Trapping and Bandicoot Camera Array between 2009 - 2021 and Spectacled Hare-wallaby Camera Array on Tableland in 2021.

Standard Live Trapping Survey

In 2021, Northern Brown Bandicoot abundance from the Standard Live Trapping Survey was 0.31/100TN (for all Sandseep and Riparian Standard Live Trapping sites) and occupancy was 11%. Bandicoots were first detected in 2009, when Marion Downs was first surveyed. Over the last decade, detections of Northern Brown Bandicoots have increased (Figure 13) with bandicoots being first detected on southern Mornington in 2012, despite substantial survey effort since 2004. This increase in detection, especially in southern Mornington, may be attributed to removal of cattle from sensitive areas and improved fire management of MMDT.

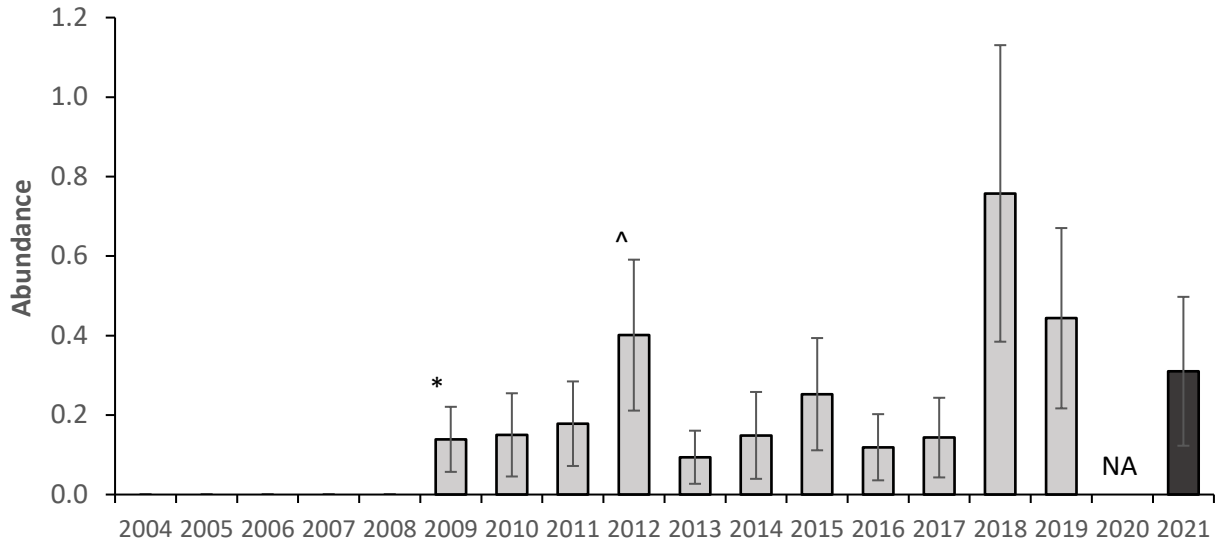


**Figure 13. Northern Brown Bandicoots average abundance (individuals per 100 trap nights) across Sandseep and Riparian Standard Live Trapping Sites, including data from 2021 and historical data. ***Marion Downs was first surveyed in 2009, where bandicoots were detected in Phillips Range. ^Bandicoots were first detected on southern Mornington in 2012, despite significant survey effort since 2004. Surveys were not conducted in 2020.

Spectacled Hare-wallaby

In 2021, Spectacled Hare-wallaby activity increased slightly to 0.32 from 0.04 in 2020. This increase translates to 5 detections, most likely of one individual, compared to only one detection in 2020. Spectacled Hare-wallabies are notoriously difficult to detect, and surveys will continue to be refined to improve detection probability. Spectacled Hare-wallabies were only detected at 1 of the 10 sites in 2021, as per 2020, resulting in an occupancy of 10% (Figure 14).

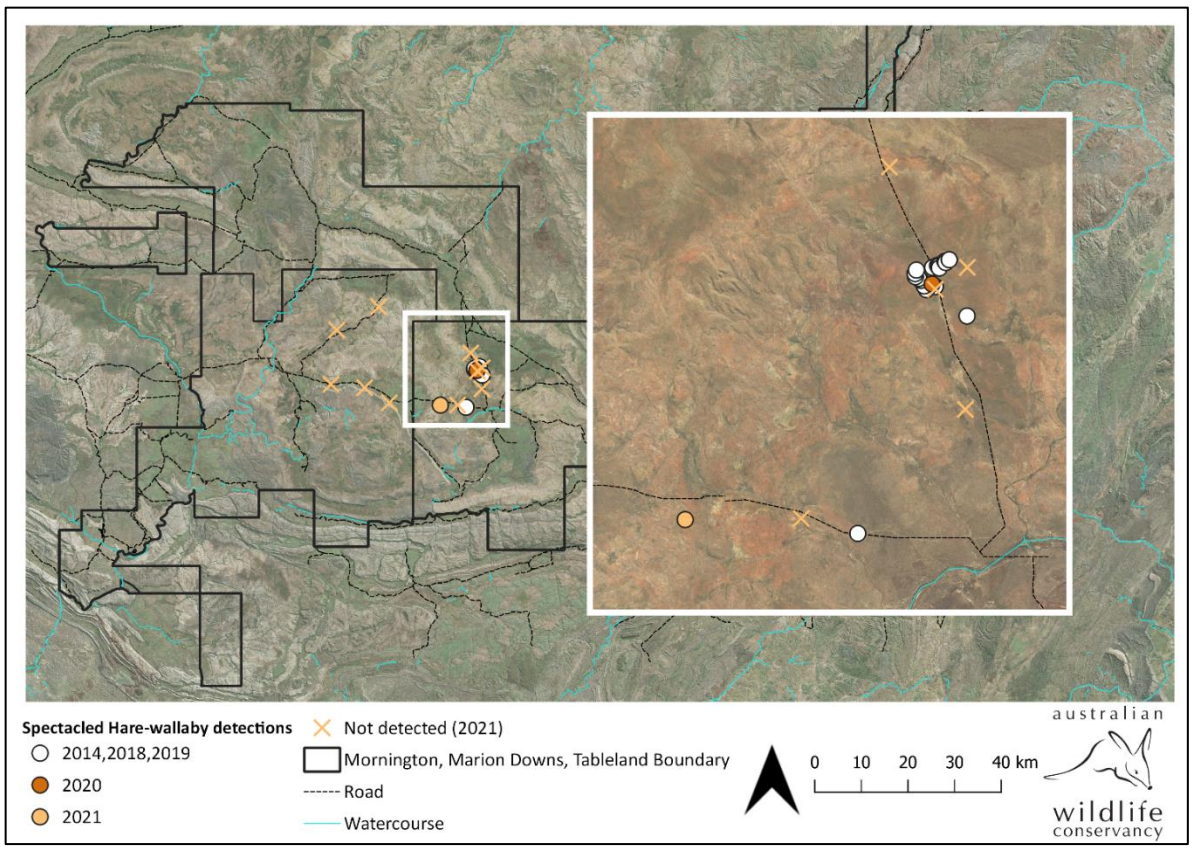


Figure 14. Spectacled Hare-wallaby detections in 2021 (Site 5 – see Figure 7) from Spectacled Hare-wallaby Targeted Survey and historical detections.

Purple-crowned Fairy-wren

The end-of-year (November) census in 2021 identified 204 birds across 54 territories within the 15 km focal area. The 2021 results represent a substantial increase (142%) in the total number of birds compared to 2020 (143 individual birds; Figure 15). Fairy-wren density (the number of birds per km) within the focal area has also been steadily increasing, now at 13.8 birds/km since June surveys of 2020 (8.6 birds/km). These increases can be attributed to successful breeding during the 2020-2021 wet season, which was associated with above average rainfall, and during the subsequent dry season, when breeding is usually rare. Overall, the data show that the population of Purple-crowned Fairy-wrens in the Annie Creek - south Adcock focus area increased steadily from 2005 – 2018 following cattle removal in 2004. A substantial population decline occurred in 2019 following 2 very dry wet seasons and a fire at Annie creek, which appears to now be recovering in 2021 (Figure 15).

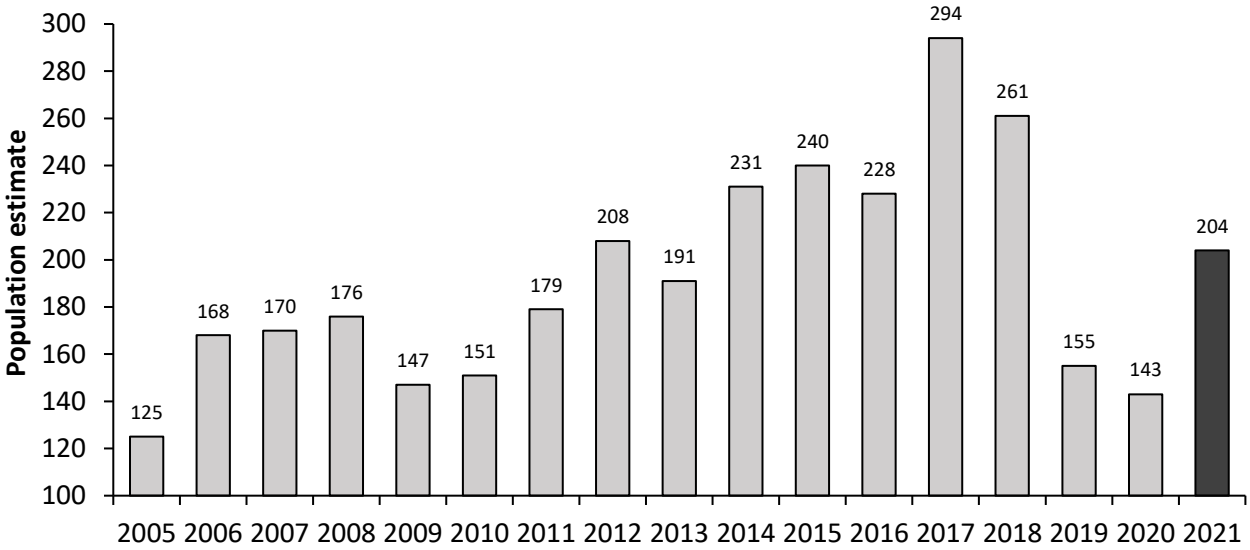


Figure 15. Purple-crowned Fairy-wrens population estimate (total number of individuals) in November from 2005 - 2021 in the focus area (Annie Creek and Adcock) on Mornington.

Gouldian Finch

No Gouldian Finch Waterhole Surveys were conducted in 2021. Historical trends (2005 to 2019) of Gouldian Finch abundance and occupancy across Southern Mornington are displayed in Figure 16 and Figure 17. Gouldian Finch were more abundant in 2019 than 2018 (Figure 17), however, there was less water in the landscape in 2019 compared to 2018. With fewer waterholes in the landscape, birds are generally more concentrated around the available water, therefore, the 2019 survey was likely to be more thorough (i.e. surveyed a greater percentage of the population). Thus, it is possible that the recorded abundance of Gouldian Finch was greater in 2019 due to increased detectability, rather than an increase in the actual abundance of birds in the area. Occupancy of Gouldian Finch was also higher in 2019, present at 21% of surveyed waterholes, compared to 2018 where only 10% of surveyed waterholes had Gouldian Finches (Figure 16). Occupancy gives an indication of the spread of birds across surveyed waterholes. Similar to abundance, the decreased availability of water in the landscape in 2019 most likely influenced results.

Although it appears there has been an increase in abundance and occupancy of Gouldian Finches from 2018 to 2019, interpretation is confounded by the impact of changes in detectability described above. Currently, informative conclusions on the state of Gouldian Finch populations over time cannot be drawn, except to say that Gouldian Finch remain present. A preliminary look at the long-term data suggests that the abundance and occupancy of Gouldian Finch changes with area surveyed (watercourse) on southern Mornington, and the presence of Gouldian Finch on northern Mornington is intermittent.

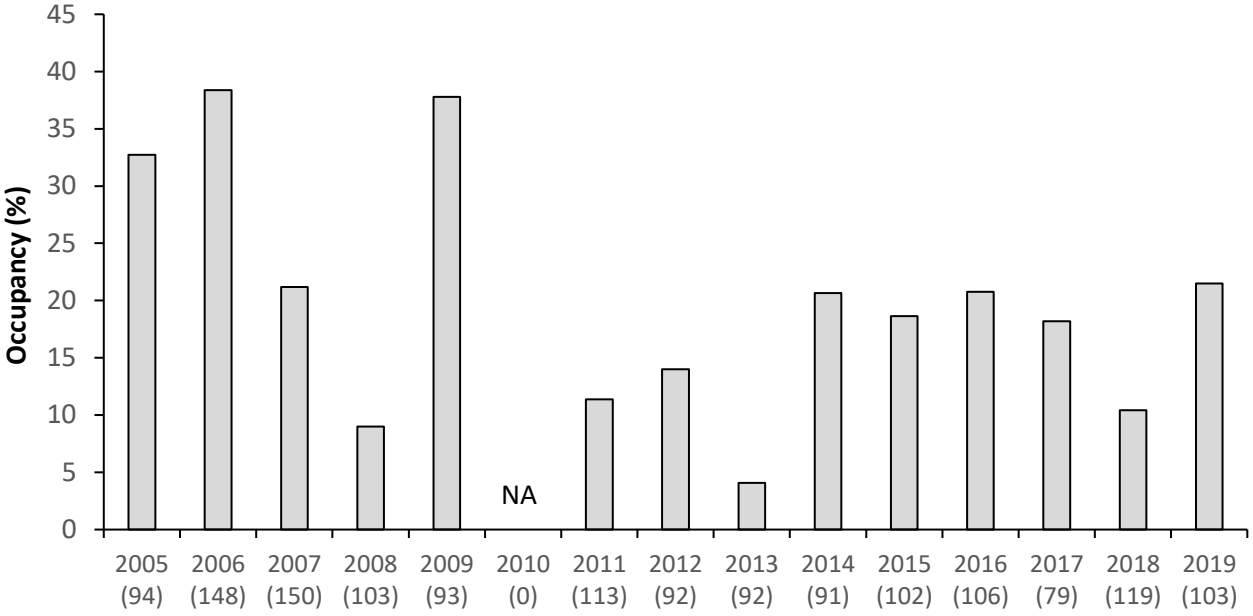


Figure 16. Gouldian Finch occupancy at surveyed waterholes on southern Mornington between 2005-2019, with number of waterholes in parentheses. No surveys were conducted in 2010.

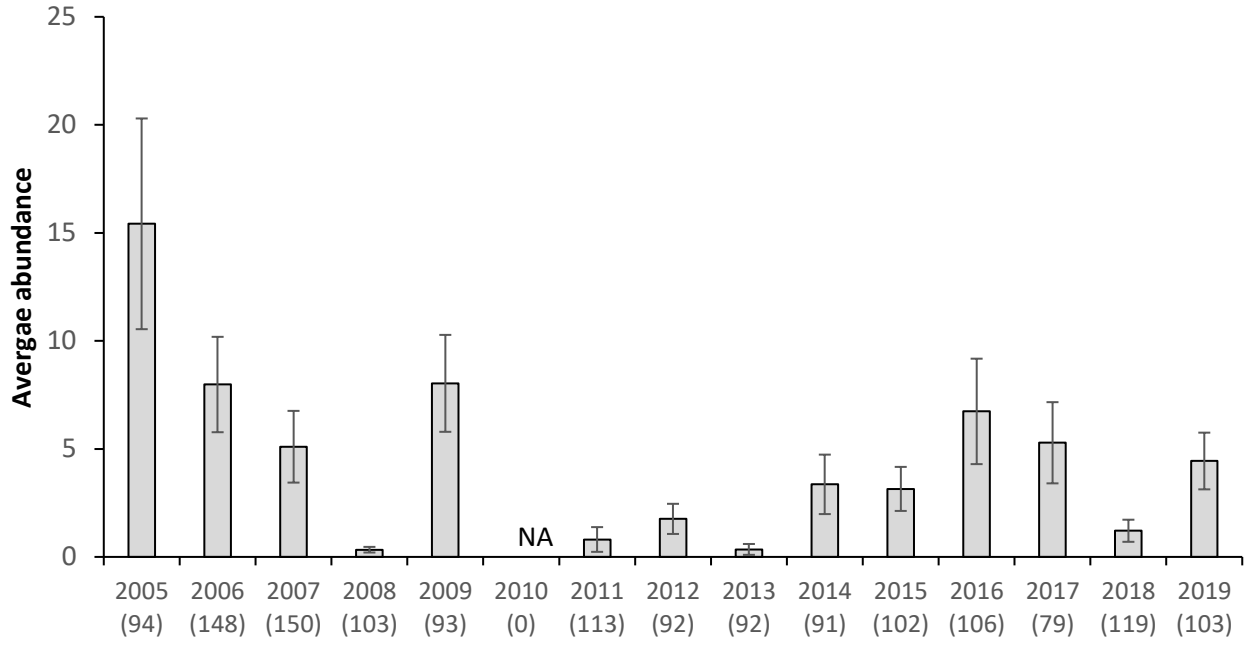


Figure 17. Gouldian Finch average abundance per waterhole on southern Mornington between 2005 – 2019 (no surveys were conducted in 2010).

Assemblages and surveillance species

Mammals

Twenty-five native mammals are known to, or likely to, occur on MMDT, excluding the 22 species of bats in the order of Chiroptera which are currently not surveyed as part of the MMDT Ecohealth program. Of the 25 native mammals, 17 were recorded in Ecohealth Surveys in 2021 (including threatened and/or iconic mammals detailed above) with no new mammals confirmed on MMDT. An additional 2 native mammal species were recorded in 2021 by incidental and trial survey observations, the Savanna Glider (*Petaurus ariel*) and Rock Ringtail Possum (*Petropseudes dahli*). Mammal species (outside Chiroptera) which were not detected in 2021 but have been confirmed on MMDT previously were the Lakeland Downs Mouse (*Leggadina lakedownensis*), Northern Brushtail Possum, Western Chestnut Mouse, Stripe-faced Dunnart (*Sminthopsis*

macroura), Central Pebble-mouse (*Pseudomys johnsoni*), Water-rat (*Hydromys chrysogaster*). Many of these species not detected (or not detected through Ecohealth surveys) are cryptic, restricted in distribution and habitat on MMDT, and/or require more targeted monitoring to assess their persistence.

Small lowland mammal guild

In 2021, 34 individuals of 5 species of small mammals were captured during the Standard Live Trapping Survey. Trends in the abundance of small mammals in 2021 were primarily driven by changes in the abundance of planigales, which comprised 23 of the of the 34 individual mammals caught (Figure 18). Abundance and species richness declined abruptly between 2018 and 2019, probably due to an extended period of very dry weather from 2018 to 2019 (Figure 18; Figure 19).

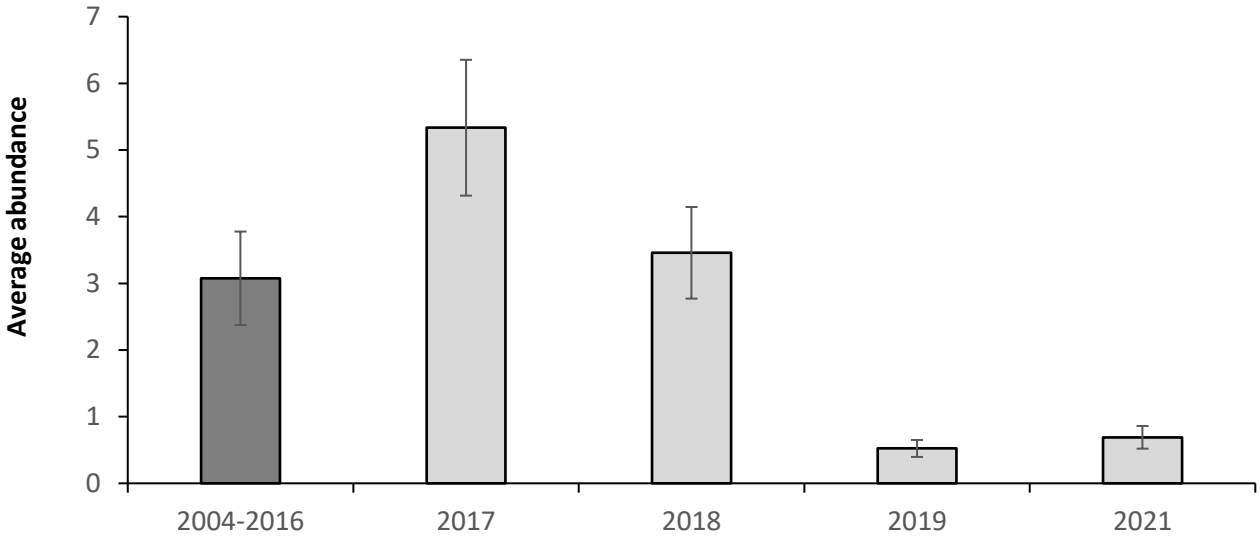


Figure 18. Average small lowland mammal guild abundance (individuals per 100 trap nights) from Standard Live Trapping on Mornington, Marion Downs and Tableland for 2004-2016, 2017, 2018, 2019 and 2021 (error bars ± SE). Values for 2004-2016 are from Legge et al. (2019). Overall abundance for 2004-2016 taken as the average of the four habitat types.

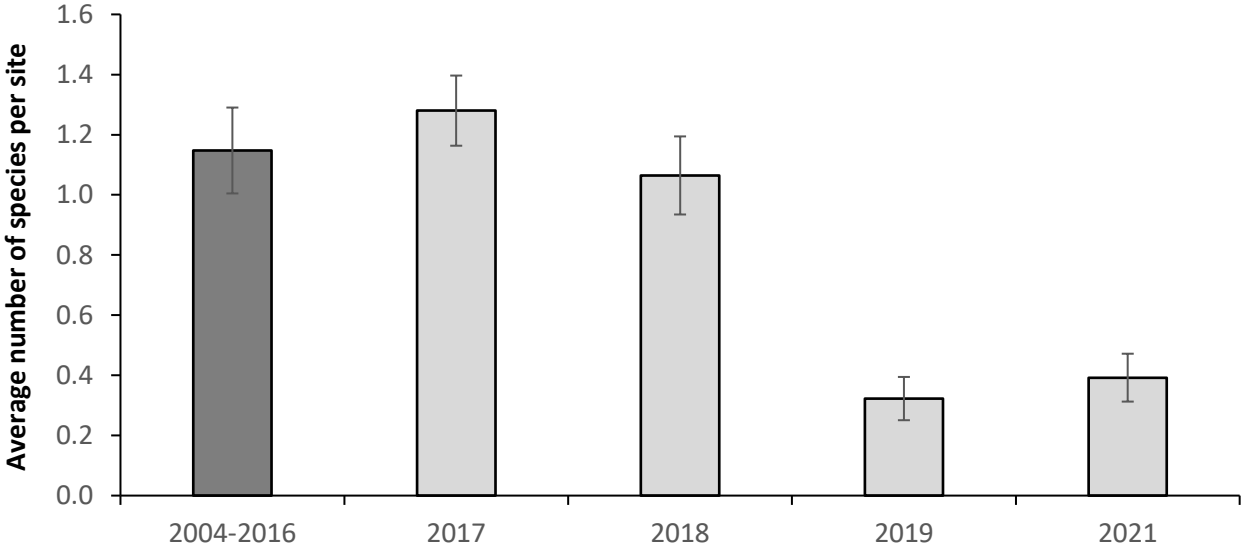
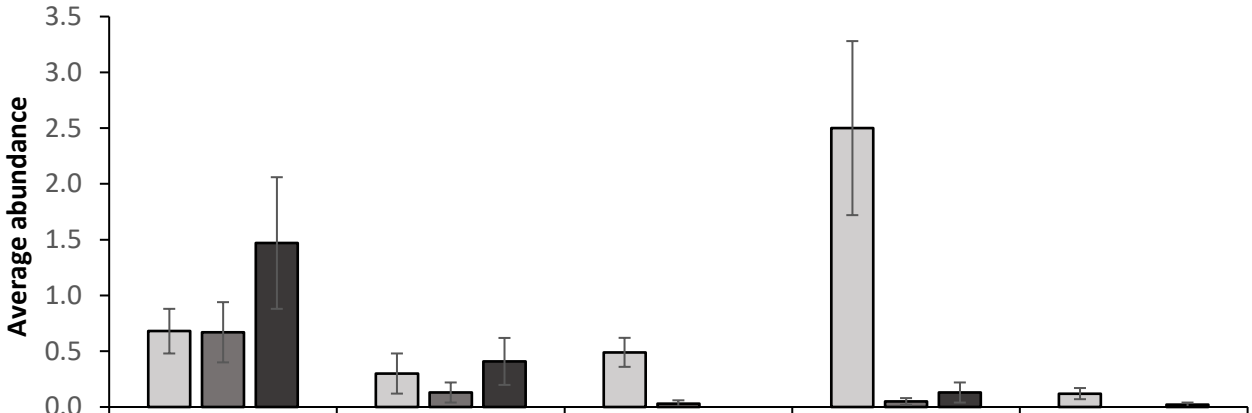


Figure 19. Average small lowland mammal guild species richness per site from Standard Live Trapping on Mornington, Marion Downs and Tableland for 2004-2016, 2017, 2018, 2019 and 2021 (error bars ± SE. Values for 2004-2016 are from Legge et al. (2019). Overall richness for 2004-2016 taken as the average of the four habitat types.

Surveillance species

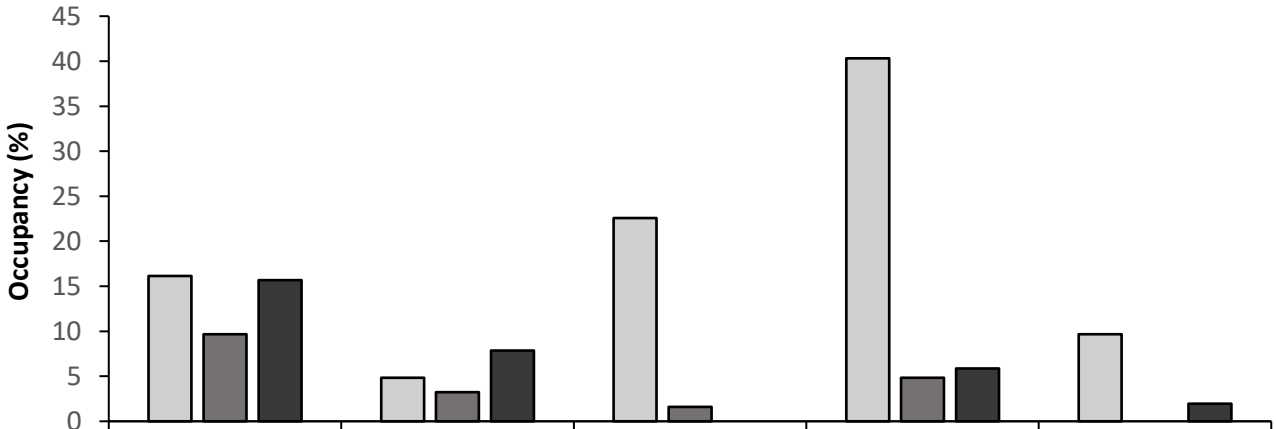
In 2021, the abundances of the 2 planigale species were the highest recorded since 2018 while all other species captures remained relatively low (Figure 20). No Western Chestnut Mice (*Pseudomys nanus*) were

detected at any of the sites in 2021. For the other 4 species, occupancy has increased since 2019 (Figure 21) but remain very low compared with 2018 observation for Pale Field Rat. It was hypothesised that after the good wet season of 2020-2021, small mammal populations may have increased, however with the exception of Long-tailed Planigale, the response to the increased rainfall has not been very strong. The results of the surveys in coming years will show if species are able to recover from the drought conditions of 2018-2019.



	Long-tailed Planigale*	Common Planigale*	Western Chestnut Mouse	Pale Field Rat	Delicate Mouse
2018	0.68	0.30	0.49	2.50	0.12
2019	0.67	0.13	0.03	0.05	0.00
2021	1.47	0.41	0.00	0.13	0.02

**Figure 20. Small mammal species abundance (individuals per 100 trap nights) from Standard Live Trapping Survey on Mornington, Marion Downs and Tableland for 2018, 2019 and 2021. ***Effort for planigales from pitfall traps only.



	Long-tailed Planigale*	Common Planigale*	Western Chestnut Mouse	Pale Field Rat	Delicate Mouse
2018	16	5	23	40	10
2019	10	3	2	5	0
2021	16	8	0	6	2

**Figure 21. Small mammal species occupancy (%) from Standard Live Trapping Survey on Mornington, Marion Downs and Tableland for 2018, 2019 and 2021. ***Effort for planigales from pitfall traps only.

Reptiles

During the period 2017-2021, 95 reptile species were detected from Standard Live Trapping and camera trapping surveys from 111 species known or likely to occur on MMDT. In 2021, 48 native reptile species were recorded in 2021 by Ecohealth Surveys (i.e., Standard Live Trapping and camera trap surveys). An additional 21 reptile species were recorded in 2021 by incidental and/or trial survey observations, particularly geckos (e.g., genus *Gehyra*) and snakes, taxa which are not readily detected or captured by established surveys. This leaves a minimum of 67 reptile species which were not detected in 2021 but have been confirmed or are

likely to occur on MMDT - species which require more targeted surveys and/or the sanctuary is at the edge of their known range.

Small lowland reptile guild

During the 2021 Standard Live Trapping Survey, 403 individuals of 36 small reptile species were captured. Both the abundance (Figure 22) and richness (Figure 23) of small lowland reptiles were higher in 2021 compared with 2018 and 2019. This increase may reflect a response to the cumulative effect of an above average wet seasons compared with the very dry wet seasons prior to 2018 and 2019 trapping. However, the increase could also be reflective of potential increase in reptile activity as 2021 had above average maximum and minimum temperatures, particularly at the time of surveys.

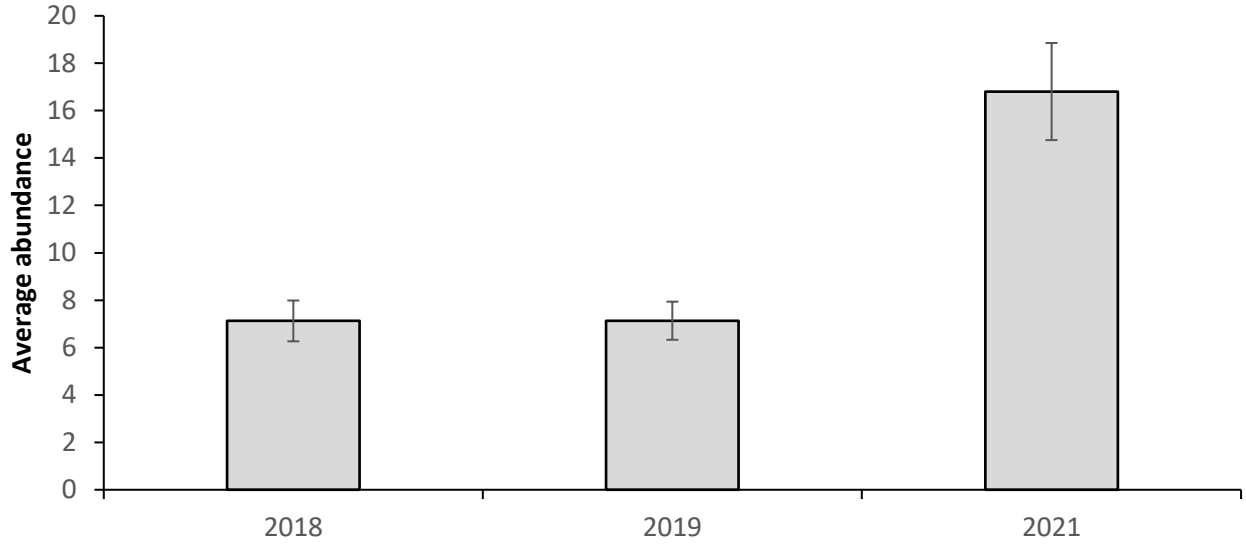


Figure 22. Average small lowland reptile guild abundance (individuals per 100 trap nights) from Standard Live Trapping on Mornington, Marion Downs and Tableland for 2018, 2019 and 2021 (error bars ± SE).

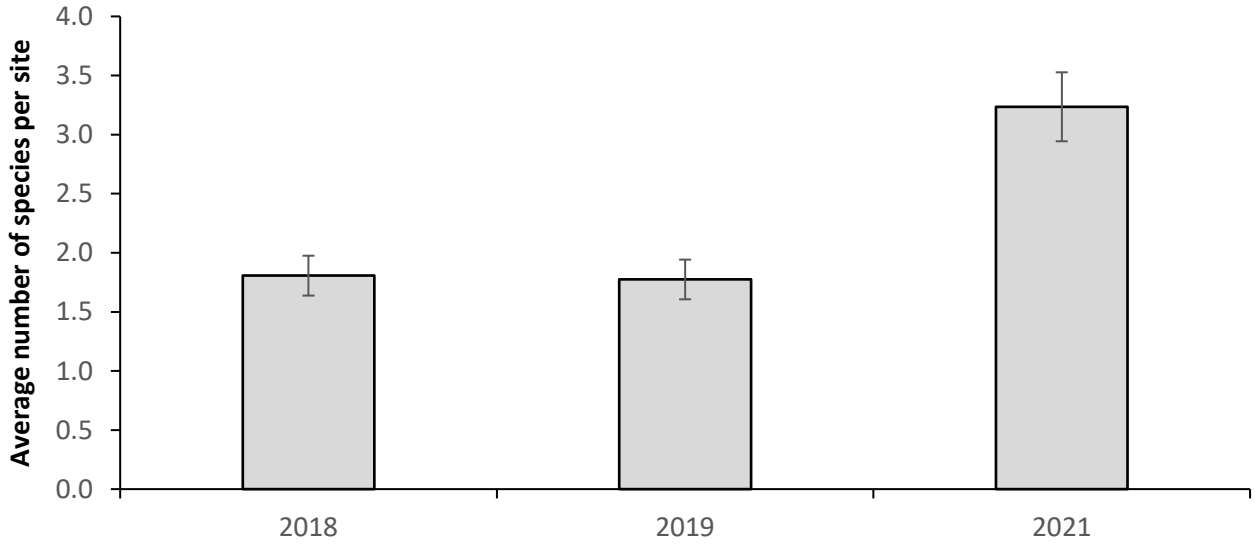


Figure 23. Average small lowland reptile guild species richness from Standard Live Trapping on Mornington, Marion Downs and Tableland for 2018, 2019 and 2021 (error bars ± SE).

Birds

Overall, 112 native bird species were recorded by 2021 Ecohealth Surveys (i.e., Standard Bird Surveys and camera trap surveys) from 212 species known or likely to occur on MMDT. An additional 36 bird species were recorded in 2021 by incidental observations, including cryptic, nocturnal, specialised, and/or seasonal bird species (e.g., Hawk-owls, Spotted Night Jar, Cuckoos, Water Birds) not readily monitored by established surveys. This leaves a minimum of 64 species not detected in 2021 but have been confirmed or are likely to

occur on MMDT - species which require more targeted surveys and/or the sanctuary is at the edge of their known range. Common Cicadabird (*Edolisoma tenuirostre*) was observed incidentally on Mornington Sanctuary in 2021 for the first time.

Savanna diurnal bird guild

A total of 2,014 individuals of 84 bird species were recorded during the 2021 Standard Brid Survey with an average of 40.3 individuals (abundance) and 17.1 species (richness) observed per site (Figure 24, Figure 25). Species richness was higher in 2021 compared with 2018 and 2019, and in line with findings from 2004-2016 (Figure 24). Abundance appears stable, with only slight variation between recent survey years (Figure 25) and can be a difficult variable to quantify given observer bias and/or large flocks potentially impacting numbers. Earlier data (2004-2014) is presented for species richness, however, is not available for abundance as number of individuals was not always recorded during surveys in this period.

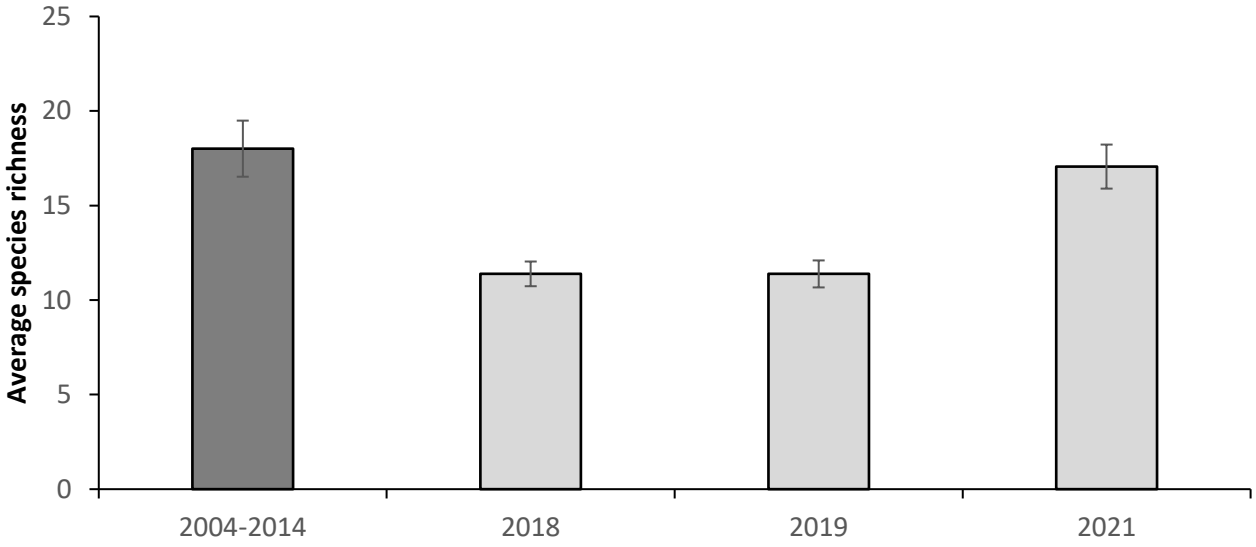


Figure 24. Average savanna diurnal bird guild species richness from Diurnal Bird Surveys on Mornington, Marion Downs and Tableland for 2004-2014, 2018, 2019 and 2021 (error bars ± SE).

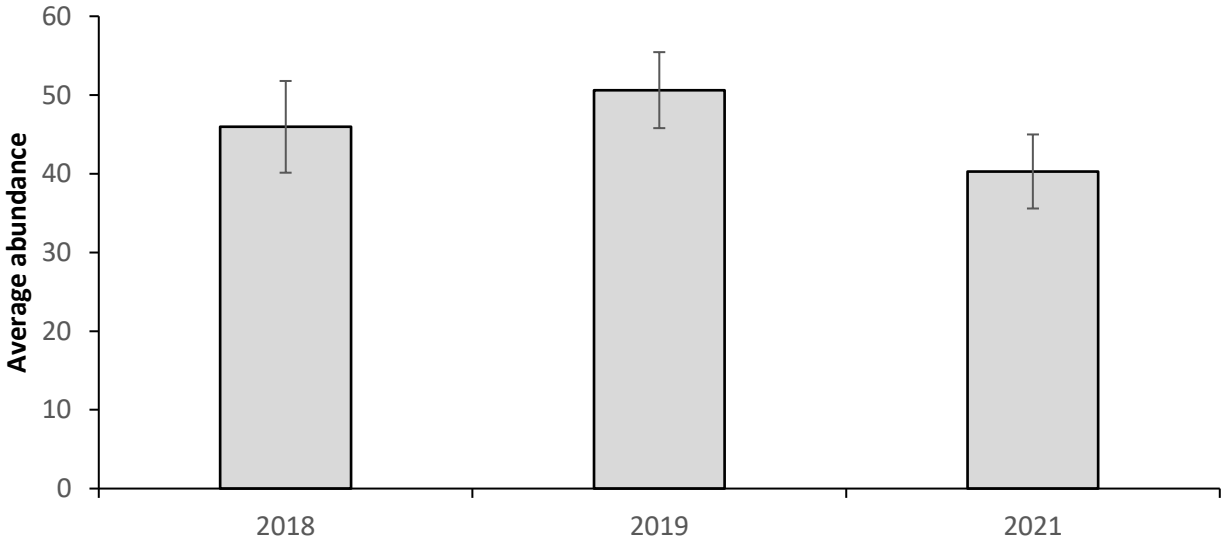


Figure 25. Average savanna diurnal bird guild abundance from Diurnal Bird Surveys on Mornington, Marion Downs and Tableland for 2018, 2019 and 2021 (error bars ± SE).

Vegetation surveys

Vegetation and structural habitat variables varied across habitat types in 2021 (Table 8). Leaf litter cover was considerably higher in Sandseep compared with the other habitat types. Vegetation ground cover (tussocks, hummocks and low shrubs <140cm) was highest in Woodland (89.78%), followed by Sandseep (69.96%),

Blacksoil (43.64%) and Riparian (36.79%). Woody debris (greater than >2.5 cm diameter) was highest in the Sandseep with almost no woody debris recorded in the Blacksoil, which was expected given low incidence of larger trees. Rock cover was also highest in Sandseep, which was expected given the close proximity of this habitat type to rocky areas. This variation in vegetation and habitat structure is likely to influence faunal composition, richness, and abundance. Comparison with previous years vegetation surveys is not feasible due to changes in methods and transect placement.

Table 8. Vegetation and habitat structure metrics at Standard Live Trapping sites in 2021 on Mornington, Marion Downs and Tableland. Bare soil and rock also recorded along each transect account for the remaining total ground cover (%).

Habitat type	**Leaf litter cover** %	**Vegetation ground cover** %	**Total ground cover** % (<140 cm)	**Canopy cover** % (>140 cm)	**Woody debris** (records per 100 m)	**Rock cover** %
Blacksoil	1.52	43.64	45.85	2.41	0.03	0.46
Riparian	2.39	36.79	39.77	12.80	0.82	0.37
Sandseep	7.22	69.96	81.97	19.19	4.45	2.17
Woodland	1.97	89.78	93.18	16.63	1.11	0.53
Overall	**3.02**	**53.78**	**57.03**	**11.45**	**1.35**	**0.78**

Threat indicators

Feral herbivores

A total of 1,452 cattle were observed during the aerial survey in 2021, which resulted in an average density estimate of 1.65 cattle per km (Table 9, Figure 26, Figure 27). This number is higher compared with 2020, which may have been a response to an early onset of the wet season. Ideally, cattle surveys are undertaken before the rainfall begins, however, unexpected early rain in October meant that cattle may have been more dispersed in the landscape, which may have increased detectability along the flight path. Significant changes were made to the flight path and data analysis since 2020 making comparison to previous years unreliable. Methods for calculating cattle population estimates are currently under review. However, 2021 data were still very useful in targeting 2021 culls and 2022 cattle management for key areas of high ecological value.

A total of 25 horses were also observed during 880 km of feral herbivore surveys across MMDT (Table 9, Figure 27). This is similar to 2019 (n = 27) and 2020 (n = 15). Donkey numbers on MMDT have historically been low and no donkeys were observed in 2021 compared with 1 in 2019 and 4 in 2020 (Table 9).

Table 9. Feral herbivore (cattle, horses and donkeys) metrics on Mornington, Marion Downs and Tableland from 2009-2021.

Metric	**2009**	**2010**	**2012**	**2014**	**2015**	**2016**	**2018**	**2019**	**2020**	**2021**
Total length flown (km)	666	649	1,032	1,187	1,123	1,510	1,325	1,230	886	**880**
Total cattle count	2,837	2,073	4,643	4,123	4,095	3,200	1,485	2,685	1,148	**1,452**
Total donkey count	3	16	10	4	10	9	-	1	4	**0**
Total horse count	21	19	395	67	43	30	-	27	15	**25**
Cattle density (/km of survey)	**4.26**	**3.20**	**4.50**	**3.47**	**3.65**	**2.12**	**1.12**	**2.18**	**1.30**	**1.65**
Donkey density (/km of survey)	0.005	0.025	0.010	0.003	0.009	0.006	0	0.001	0.005	**0**
Horse density (/km of survey)	0.031	0.029	0.383	0.056	0.038	0.020	0	0.022	0.017	**0.028**

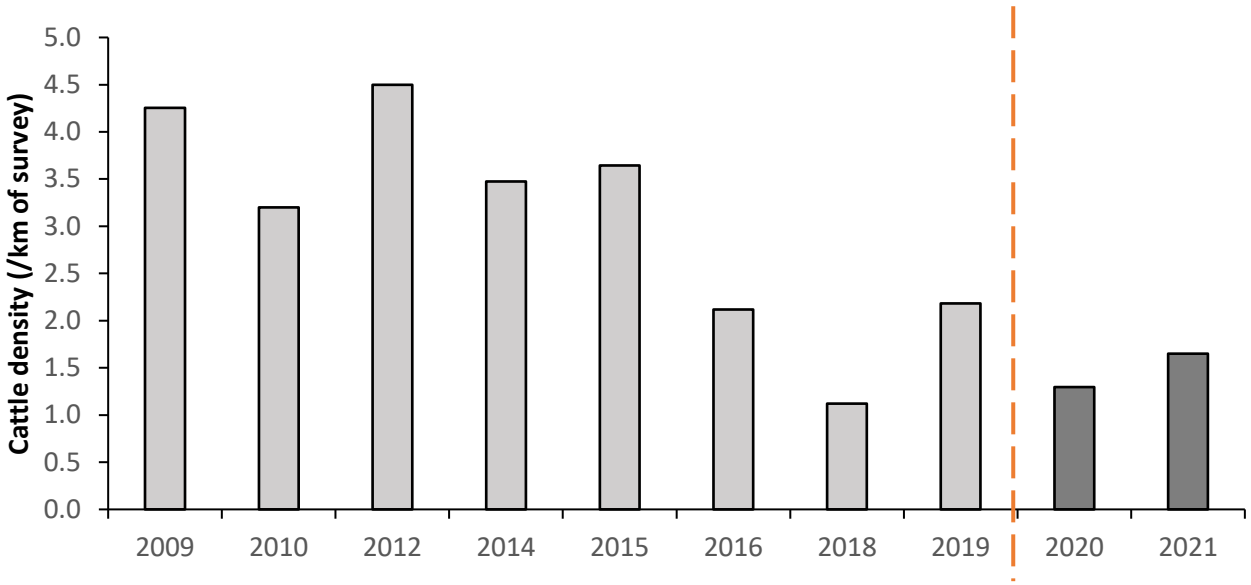


Figure 26. Feral cattle density (/km or survey) over time from Feral Herbivore Aerial Survey on Mornington, Marion Downs and Tableland. Dashed line denotes change in survey design.

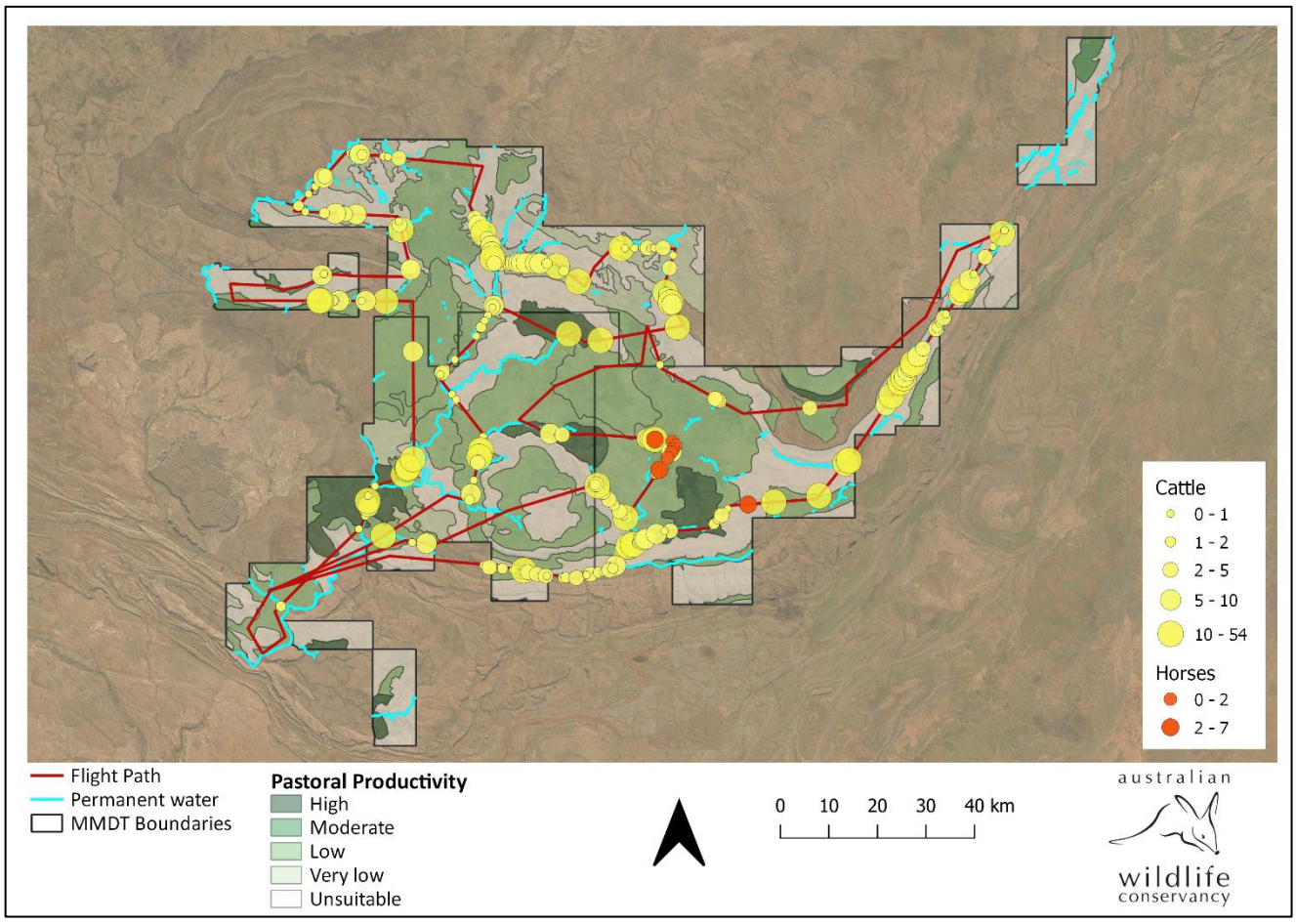


Figure 27. Feral cattle and horse detections from 2021 Feral Herbivore Aerial Survey on Mornington, Marion Downs and Tableland.

Fire

Destructive fire regimes characterised by frequent and extensive late dry-season fires are a critical threatening process for a wide range of taxa in northern Australia (Woinarski et al. 2011). Therefore, management of fire regimes is the primary conservation tool available at the landscape scale in the Kimberley. AWC manages fire regimes through a combination of planned early dry-season (EDS) burning (both

aerial and road-based) and where needed, late dry-season suppression. The primary goals of management are to create a fine-scale mosaic of burn scars and vegetation ages across the landscape, reduce the extent burnt by late-dry season fires, and reduce fire impacts on fire-sensitive species.

The results from 2021 have seen an improvement for all fire metrics that have positive consequences for ecological health, such as, a reduction in late dry season fire, an increase in area of long-unburnt vegetation and decrease in mean distance to unburnt vegetation over various time scales (Table 10, Figure 28). These changes and trends can be expected to have a range of positive impacts on biodiversity. For example, fire mosaics provide habitat for ground-dwelling mammals and birds that forage in recently burnt areas and shelter in long-unburnt vegetation (offering protection from feral predators; Legge et al. 2008).

Table 10. Metrics and outcomes of 2021 fire management on Mornington, Marion Downs and Tableland.

Metric	**Baseline** average (2000/02-06)	**AWC management** average (2008/10-21)	**2021 result**	**Trend** (AWC vs baseline)	**Trend** (2021 vs baseline)
Area burnt by early dry season (EDS) fire (%)	12	18	**18**	↑	↑
Area burnt by late dry season (LDS) fire (%)	25	10	**5**	↓	↓
Total area burnt (%)	38	28	**22**	↓	↓
Cumulative extent burnt by LDS fire in past 3 years (%)	52	27	**5**	↓	↓
Modal frequency of fires in last 7 years	3		**2**		↓
Modal frequency of LDS fires in last 7 years	2		**0**		↓
Area of long-unburnt vegetation (3+ years since fire) (%)	20	29	**55**	↑	↑
Mean distance to unburnt vegetation (km)	1.5	0.7	**0.6**	↓	↓
Mean distance to vegetation unburnt for 3 or more years (km)	2.7	0.9	**0.6**	↓	↓
Mean distance to vegetation unburnt by LDS fire for 3 or more years (km)	2.3	0.9	**0.8**	↓	↓

Notes:

Baseline values for metrics are the average for the years immediately prior to management of Mornington-Marion Downs and Tableland by AWC: i.e., 2000-2006, for annual metrics, and 2002-2006, for 3-year metrics.

AWC management values for metrics are the average for the years following management of Mornington-Marion Downs and Tableland by AWC: i.e., 2008 onwards, for annual metrics, and 2010 onwards, for 3-year metrics.

Trend: change in metric compared with baseline, considering (i) average across AWC management; (ii) current year.
Change in magnitude shown by arrows: increase ↑, no change ↔, reduction ↓).
Inferred consequences for ecological health depicted by colour: improving in green (e.g., ↑ or ↓, depending on the metric); deteriorating in red (e.g., ↑ or ↓); no change, or if the change cannot be interpreted in terms of ecological health, in black. (↔, ↑ or ↓).

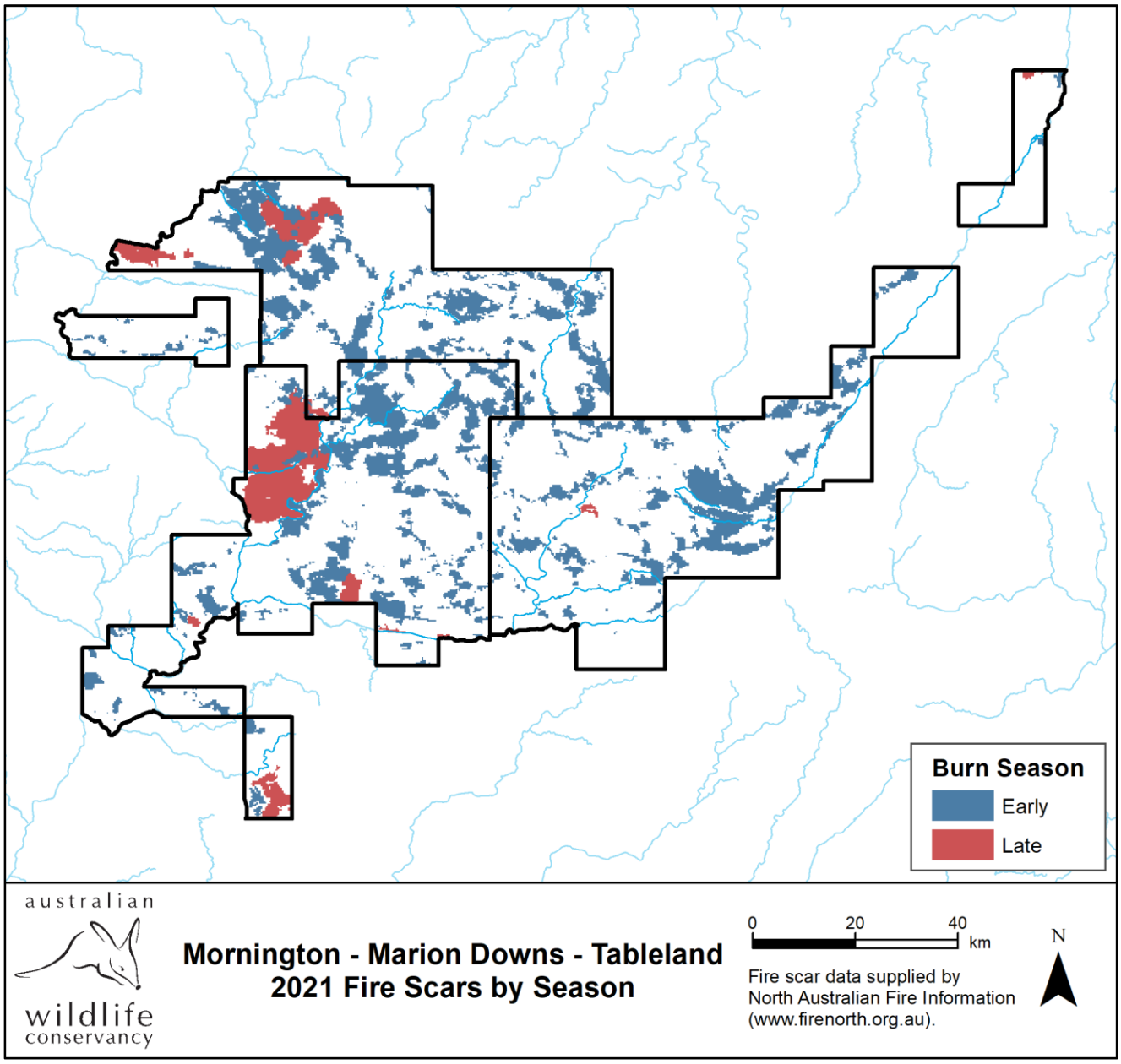


Figure 28. Fire scars in 2021, by Early (January-July) and Late (August-December) season, for Mornington, Marion Downs and Tableland.

Discussion

This MMDT Ecohealth Report summarises the results of the recent surveys conducted under the Ecohealth Monitoring Program. In 2021, a considerable survey effort of annual monitoring (5,440 camera trap nights, 6,151 live trap nights, 110 bird surveys and 886 km of aerial surveys) was undertaken. These surveys detected 21 mammals, 48 reptiles, 112 birds and 18 amphibians. Where available, results from surveys conducted in previous years (2004-2016) provided estimates for comparison. In some cases, 2021 is the first survey year, for others, methods are still in development. For these indicators, it is not possible to comment on trends in metrics.

The Northern Quoll is a carnivorous, critical weight range marsupial (350-1120 g) that was once abundant and widespread across most woodland, riparian and rocky habitats of northern Australia but has suffered significant range contraction and population decline, and is now classed as "Endangered" (EPBC 1999; Braithwaite and Griffiths 1994, Hill and Ward 2010, Woinarski et al. 2014). The primary threat to Northern Quoll is ingestion of bufotoxins in cane toads (Burnett 1997, Hill and Ward 2010, Shine 2010) followed by other threats that affect most Australian critical weight range mammals including habitat alteration, inappropriate fire regimes, predation by feral cats, feral herbivores, and weeds. AWC and collaborators were unsuccessful when trialling cane toad taste aversion on MMDT and as the front progressed across the Kimberley, Northern Quoll populations declined, at both trial and control sites (Indigo et al. 2018). The negative impacts of cane toad arrival on MMDT are still evident, with strong declines in Northern Quolls since 2017, and remaining low in 2021. Only one Northern Quoll was detected on a camera trap at Sir John Gorge with no quolls captured during live trapping. The decline of Northern Quolls on MMDT following the arrival of cane toads is consistent with trends observed elsewhere for this species (Hill and Ward 2010, Webb et al. 2015). Opportunistic surveys from a supporter event camera detected a small population at Spider Gorge, holding hope that some populations may be persisting on MMDT.

Above-average rainfall in the 2020-21 wet season (1,082.2 mm) followed two below average dry seasons, one of which was the driest wet seasons on record (2018-2019 = 433 mm). Rainfall is hypothesised to be a key variable explaining some of the trends in abundance and occupancy observed across many taxa in 2021. In particular, the population estimate for Purple-crowned Fairy-wren. The Purple-crowned Fairy-wren is an insectivorous, socially intricate bird, restricted to riparian habitat with a dense intact middle storey of Pandanus and a shady canopy of emergent trees (Skroblin and Legge 2012). The western subspecies is found along tropical creek lines and rivers of the Kimberley region and is nationally listed as "Endangered" (EPBC 1999) due to ongoing population decline (Birdlife International 2016). This is largely a result of habitat degradation from altered fire regimes (Woinarski 1990), weed invasion and feral herbivores (McKenzie et al. 2009). Due to the strong connection between intact riparian environments and Purple-crowned Fairy-wrens abundance and distribution, this species is considered a good indicator of riparian health (Skroblin and Legge 2012). Populations of wrens have been monitored at Mornington Wildlife Sanctuary since 2005, a year after these habitats were de-stocked of feral herbivores. These surveys have shown a general increase in population size since the beginning of the survey with a sudden decline associated with the extended dry period of 2017-18 and a fire at Annie creek in March 2019. The population estimate for this species is showing evidence of rebounding with an increase of 142% since the increased rainfall of the 2019-2020 wet season. Purple-crowned Fairy-wrens were breeding out of season in late 2020, and multiple times throughout 2021, which may have driven an increase in population in 2021.

The distributional range of Spectacled Hare-wallabies historically covered the northern half of Australia (Ingleby 1991, Woinarski et al. 2014). Their range has since reduced significantly, particularly in the past three decades, with patchy populations currently occurring throughout northern Australia. In Western Australia, Spectacled Hare-wallabies are currently considered rare and are limited to a few isolated populations in the Pilbara and Kimberley (Ingleby 1991, Woinarski et al. 2014) and are listed as Priority 4 (near threatened) under the Western Australian Biodiversity Conservation Act 2016. They are known to be a highly cryptic species, with low detectability (Ingleby 1991, McCosker 1997) and their distribution and abundance in the Kimberley is poorly understood (Woinarski et al. 2014). Targeted camera trapping surveys for Spectacled Hare-wallabies occurred for the second year in 2021 with only one camera detecting what was likely to have been one individual. The surveys have recorded Spectacled Hare-wallabies at 1 site in each year, thus little can be inferred from the survey results to date. Future expansion of this survey will involve effort in a wider

area of suitable habitat and refining of the survey methodology in an attempt to discover new populations and collect data that can be informative about long-term trends. A Conservation Management Plan is in preparation; this document will guide future survey efforts and management responses.

The abundance, occupancy and species richness of the small lowland mammal guild declined severely across MMDT in 2019, as was observed in other parts of the Kimberley (Sayers et al. 2021). This trend was driven strongly by rodent species and may have been a population 'bust' in response to poor rainfall (Dickman et al. 2010, Radford et al. 2014). It was hypothesised after a good wet season, populations would 'boom' again, however the data from the MMDT Live Trapping Survey does not support this, with the exception of planigales. The response to higher rainfall may be delayed, particularly in the dryer regions of the Central Kimberley, where small mammals may require multiple years of good rainfall to recolonise the region and to increase in abundance (Dickman et al. 2010). Furthermore, if dry years have caused any local extinction, it may take time for populations to recover via immigration (Dickman et al. 1995), particularly between the isolated refugia of MMDT. The occurrence and abundance of Northern Brown Bandicoots has been shown to respond more rapidly in relation to resource pulses (Radford et al. 2014) so they may be able to respond rapidly to the improved rainfall in 2020-2021. The results at the smaller area of bandicoot monitoring on southern Mornington (Northern Brown Bandicoot Camera Survey) show an increase in population metrics. However, the survey results from across MMDT (Standard Live Trapping Survey) show that population numbers are still low in 2021 after a decline associated with low rainfall beginning in 2019. This may indicate populations are increasing locally in high quality habitat, but it may take longer for the increase to occur across the sanctuary where populations may have been more affected by the low rainfall.

Small lowland reptile guild abundance and richness were higher in 2021 compared with previous years, which may reflect a response to the improved rainfall in 2020-2021. However, it may also be reflective of warmer than average temperatures during the survey period, possibly increasing reptile activity.

Savanna bird guild richness increased in 2021, possibly driven by higher rainfall supporting more fruiting and flowering plant species and water sources. The abundance and occupancy of Gouldian Finch appeared to increase on MMDT in the most recent surveys of 2019. However, caution is recommended in interpreting these results, as the availability of water in the landscape strongly influences the effectiveness of the survey methods. For example, the highest numbers of Gouldian Finch occurred in the dryer years, which is likely to be a result of increased reliance on permanent water in the landscape, leading to concentrations of birds at survey sites ultimately inflating results.

Knowledge of the impacts of, and interactions among, key threatening processes such as fire, feral herbivores and cat predation is a key driver behind land management across MMDT. For the feral herbivore surveys, care should be taken with interpreting the long-term results as there was a significant change in survey design in 2020, however the aerial herbivore surveys showed cattle density appear lower in more recent years. This is an expected result as cattle management has been ongoing on MMDT for many years. Between 2019 and 2020, the density increased slightly, this increase in cattle numbers may be due to the early onset of the wet season allowing cattle to move throughout the landscape and thus increasing detection. Data from these surveys allow us to target cattle removal from ecologically sensitive areas and will help AWC review the feral herbivore strategy for MMDT.

An improvement for all fire metrics was observed for 2021, including, a reduction in late dry season fire, an increase in area of long-unburnt vegetation and decrease in mean distance to unburnt vegetation over various time scales. These changes to vegetation improve habitat availability for ground-dwelling mammals and birds that forage in recently burnt areas and shelter in long-unburnt vegetation (Legge et al. 2008). Ecofire and Ecohealth Programs will continue to be implemented in 2022 and beyond on MMDT.

Acknowledgments

AWC acknowledges the Bunuba, Kija and Ngarinyin Peoples as the Traditional Custodians of the lands designated as southern Mornington; north and eastern Mornington and Tableland; and Marion-Downs, respectively. AWC acknowledges all First Nations Peoples ongoing connection to land, waters, community, and culture.

For their assistance in conducting Ecohealth surveys at MMDT in 2021, we particularly thank the MMDT 2021 field team, including land management officers, other AWC staff and numerous enthusiastic volunteers, for their many hours in the field and at the computer tagging photos and cleaning data.

AWC's Ecohealth Program is only possible because of the generosity of AWC's supporters.

References

Berry L, Holland G, Anson J, Pierson J, Kanowski J (2021) *Bridled Nailtail Wallaby: Population Management Plan Scotia Wildlife Sanctuary*. Internal report, Australian Wildlife Conservancy, Perth, WA.

BOM (2021) Climate data online. Bureau of Meteorology, Commonwealth of Australia, 2021.

Braithwaite RW, Griffiths AD (1994) Demographic variation and range contraction in the northern quoll, Dasyurus hallucatus (Marsupialia: Dasyuridae). *Wildlife Research* 21, 203–217.

Burnett S (1997) Colonizing cane toads cause population declines in native predators: reliable anecdotal information and management implications. *Pacific Conservation Biology* 3, 65.

Dickman CR, Greenville AC, Beh C-L, Tamayo B, Wardle GM (2010) Social organization and movements of desert rodents during population "booms" and "busts" in central Australia. *Journal of Mammalogy* 91, 798–810.

Dickman CR, Predavec M, Downey FJ (1995) Long-range movements of small mammals in arid Australia: implications for land management. *Journal of Arid Environments* 31, 441–452.

Hill B, Ward S (2010) *National recovery plan for the Northern Quoll Dasyurus hallucatus*. Department of Natural Resources, The Arts and Sport, Darwin, NT.

Indigo N, Smith J, Webb JK, Phillips B (2018) Not such silly sausages: evidence suggests northern quolls exhibit aversion to toads after training with toad sausages. *Austral Ecology* 43, 592–601.

Ingleby S (1991) Distribution and status of the spectacled hare-wallaby, (*Lagorchestes conspicillatus*). *Wildlife Research* 18, 501–519.

Kanowski J, Joseph L, Kavanagh R, Fleming A (2018) Designing a monitoring framework for Australian Wildlife Conservancy, a national conservation organisation. In: *Monitoring Threatened Species and Ecological Communities* (Eds S Legge, DB Lindenmayer, NM Robinson, BC Scheele, DM Southwell, BA Wintle), CSIRO Publishing, Melbourne, Australia.

Legge S, Kennedy MS, Lloyd R, Murphy SA, Fisher A (2011) Rapid recovery of mammal fauna in the central Kimberley, northern Australia, following the removal of introduced herbivores. *Austral Ecology* 36, 791–799.

Legge S, Murphy S, Heathcote J, Flaxman E, Augusteyn J, Crossman M (2008) The short-term effects of an extensive and high-intensity fire on vertebrates in the tropical savannas of the central Kimberley, northern Australia. *Wildlife Research* 35, 33–43.

Legge S, Murphy S, Milne D, Risler J, Fisher A (2004) *Preliminary fauna survey and monitoring the effects of destocking.* Australian Wildlife Conservancy, Perth, WA.

Legge S, Smith JG, James A, Tuft KD, Webb T, Woinarski JCZ (2019) Interactions among threats affect conservation management outcomes: Livestock grazing removes the benefits of fire management for small mammals in Australian tropical savannas. *Conservation Science and Practice* 1 (7), 1-13.

McCosker J (1997) The ecology and conservation of spectacled hare-wallabies *Lagorchestes conspicillatus* in central Queensland. Masters, University of Queensland, Brisbane.

McKenzie NL, Start AN, Burbidge AA, Kenneally KF, Burrows ND (2009) *Protecting the Kimberley: a synthesis of scientific knowledge to support conservation management in the Kimberley region of Western Australia*. Department of Environment and Conservation, Western Australia, Perth, WA.

Millen C, Diete R, Hogget A, Cameron S, Kanowski J (2022) *Mornington- Marion Downs and Tableland Wildlife Sanctuaries: 2021 Fire Pattern Analysis*. Australian Wildlife Conservancy, Perth, WA.

Radford IJ, Dickman CR, Start AN, Palmer C, Carnes K, Everitt C et al. (2014) Mammals of Australia's tropical savannas: A conceptual model of assemblage structure and regulatory factors in the Kimberley region (P Adam, Ed). *PLoS ONE* 9, e92341.

Sayers T, Albury R, Cameron S, Porter J, Potter L, Riles B et al. (2021) *Charnley River - Artesian Range Wildlife Sanctuary Ecohealth Report 2020*. Australian Wildlife Conservancy, Perth, WA.

Shine R (2010) The ecological impact of invasive cane toads (*Bufo Marinus*) in Australia. *The Quarterly Review of Biology* 85, 253–291.

Skroblin A, Legge S (2012) Influence of fine-scale habitat requirements and riparian degradation on the distribution of the purple-crowned fairy-wren (*Malurus coronatus coronatus*) in northern Australia. *Austral Ecology* 37, 874–884.

Southgate R, Palmer C, Adams M, Masters P, Triggs B, Woinarski J (1996) Population and Habitat Characteristics of the Golden Bandicoot (*Isoodon Auratus*) on Marchinbar Island, Northern Territory. *Wildlife Research* 23, 647–664.

Strahan R (1995) *The Mammals of Australia: The National Photographic Index of Australian Wildlife, 2nd ed. Smithsonian*. Chatswood, NSW, Reed Books, the Australian Museum.

Vigilante T (2001) Analysis of explorers' records of Aboriginal landscape burning in the Kimberley region of Western Australia. *Australian Geographical Studies* 39, 135–155.

Vigilante T, Bowman DMJS (2004) Effects of fire history on the structure and floristic composition of woody vegetation around Kalumburu, North Kimberley, Australia: a landscape-scale natural experiment. *Australian Journal of Botany* 52, 381–404.

Webb J, Legge S, Tuft K, Cremona T, Austin C (2015) Can we mitigate cane toad impacts on northern quolls? Charles Darwin University, Darwin.

Woinarski JCZ (1990) Effects of fire on the bird communities of tropical woodlands and open forests in northern Australia. *Australian Journal of Ecology* 15, 1–22.

Woinarski JCZ, Ash AJ (2002) Responses of vertebrates to pastoralism, military land use and landscape position in an Australian tropical savanna. *Austral Ecology* 27, 311–323.

Woinarski JC, Burbidge AA, Harrison PL (2014) *The Action Plan for Australian Mammals 2012*. CSIRO Publishing, Collingwood, VIC, Australia.

Woinarski JCZ, Legge S, Fitzsimons JA, Traill BJ, Burbidge AA, Fisher A et al. (2011) The disappearing mammal fauna of northern Australia: context, cause, and response. *Conservation Letters* 4, 192–201.

Appendices

Appendix 1. Survey Methods

Targeted surveys

Northern Quoll Live Trapping Survey

Total trap effort for Northern Quoll monitoring from 2011-2020 is 5,476 trap-nights, with a breakdown by year and month shown in Table A1.

Table A1. Trap effort for live trapping to monitor Northern Quoll populations in Sir John Gorge on the north and south sides of the Fitzroy River between 2011 and 2020.

Year	Month	Effort		Total effort
		North	South	
2011	February	46	0	46
	April	80	0	80
	June	60	0	60
	August	240	0	240
	October	80	40	120
	December	270	0	270
2012	February	66	32	98
	April	87	84	171
	July	216	38	158
	September	150	160	310
	November	120	0	120
2013	March	168	90	278
	June	198	30	228
	September	180	30	210
2014	January	124	0	124
	March	171	90	261
	June	180	90	270
	October	156	90	246
2015	April	172	120	292
	June	180	90	270
	October	210	90	300
2016	April	80	48	128
	July	64	64	128
2017	May	160	140	300
2018	*No live quoll trapping for population monitoring was undertaken in 2018*			
2019	July	368	320	688
2020	July	80	80	160
2021	July	60	80	140