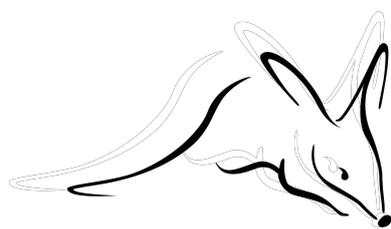


Charnley River-Artesian Range
Wildlife Sanctuary
Ecohealth Report 2021



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Summary

Australian Wildlife Conservancy (AWC) has implemented an Ecological Health Monitoring Program (Ecohealth) across Charnley River – Artesian Range Wildlife Sanctuary (CRAR) 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 going back to 2016. The complete set of metrics and their values are summarised in the accompanying Ecohealth Scorecard.

In implementing the Ecohealth program in 2021, AWC conducted 4,071 live trap nights, 8,586 camera trap nights, 448 km of transects, and 74 bird surveys. AWC has conducted inventory surveys and ecological research on CRAR, particularly the Artesian Range, since 2012, with standardised Ecohealth surveys dating back to 2016 on Charnley. Since 2016, new surveys continue to be added to CRAR's Ecohealth Program and in 2021 the first standardised Ecohealth surveys in the Artesian Range commenced.

Ecohealth surveys in 2021 detected 33 mammal species (including 4 introduced species) compared to 60 known or likely to occur; 66 reptile species compared to 120 known or likely to occur; 133 bird species compared to 198 known or likely to occur; and 27 amphibian species compared to 32 known or likely to occur. Overall, 259 vertebrate species were recorded in 2021. Species that were not detected in 2021 are cryptic, restricted in distribution and habitat on CRAR, and/or require more targeted monitoring to assess their persistence. In coming years, effort will be made to search for these species.

Notable results from threatened species monitoring include the persistence of the Northern Quoll (*Dasyurus hallucatus*) after the recent arrival of the cane toad. In 2021, quolls still occupied several refugial sites in central Charnley. The 2020-2021 wet season was significant for the Northern Quoll in the Artesian Range, with cane toads reaching the range early in 2020. Northern Quoll abundance declined significantly during the 2020-2021 wet season, relative to pre cane toad levels. Follow-up monitoring is planned in 2022 to assess further population status. Northern Brown (*Isoodon macrourus*) and Golden Bandicoots (*Isoodon auratus*) remain a key target complex for monitoring on CRAR, in particular in the Artesian Range which has a high occupancy of both bandicoot species, and in other refugial rocky areas and lowland riparian areas on Charnley. Other notable threatened species detected on CRAR in 2021 include the Northern Brushtail Possum (*Trichosurus vulpecula arnhemensis*) in the southeast of the Wildlife Sanctuary, increasing its known range on CRAR.

The results of the 2021 Ecohealth surveillance monitoring showed evidence of a rebound in some biodiversity metrics, likely due to the above average wet season in 2020-2021. For example, there was a doubling in the abundance and species richness of the small lowland mammal guild, and an increase in abundance and species richness of the small-medium reptile guild and rock monitor guild, relative to 2020. Overall, results show that the Artesian Range continues to be a stronghold for several Kimberley endemics that have declined elsewhere in their historic distributional range (i.e., central and eastern Charnley) including the Monjon (*Petrogale burbidgei*) /Nabarlek (*Petrogale concinna*), Golden-backed Tree-rat (*Mesembriomys macrurus*), Wyulda (*Wyulda squamicaudata*), bandicoots, and Kimberley Rock-rat (*Zyzomys woodward*).

Multiple threats continue to put pressure on CRAR wildlife, which AWC continue to abate and monitor the outcomes. Feral cattle (*Bos taurus*) and pigs (*Sus scrofa*) pose a significant threat to the ecosystems and wildlife of CRAR, with cattle continuing to reside in destocked areas of the Wildlife Sanctuary. Concerted efforts will continue to be made to remove cattle from sensitive and ecological priority areas in addition to fence maintenance and construction to limit cattle dispersing from the leased stocked area. Feral pigs were found to occupy one third of the waterhole and wetland sites monitored in 2021, which informs the Feral Pig Management Strategy and targeted control. Unfortunately, cane toads (*Rhinella marina*) now range across 100% of CRAR as of late 2020, and feral cats (*Felis catus*) remain pervasive in the Synnot Range, and grassy plains and rocky outcrops of eastern Charnley. AWC continues to indirectly counter cat predation on wildlife by improving habitat condition through the fire management (Ecofire) program and destocking of feral herbivores. Fire regimes have improved markedly on CRAR since AWC management, and all fire metrics derived from the 2021 fire program shifted in a positive direction relative to both the pre-management and AWC management baselines.

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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 Charnley River – Artesian Range (CRAR) Wildlife Sanctuary. The companion Ecohealth Scorecard presents the indicators and their metrics in a summary format.

Charnley River – Artesian Range

Charnley River – Artesian Range (CRAR) Wildlife Sanctuary is located in the Kimberley in northern Western Australia, and is 300,059 ha in extent (Figure 1, Figure 2). Prior to the establishment of the CRAR Wildlife Sanctuary in 2015, AWC was involved in the conservation-oriented fire management on CRAR in 2007-2008 under AWC's regional 'Ecofire' program (Legge et al. 2011b). In 2010, AWC began managing a 139,000 ha section of the Artesian Range, located on Charnley River pastoral lease, with the remainder of the range, then under the control of the WA Department of Environment and Conservation (the 'DEC triangle': 37,000 ha), added to AWC's management in 2011. In 2015, AWC's extended its management to the remainder of the Charnley River pastoral lease, to establish the CRAR Wildlife Sanctuary. In 2017, AWC relinquished management of the DEC triangle, and entered a partnership with Australian Capital Equity (ACE, owners of Mt House Station) for the sustainable management of cattle (*Bos taurus*) on eastern parts of the pastoral lease (i.e., the current stocked/sub leased area, Figure 2).

The property encompasses both relatively intact, high conservation value ecosystems, as well as ecosystems with potential for improvement under conservation land management and effective control of threats including feral herbivores and predators, and inappropriate fire regimes. The vegetation on CRAR overall consists of a mixture of grassland and high grass savanna woodland (Figure 2). As of early 2022, the CRAR is confirmed to support 49 mammal species (with an additional 11 species likely or very likely to occur), 181 bird species (plus 17 species likely or very likely to occur), 94 reptile species (plus 26 species likely or very likely to occur), and 28 amphibian species (plus 4 species likely or very likely to occur). A total of 15 vertebrate species are listed as threatened either under federal (Environment Protection and Biodiversity Conservation [EPBC] Act 1999) or state (WA Biodiversity Conservation Act 2016) legislation. At least 387 species of plants have been recorded on CRAR. As some parts of the property are yet to be surveyed and additional targeted surveys are yet to be developed, overall known species numbers are set to increase over coming years.

Charnley

The central and south-eastern regions of CRAR Wildlife Sanctuary encompassing the Munboon Plateau and Synnot Range and land to the east and south of these rugged features (hereafter termed 'Charnley', and 'central' or 'eastern' Charnley; Figure 2), are dominated by savanna grassland and woodland communities on a complex of sandstone, volcanic and alluvial soils. Extensive areas of Charnley have been subject to impacts from cattle (within and outside the stocked area), feral pigs (*Sus scrofa*), feral cats (*Felis catus*), cane toads (*Rhinella marina*), and frequent wildfires prior to active management by AWC; there is also a substantial grader grass (*Themeda quadrivalvis*) infestation in central and eastern Charnley. Except for isolated rugged refugial areas, such as Munboon Plateau escarpments, the Synnot Range (Figure 2), smaller features such as volcanic outcrops (e.g. Mount Glemont) and rainforest pockets, Charnley currently does not support the same high level of wildlife richness and abundance relative to the Artesian Range (Figure 2) and other parts of the north-west Kimberley.

Artesian

The north-west of CRAR Wildlife Sanctuary comprising the Artesian Range and Sub-Artesian (north of the Munboon Plateau and west of the Synnot Range, and hereafter termed 'Artesian') is a remote and rugged landscape with no road access (Figure 2). The landscape is dominated by spinifex-covered sandstone ranges dissected by complex gorges, many of which support rainforest pockets in fire-protected locations. It can be thought of as relatively ecologically intact landscape, with very few feral herbivores, feral cats or weeds detected within the region (Legge et al. 2013), although the introduced cane toad recently invaded the area (in 2020). Consequently, many of the threatened, endemic, and/or high conservation value species that have declined or disappeared from the central Kimberley, including central and eastern Charnley, currently persist in higher abundance in the Artesian Range., including the Northern Quoll (*Dasyurus hallucatus*), Monjon (*Petrogale burbidgei*) /Nabarlek (*Petrogale concinna*), Golden-backed Tree-rat (*Mesembriomys macrurus*), Wyulda (*Wyulda squamicaudata*) and Bandicoots (Northern Brown (*Isodon macrourus*) and Golden Bandicoots (*Isodon auratus*)).

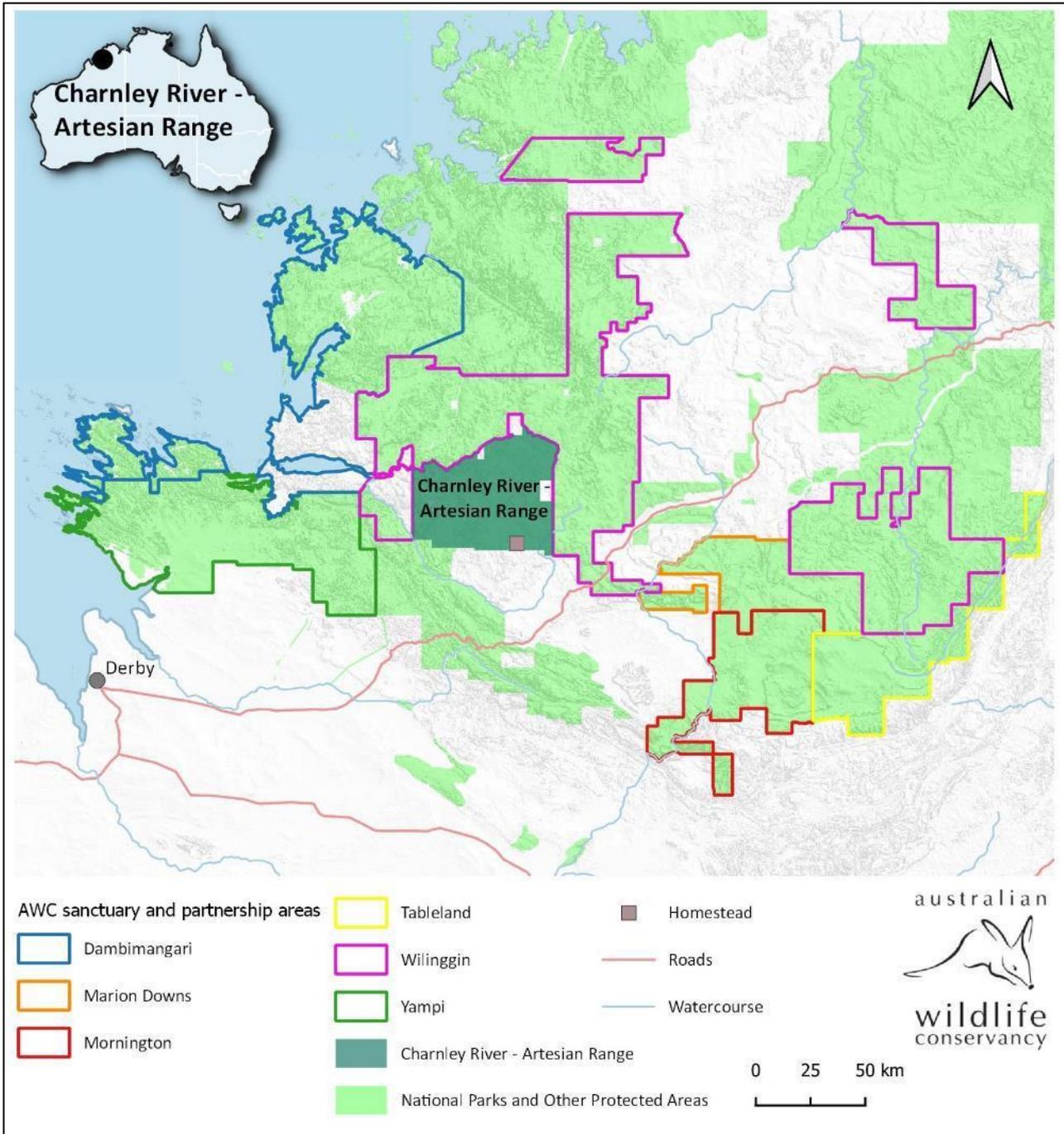


Figure 1. Location and regional context of Charnley River – Artesian Range Wildlife Sanctuary (CRAR), with reference to other AWC Sanctuaries and Partnership areas in the Kimberley. CRAR resides on Wiltinggin Country - AWC acknowledges the Ngarinyin People, the Traditional Custodians of the land.

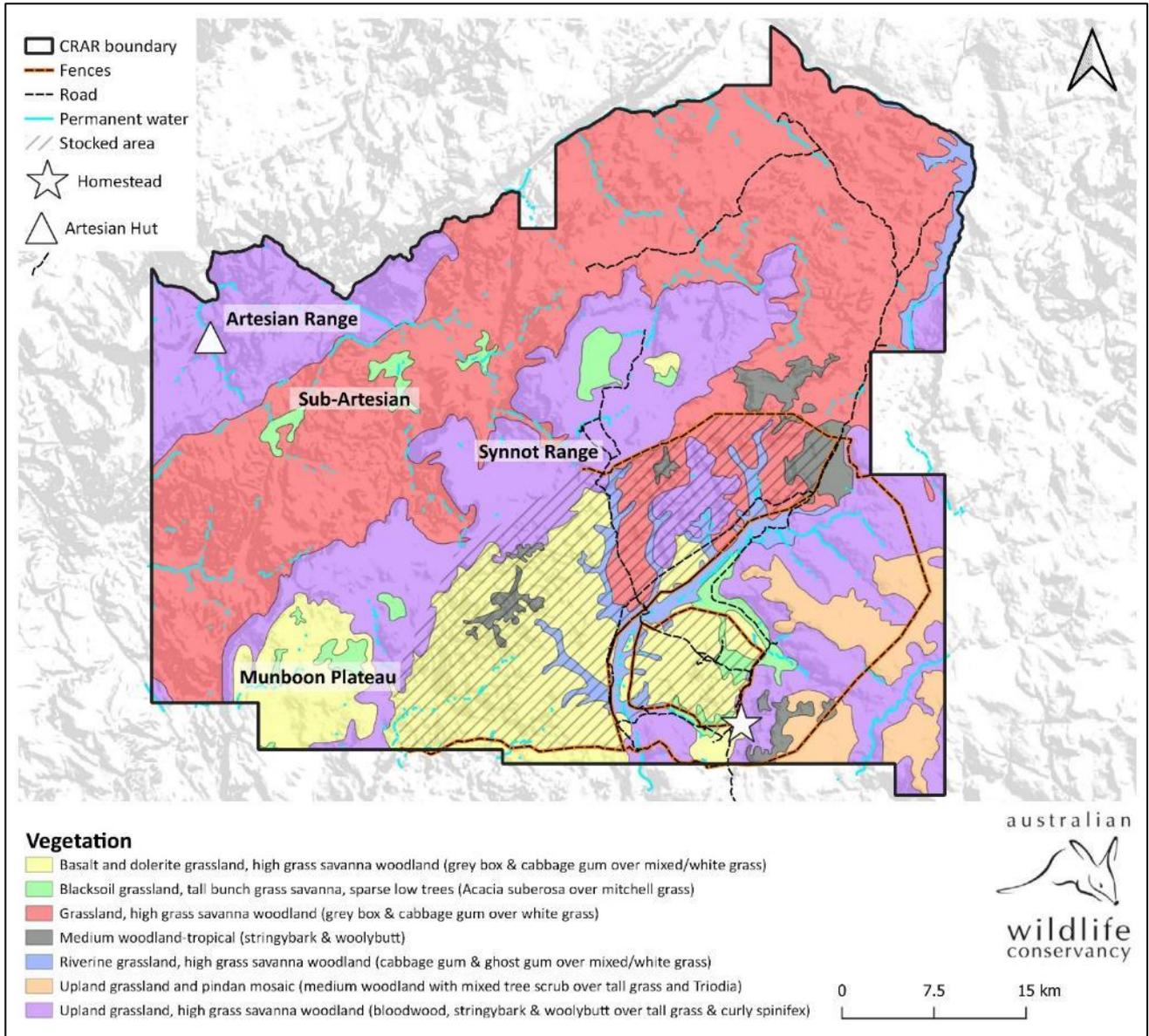


Figure 2. Extent and distribution of broad vegetation types of Charnley River – Artesian Range Wildlife Sanctuary (CRAR), also showing the main roads, fence lines (and adjacent roads), designated stocked area, permanent water, homestead location, and names of significant landscape features. Note that smaller habitat features such as rainforest pockets are not illustrated here, and that the Charnley River forms the northern boundary of CRAR Wildlife Sanctuary.

Climate and weather summary

CRAR Wildlife Sanctuary is located in tropical Australia and is characterised by distinct wet and dry seasons. The property straddles the transition from the lower rainfall (below 1,000 mm annually) and less-rugged Central Kimberley to the higher rainfall (above 1,000 mm annually) and generally more rugged North-West Kimberley bioregions. The 2020-2021 wet season on CRAR was significantly above average (977 mm) with 1,282 mm of rain recorded, which was considerably more rainfall than the previous 2019-2020 and 2018-2019 wet seasons with 905 and 515 mm, respectively (Figure 3). This was the first above average wet season since 2017-2018 and comes two years after the 2018-2019 wet season which was one of the driest seasons on record (the ‘failed wet’; Figure 3). Most of the rainfall during the 2020-2021 wet season fell during a 5-month period particularly in December, January and February associated with persistent monsoonal lows (Figure 4). Based on long term trends (1968 – 2021) the average total rainfall is increasing on CRAR (by 8 mm per year).

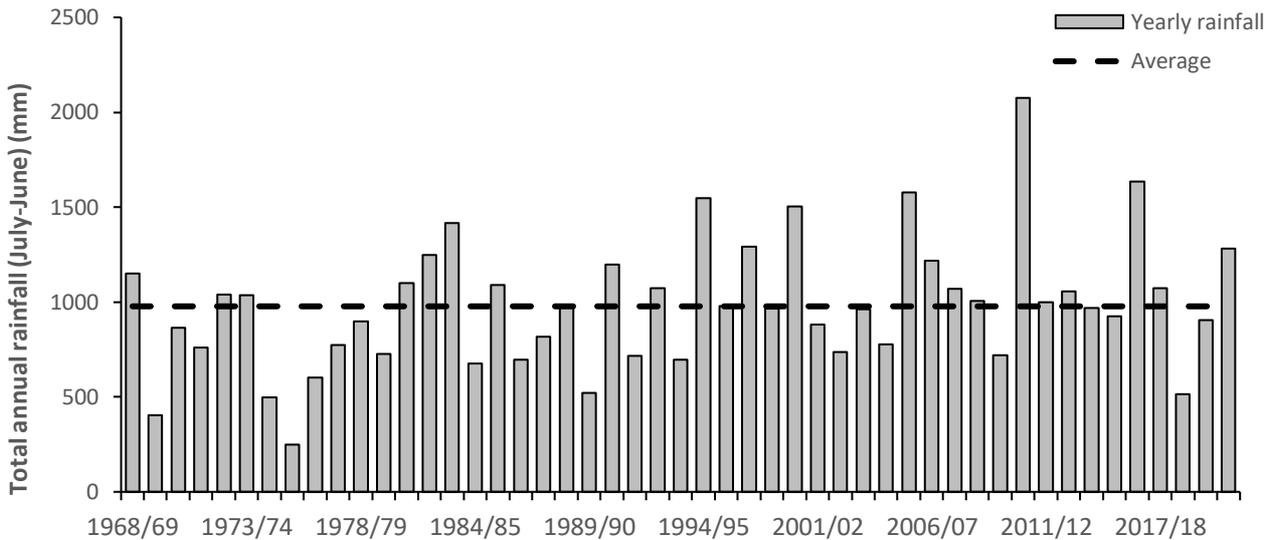


Figure 3. Total annual rainfall (July-June) from 1968-1969 – 2020-2021 at Charnley Homestead. Dashed line = average totals from 1968-1969 – 2020-2021. Note that four years have been excluded as there were significant gaps in wet season rainfall data, resulting in 49 years of wet season rainfall data.

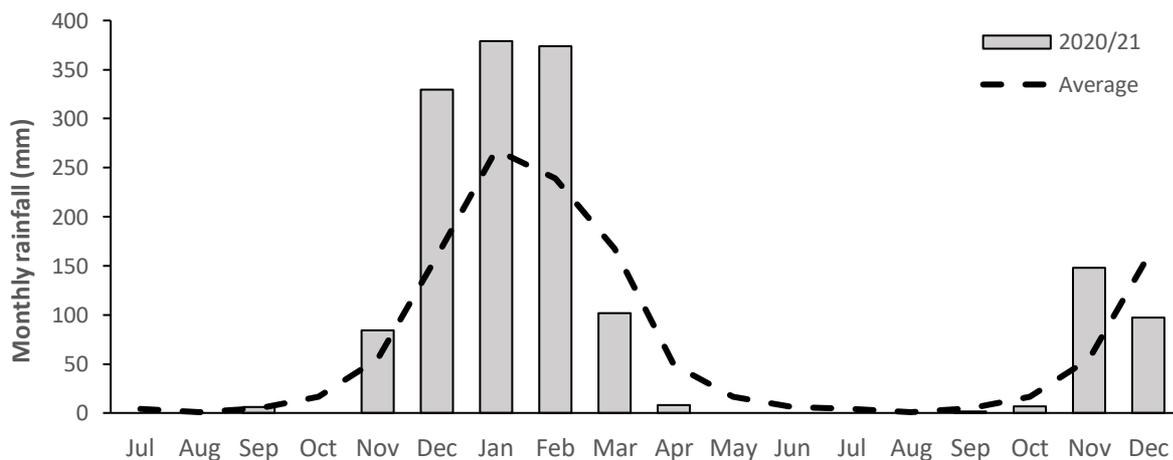


Figure 4. Monthly rainfall at Charnley Homestead for 2020 – 2021. Dashed line = average monthly rainfall from 1968-1969 – 2020-2021. Note that rainfall data for October 2020 was not collected.

Methods

Monitoring and evaluation framework

CRAR'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. Note that CRAR Wildlife Sanctuary does not currently have any reintroduction programs.

AWC will develop *Conservation Plans* for the extant threatened and iconic species, to ensure early detection of any serious issues that arise and to trigger timely responses. These plans will specify metrics to monitor outcomes for target species against nominated performance criteria.

Vertebrate assemblages and surveillance species

AWC's mission involves the conservation of all wildlife, not only threatened or reintroduced species. For this reason, AWC's monitoring program extends to surveillance monitoring of faunal assemblages and individual species (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 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 and species, 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 assemblages and species.

Indicators and metrics

On CRAR Wildlife Sanctuary, 46 biodiversity (species, guilds and vegetation structure) indicators have been selected for monitoring (Table 1). Forty-five of these indicators are reported on in this 2021 Ecohealth Report, including 8 related to threatened and iconic species, and the remainder to surveillance monitoring of faunal assemblages, individual species and vegetation structure.

Threat metrics are selected to monitor the status and trends of introduced weeds, feral predators and herbivores, and fire regimes. Nine threat indicators have been selected for monitoring (Table 2). Seven of these threat indicators are reported upon in this 2021 report.

Table 1. Biodiversity indicators and metrics for Charnley River – Artesian Range Wildlife Sanctuary.**Key threatened and iconic vertebrates**

Indicator	Survey name	Survey method	Metric/s
Mammals			
Northern Quoll (<i>Dasyurus hallucatus</i>)	Charnley Rocky Area Array, Artesian Rocky Area Array, Artesian Northern Quoll Camera Array	Camera traps	Abundance, activity, occupancy
Northern Brown (<i>Isoodon macrourus</i>) and Golden Bandicoots (<i>Isoodon auratus</i>)	Charnley Rocky Area Array, Artesian Rocky Area Array (<i>Charnley Bandicoot Lowland Camera Array and Live Trapping planned</i>)	Camera traps	Activity, occupancy
Northern Brushtail Possum (<i>Trichosurus vulpecula arnhemensis</i>)	Effective targeted and long-term survey method yet to be developed (<i>Charnley Arboreal and Lowland Camera Arrays planned</i>)	Camera traps	Activity, occupancy
Monjon (<i>Petrogale burbidgei</i>) /Nabarlek (<i>Petrogale concinna</i>)	Artesian Rocky Area Camera Array (<i>more targeted surveys planned</i>)	Camera traps	Activity, occupancy
Birds			
Black Grasswren (<i>Amytornis housei</i>)	Artesian Black Grasswren Targeted Playback Survey, Artesian Rocky Area Camera Array (<i>more targeted surveys planned</i>)	Targeted playbacks, camera traps (song meters)	Activity, occupancy
Gouldian Finch (<i>Erythrura gouldiae</i>)	Effective targeted and long-term survey method yet to be developed (i.e., vegetation assessment, acoustic recorders, camera traps)	TBD	Activity, occupancy
Reptiles			
Water monitor guild (Merten's Water Monitor, <i>Varanus mertensi</i> , Mitchell's Water Monitor, <i>Varanus mitchelli</i>)	Effective targeted and long-term survey method yet to be developed (<i>Charnley Varanid Camera Array planned</i>)	Camera traps	Activity, occupancy
Yellow Spotted Monitor (<i>Varanus panoptes</i>)	Effective targeted and long-term survey method yet to be developed (<i>Charnley Varanid Camera Array planned</i>)	Camera traps	Activity, occupancy

Vertebrate assemblages and surveillance species

Indicator	Survey name (note multiple surveys may assess an indicator)	Survey method	Metric/s
Mammals			
Assemblage richness	All relevant mammal surveys and incidentals	Various	Number of species
Small lowland mammals			
Assemblage richness	All relevant small lowland mammal surveys and incidentals	Various	Number of species
Small mammal lowland guild (<i>dasyurids, rodents, comprises six species listed below</i>)	Charnley Standard Live Trapping	Pitfall traps, Elliot traps, cage traps	Abundance, richness (separated by habitat and combined)
Long-tailed Planigale (<i>Planigale ingrami</i>)	Charnley Standard Live Trapping	Pitfall traps	Abundance, occupancy

Indicator	Survey name (note multiple surveys may assess an indicator)	Survey method	Metric/s
Common Planigale (<i>Planigale maculata</i>)	Charnley Standard Live Trapping	Pitfall traps	Abundance, occupancy
Lakeland Downs Mouse (<i>Leggadina lakedownensis</i>)	Charnley Standard Live Trapping	Pitfall traps, Elliot traps	Abundance, occupancy
Delicate Mouse (<i>Pseudomys delicatulus</i>)	Charnley Standard Live Trapping	Pitfall traps, Elliot traps	Abundance, occupancy
Western Chestnut Mouse (<i>Pseudomys nanus</i>)	Charnley Standard Live Trapping	Pitfall traps, Elliot traps, cage traps	Abundance, occupancy
Pale Field Rat (<i>Rattus tunneyi</i>)	Charnley Standard Live Trapping	Pitfall traps, Elliot traps, cage traps	Abundance, occupancy
Small-medium rocky mammals			
Assemblage richness	All relevant small -medium rocky mammal surveys and incidentals	Various	Number of species
Small-medium rocky mammal guild (dasyurids, rodents)	Charnley Rocky Area Camera Array, Artesian Rocky Area Camera Array	Camera traps	Activity, richness
Echidna (<i>Tachyglossus aculeatus</i>)	Charnley Rocky Area Camera Array, Artesian Rocky Area Camera Array	Camera traps	Activity, occupancy
Ningbing False Antechinus (<i>Pseudantechinus ningbing</i>)	Charnley Rocky Area Camera Array, Artesian Rocky Area Camera Array	Camera traps	Activity, occupancy
Kimberley Rock Rat (<i>Zyomys woodward</i>)	Artesian Rocky Area Camera Array, Charnley Rocky Area Camera Array	Camera traps	Activity, occupancy
Macropods			
Assemblage richness	All relevant small macropod surveys and incidentals	Various	Number of species
Large macropod guild (Agile Wallaby, <i>Macropus agilis</i> , Antilopine / Common Wallaroo <i>Macropus antilopinus/robustus</i> , Northern Nail-tail Wallaby, <i>Onychogalea unguifera</i>)	Charnley Waterhole/Wetland Camera Array	Camera traps	Activity, richness
Short-eared Rock Wallaby (<i>Petrogale brachyotis</i>)	Charnley Rocky Area Camera Array, Artesian Rocky Area Camera Array	Camera traps	Activity, occupancy
Arboreal mammals			
Assemblage richness	All relevant arboreal mammal surveys and incidentals	Various	Number of species
Savanna Glider (<i>Petaurus ariel</i>)	Assess when effective/targeted method developed (<i>Charnley Arboreal Mammal Camera Array planned</i>)	Camera traps	Activity, occupancy
Rock Ringtail Possum (<i>Petropseudes dahli</i>)	Charnley Rocky Area Camera Array	Camera traps	Activity, occupancy
Wyulda (<i>Wyulda squamicaudata</i>)	Artesian Rocky Area Camera Array, Charnley Rocky Area Camera Array (<i>Charnley Arboreal Mammal Camera Array planned</i>)	Camera traps	Activity, occupancy
Golden-backed Tree-rat (<i>Mesembriomys macrurus</i>)	Artesian Rocky Area Camera Array	Camera traps	Activity, occupancy
Predators			
Dingo (<i>Canis lupis dingo</i>)	Charnley Rocky Area Camera Array, Charnley Waterhole/Wetland Camera Array, Artesian Rocky Area	Camera traps	Activity, occupancy

Indicator	Survey name (note multiple surveys may assess an indicator)	Survey method	Metric/s
	Camera Array (<i>and Charnley Predator Camera Array – redesign planned</i>)		
Birds			
Assemblage richness	All relevant bird surveys and incidentals	Various	Number of species
Lowland savanna birds			
Assemblage richness	All relevant lowland savanna bird surveys and incidentals	Various	Number of species
Savanna diurnal bird guild	Charnley Standard Diurnal Bird Survey	2 ha plot 20-min counts	Abundance, richness (separated by habitat and combined)
Reptiles			
Assemblage richness	All relevant reptile surveys and incidentals	Various	Number of species
Small lowland reptiles			
Assemblage richness	All relevant lowland small reptile surveys and incidentals	Various	Number of species
Lowland savanna small reptile guild (skinks, dragons, geckoes, flap-footed lizards, small snakes)	Charnley Standard Live Trapping	Pitfall traps, funnel traps	Abundance, richness (separated by habitat and combined)
Large reptiles			
Assemblage richness	All relevant large reptile surveys and incidentals	Various	Number of species
Rock monitor guild (Black-palmed Rock Monitor, <i>Varanus glebopalma</i> , Kimberly Rock Monitor, <i>Varanus glauerti</i> , and Spiny-tailed Monitor, <i>Varanus acanthurus</i>)	Charnley Rocky Area Camera Array, Artesian Rocky Area Camera Array (<i>Charnley Varanid Camera Array planned</i>)	Camera traps	Activity, richness
Freshwater Crocodiles (<i>Crocodylus johnsoni</i>)	Freshwater Crocodile Aerial Survey, spotlight transects	Aerial and spotlight transects	Density (/km)
Northern Blue-tongued Skink (<i>Tiliqua scincoides intermedia</i>)	Effective targeted and long-term survey method yet to be developed	Camera traps	Activity, occupancy

Vegetation indicators and surveillance species

Indicator	Survey name	Survey method	Metric/s
Vegetation			
Leaf litter	Charnley Standard Vegetation Survey	Transect point measurement (every 1m)	Density (% points surveyed)
Vegetation ground cover (tussock, hummock, vegetation <140cm combined)	Charnley Standard Vegetation Survey	Transect point measurement (every 1m)	Density (% points surveyed)
Total ground cover (leaf litter, vegetation ground cover, elevated dead debris combined)	Charnley Standard Vegetation Survey	Transect point measurement (every 1m)	Density (% points surveyed)
Canopy cover (trees/vegetation >140cm)	Charnley Standard Vegetation Survey	Transect point measurement (every 1m)	Density (% points surveyed)
Woody debris	Charnley Standard Vegetation Survey	Transect records per 100 m (continuous)	Density (records per 100 m)

Table 2. Threat indicators and metrics for CRAR.

Indicator	Survey name/methods	Metric/s	Performance criteria
Pest animals			
Feral cat (<i>Felis catus</i>)	Charnley Rocky Area Camera Array, Charnley Waterhole/Wetland Array, Artesian Rocky Area Camera Array (and planned Charnley Predator Camera Array - redesigned)	Activity, occupancy	TBD
Feral cattle (<i>Bos taurus</i>)	Feral Herbivore Aerial Surveys, Charnley Waterhole/Wetland Camera Array (and drone mapping and on-ground habitat assessments in development)	Density (head / km), population/density estimate (head / ha), occupancy, activity	TBD
Donkey (<i>Equus asinus</i>)	Feral Herbivore Aerial Surveys, Charnley Waterhole/Wetland Camera Array	Density (head / km), activity, occupancy	TBD
Horse (<i>Equus caballus</i>)	Feral Herbivore Aerial Surveys, Charnley Waterhole/Wetland Camera Array	Density (head / km), activity, occupancy	TBD
Pig (<i>Sus scrofa</i>) – associated with Feral Pig Management Strategy	Charnley Waterhole/Wetland Camera Array, Feral Herbivore Aerial Surveys (and drone mapping and on-ground habitat assessments in development)	Density (head / km), activity, occupancy	TBD
Cane toad (<i>Rhinella marina</i>)	Charnley Rocky Area Camera Array, Charnley Waterhole/Wetland Array, Artesian Rocky Area Camera Array	Distribution (extent of infestation)	TBD
Weeds			
Grader Grass (<i>Themeda quadrivalvis</i>)	Targeted Aerial Grader Grass Survey	Density (% area surveyed)	TBD
Other weeds	Regional methods in development	Distribution (extent of infestation), density	TBD
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 established surveys repeated on a schedule of 1-5 years, as required, to obtain timely information on each indicator. These include:

For key threatened and iconic vertebrates, a range of targeted surveys including:

- Artesian Northern Quoll Camera Array
- Artesian Black Grasswren Targeted Playback Survey

Note that some threatened and iconic species are assessed by some of the assemblage surveillance monitoring surveys listed below (Table 1)

For assemblages and surveillance species, these include:

- Charnley Standard Live Trapping
- Charnley Rocky Area Camera Array
- Artesian Rocky Area Camera Array
- Charnley Waterhole/Wetland Camera Array
- Charnley Savanna Standard Diurnal Bird Survey
- Charnley Standard Vegetation Survey
- Freshwater Crocodile Aerial Survey

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

- Feral Herbivore Aerial Survey
- Grader Grass Aerial Survey

Note that several surveys listed above, which survey biodiversity assemblages, also survey threats (Table 2).

Non-standardised, opportunistic, and inventory surveys, and incidental observations (e.g., spotlighting surveys, incidental sightings) are not considered repeatable to obtain Ecohealth metrics but will continue to be used to enhance inventory and to assess overarching species detectability and persistence on CRAR.

Standardised Ecohealth surveys (e.g., Standard Live Trapping) date back to 2016 on Charnley, with several preliminary surveys undertaken in the few years prior. Though AWC has been conducting inventory surveys and ecological research in the Artesian Range since 2012 (Legge et al. 2013, Hohnen 2015, Hohnen et al. 2015, 2016b, a), standardised Ecohealth surveys in the Artesian only commenced in 2021. Several surveys that were trialed in previous years (e.g., pilot 2019 Varanid Camera Array, pilot 2019 Possum Camera Array, 2017-2019 Charnley Predator Camera Array) and in 2021 (e.g., Artesian Standard Live Trapping, Artesian Diurnal Bird Surveys) and that will not continue (or will undergo significant redesign) as part of long term Ecohealth monitoring, are also not presented in this report and are instead presented in relevant internal survey reports.

Nine of the established Ecohealth surveys were conducted at CRAR Wildlife Sanctuary in 2021 (Table 3). The Fire Scar Analysis has been completed using satellite data from 2000 (8 years prior to AWC management) 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 Charnley River – Artesian Range Wildlife Sanctuary reported on in this report. TN = Trap nights.

Survey name	Effort (2021)	Description/comment	Previous surveys
Artesian Northern Quoll Camera Array	3,360 (TN)	120 cameras across 8 sites (12 cameras at 6 sites and 24 at 2 sites for 28 nights each), involves 3 camera formations (see Figure 5) with 4 sites deployed in 3 x 4 grid with cameras 200 m apart.	2020-120 cameras, 8 sites (3,360 TN) 2019-120 cameras, 8 sites (2,920 TN)

Survey name	Effort (2021)	Description/comment	Previous surveys
Artesian Black Grasswren Targeted Playback Survey	9 km of transects	At each site (n=9), two fixed 500 m transects through suitable rocky Black Grasswren habitat, conducting call playback and recording habitat variables every 100 m.	
Charnley Standard Live Trapping	4,071 (TN)	34 trapping sites each surveyed with 8 pitfall, 20 Elliot, 4 cage and 8 funnel traps, stratified across four habitat types. Each site was trapped for 3 consecutive nights.	2020 – 34 sites (4,067 TN) 2019 – 34 sites (4,007 TN) 2017 – 26 sites (3,111 TN) 2016 – 18 sites (2,152 TN)
Charnley Rocky Area Camera Array	2,800 (TN)	100 cameras across 20 sites (5 cameras per site), spaced 150-200 m apart for 28 TN each.	2020 – 100 cameras, 20 sites (2,800 TN)
Artesian Rocky Area Camera Array	1,642 (TN)	60 cameras across 12 sites (5 cameras per site), spaced 100-200 m apart for 28 TN each.	
Charnley Waterhole/Wetland Camera Array	784 (TN)	56 cameras across 12 sites (5 cameras at 10 sites and 3 at 2 wetland sites), spaced as evenly as possible at permanent water sites for 14 TN each.	Not comparable with previous Waterhole Camera Array
Charnley Savanna Diurnal Bird Survey	34 sites; 28 sites surveyed 2 mornings and 6 sites 3 mornings (74 surveys)	2-ha 20 min surveys at 34 Charnley Standard Live Trapping sites on 2-3 mornings at each site.	2020 – 34 sites; 34 sites surveyed 2 mornings 2019 – 34 sites; 1 site 4 mornings, 18 sites 3 mornings, 15 sites 2 mornings, 2 sites 1 morning
Charnley Standard Vegetation Survey	34 sites (10.2 km of transects)	300 m point-measurements of ground and canopy cover surveyed at the 34 Charnley Standard Live Trapping sites.	2020 – 34 sites 2019 – 34 sites
Feral Herbivore Aerial Survey	438 km transect	438 km aerial transect survey (slightly revised from original transect to encompass portion of SE Charnley). Although the exact flight path has varied slightly year to year since 2016, the flight paths are comparable overall, covering the same regions of CRAR.	2020 – 360 km 2019 – 422 km 2018 – 398 km 2016 – 396 km

Survey design and methods

Targeted threatened and iconic species surveys

Artesian Northern Quoll Camera Array

For several years, Northern Quolls have been monitored at sites (of multiple habitat type) across the Artesian Range and Sub-Artesian Range using camera arrays, in addition to trialling cane toad Condition Taste Aversion (CTA), which proved unsuccessful (Wilson et al. 2020). The 2020-2021 Camera Array involved eight sites, which were also monitored during the 2018-2019 and 2019-2020 wet seasons (December-January) pre-cane toad arrival, using a standardised survey design. The survey involved three different camera formations: i) four sites with 12 cameras in a grid formation; ii) two sites along creeks with 12 cameras as a linear transect; and iii) two sites containing 24 cameras at 'intensive sites' (Figure 5). All eight sites were surveyed between December 2020 and January 2021 over 28 trap nights. Cameras were positioned facing downwards at a 45° angle towards a generous smear of bait as per the AWC standard camera trapping procedure. Cameras were set to five images per trigger, Rapidfire™ mode, no delay between triggers, and high sensitivity. Dorsal spot patterns were used to differentiate individuals.

This targeted survey was in response to the cane toad front advancing from the east, with the Artesian Range likely the last region on CRAR Wildlife Sanctuary to be invaded. The 2018-2019 and 2019-2020 Artesian

surveys provide a pre-toad baseline for quoll abundance and density - the recent 2020-2021 survey is the first survey in the Artesian with cane toads now established in the landscape. The impact this has had and will continue to have on the persistence of the Northern Quoll in the Artesian Range will be monitored by AWC, with initial results presented in this report.

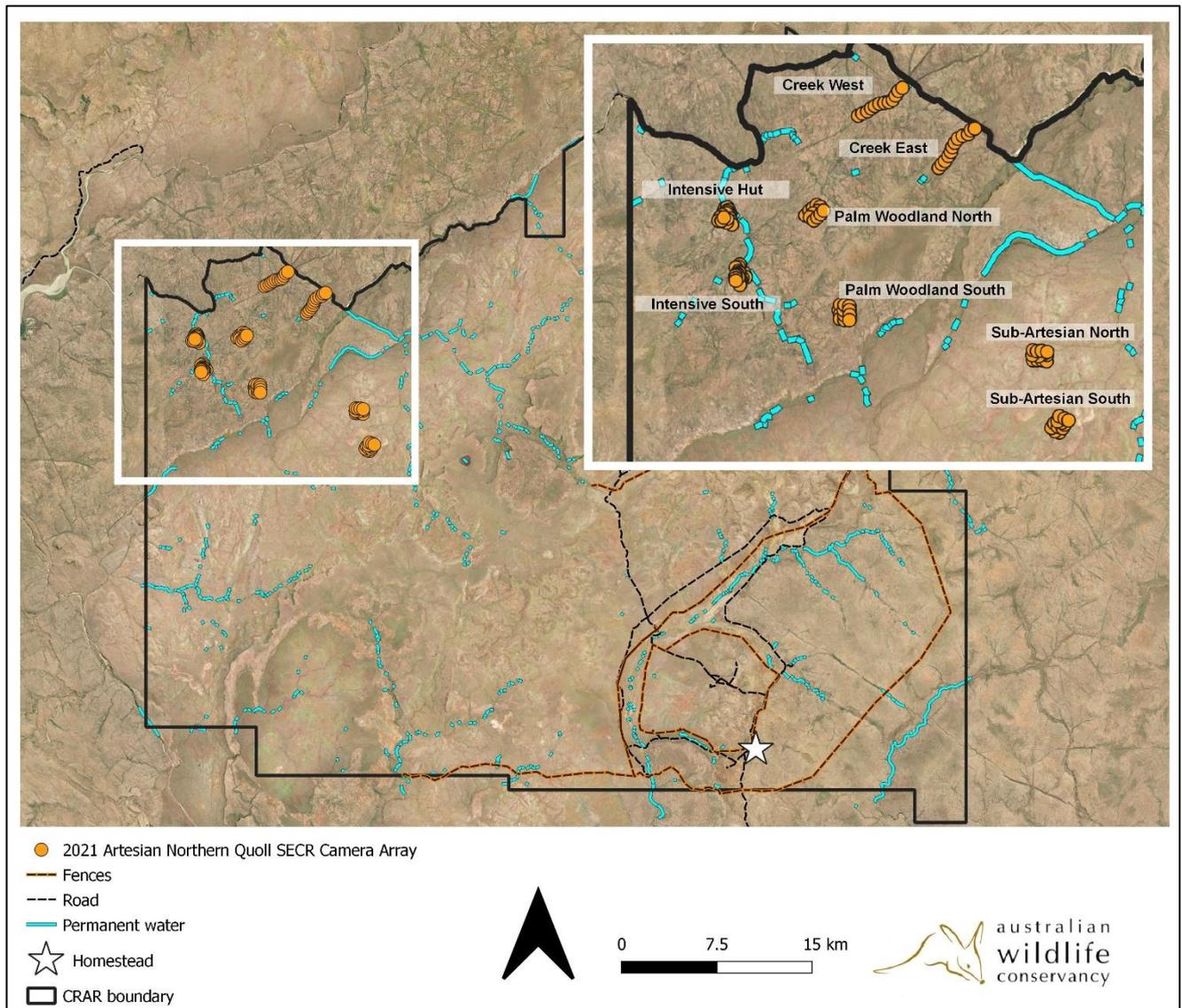


Figure 5. Northern Quoll Camera Array (8 sites) in the Artesian Range and Sub-Artesian, on Charnley River – Artesian Range Wildlife Sanctuary.

Artesian Black Grasswren Targeted Playback Survey

To assess the occupancy and activity of Black Grasswrens (*Amytornis housei*) in the Artesian Range, targeted playback surveys were undertaken at nine Ecohealth sites (Palm Woodland North, Palm Woodland South, Creek East, Creek West, Intensive Hut, Intensive South, Rainforest East, Rainforest West, and Charnley River West) along standardised transects (refer to Figure 9 for site locations). Surveys were not conducted at either of the Sub-Artesian sites or at Charnley River East due to unsuitability of habitat. At each survey site, two 500 m transects were selected consisting of suitable Black Grasswren habitat. Along each transect six call playbacks (from the starting point and every 100 m) were undertaken for 30 seconds each, waiting and listening 2 minutes each time for Black Grasswren calls/responses. Black Grasswrens were also searched and listened for across the entire transect and when detected recorded on GPS (recording the number of individuals if possible). It is predicted that this species is likely to occur across rugged landscapes where abundant vegetation cover is available. Both targeted playback surveys and camera trapping arrays intend be used to monitor Black Grasswren persistence in the Artesian Range going forward.

Live trapping surveys

Charnley Standard Live Trapping

In central and eastern Charnley, the Standard Live Trapping Survey is restricted to lowland landscapes in which a pitfall trap can be installed. This survey targets small lowland mammal and reptile assemblages. In 2021, from mid-July to late-August, 34 sites were surveyed over three days each across four main habitat types: Blacksoil (n = 6), Riparian (n = 10), Sandseep (n = 5) and Woodland (n = 13), based on a combination of soil, vegetation types, and tenure (stocked and destocked; Figure 6, Table 4). As much as practical, sites are spread out across Charnley despite some logistical and accessibility limitations. Note that the 2021 survey replicated the 2020 survey, but there are some differences in the number and/or location of survey sites in 2016-2019 as the survey became more established (Table 3). As such, survey effort has been accounted for when comparing abundance across years to improve comparability.

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 7). Riparian sites are deployed differently to keep within the riparian habitat, which is more linear in configuration (20 m x 80 m; Figure 7). Elliot and cage traps were baited with the standard bait of peanut butter, oat mix 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, respectively).

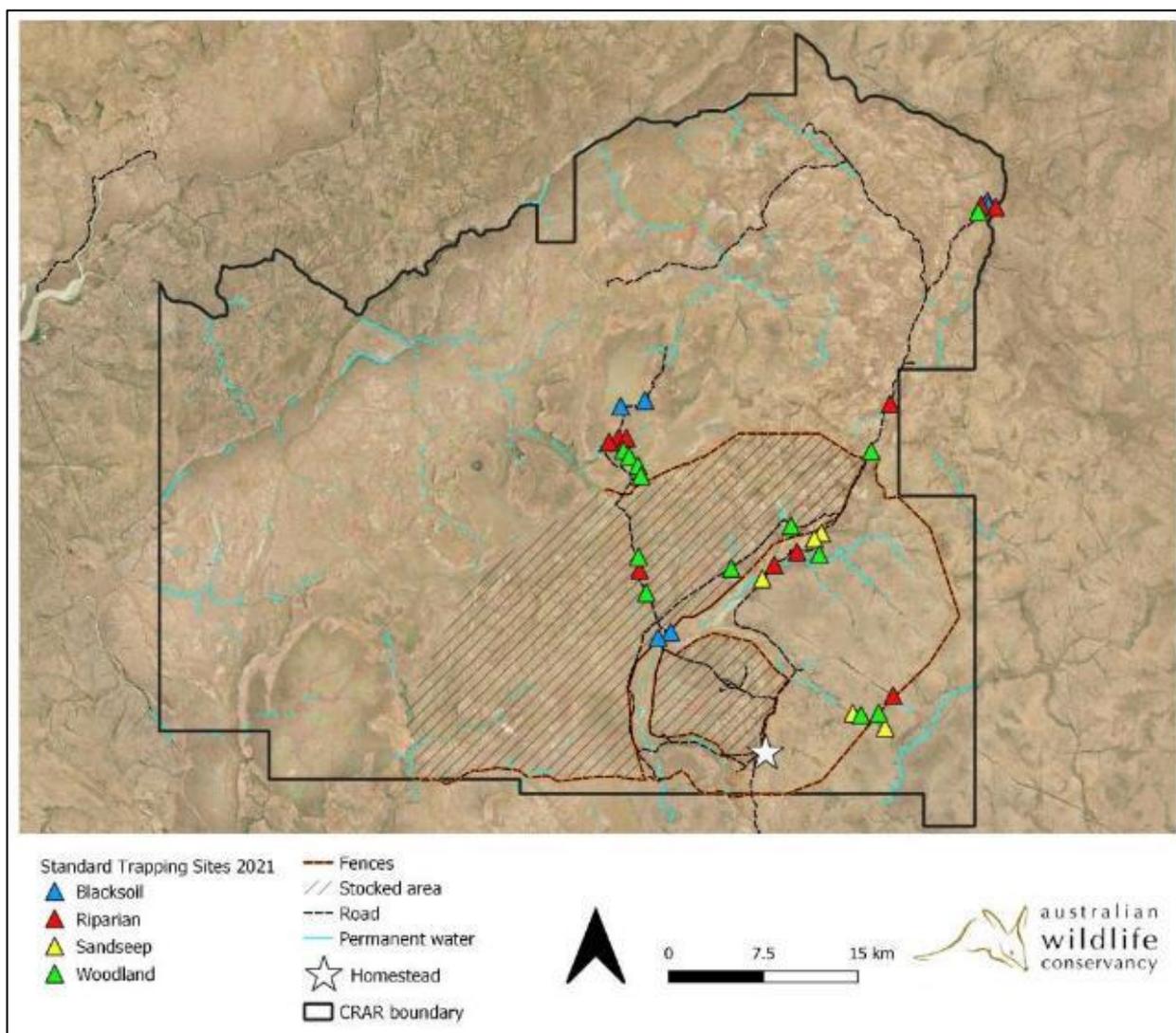


Figure 6. Standard Live Trapping sites across the four habitat types on eastern Charnley with stocked area shown: Blacksoil (n = 6), Riparian (n = 10), Sandseep (n = 5), and Woodland (n = 13).

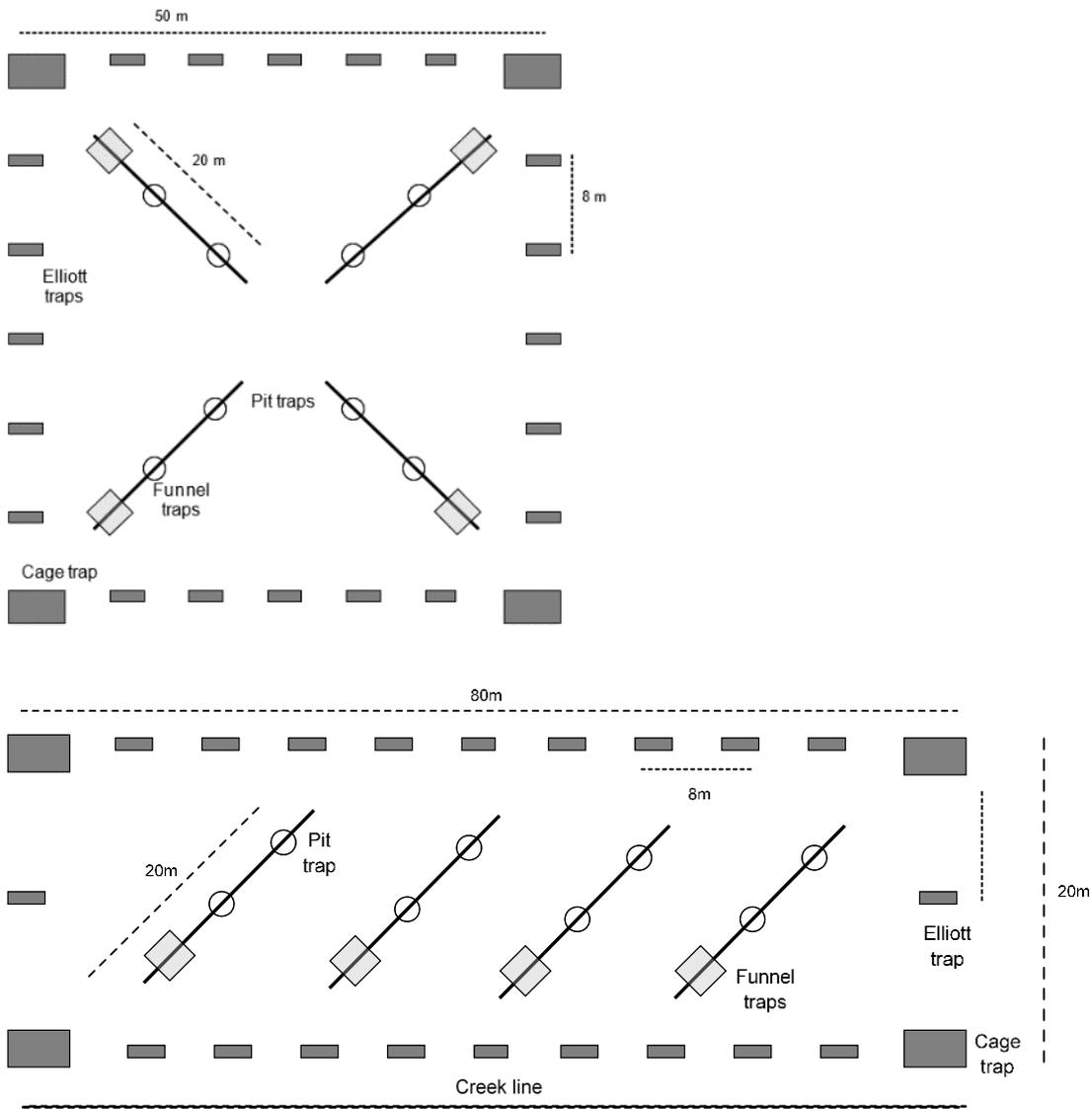


Figure 7. Site schematic for Standard Live Trapping sites (top) and Riparian habitat sites (bottom). Each site is 50 x 50 m (20 x 80 m for Riparian), with 4 cage traps, 20 Elliott traps, 8 pitfall traps and 8 funnel traps.

Table 4. Description of Standard Live Trapping site stratification (habitat types) in eastern Charnley.

Habitat	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 <i>Vachellia suberosa</i> .	6
Riparian	Riparian vegetation along waterways on alluvium soils. Typically, with <i>Melaleuca/Lophostemon/Ficus/Terminalia</i> overstorey, <i>Pandanus/Sesbania</i> midstorey and often with dense grassy ground layer.	10
Sandseep	Periodically inundated sandy soils at the base of sandstone ranges. Typically dominated by <i>Grevillea/Acacia/Banksia</i> overstorey and matted <i>Chrysopogon/ Triodia</i> ground layer.	5
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 <i>Eucalyptus tectifica</i> overstorey and <i>Sehima nervosum</i> ground layer, or complex with <i>Eucalyptus miniata/Corymbia</i> overstorey, a wide range of fruiting mid-storey trees and a diverse ground layer.	13
Total		34

Camera surveys

Remote sensor camera arrays (Reconyx PC850 and PC800 Hyperfire white flash camera traps) are generally intended as broad-spectrum surveys, with cameras set to standard AWC Kimberley specifications - five images per trigger, Rapidfire™ mode, no delay between triggers, and high sensitivity. A large camera array will typically be useful for monitoring a variety of indicator species (Table 1, Table 2). All camera arrays on CRAR are designed to survey the major habitats (e.g., rocky habitats, waterholes, refugial pockets, and roads) and species that are not suited to live trapping. In 2021, Ecohealth camera trap surveys were conducted at rocky areas at both Charnley and Artesian, involving the Charnley Rocky Area Camera Array, the new Artesian Rocky Area Camera Array, and the targeted Artesian Northern Quoll Camera Array (outlined above). Cameras were also deployed at waterholes and wetlands in the newly designed Charnley Waterhole/Wetland Camera Array. Unless otherwise noted, all cameras were set to the standard NW specifications (as described above).

Charnley Rocky Area Camera Array

Charnley Rocky Area cameras were deployed at 20 sites across central and eastern Charnley in July 2021 and collected in August 2021 (Figure 8), which replicated the 2020 deployment, and marks the second year of the standardised Rocky Area Array. Five cameras were deployed at each site (totalling 100 cameras) for 28 nights. All cameras were spaced approximately 150-200 m apart within each site and set 1.5 m above the ground facing downwards at a 45° angle towards a generous smear of bait.

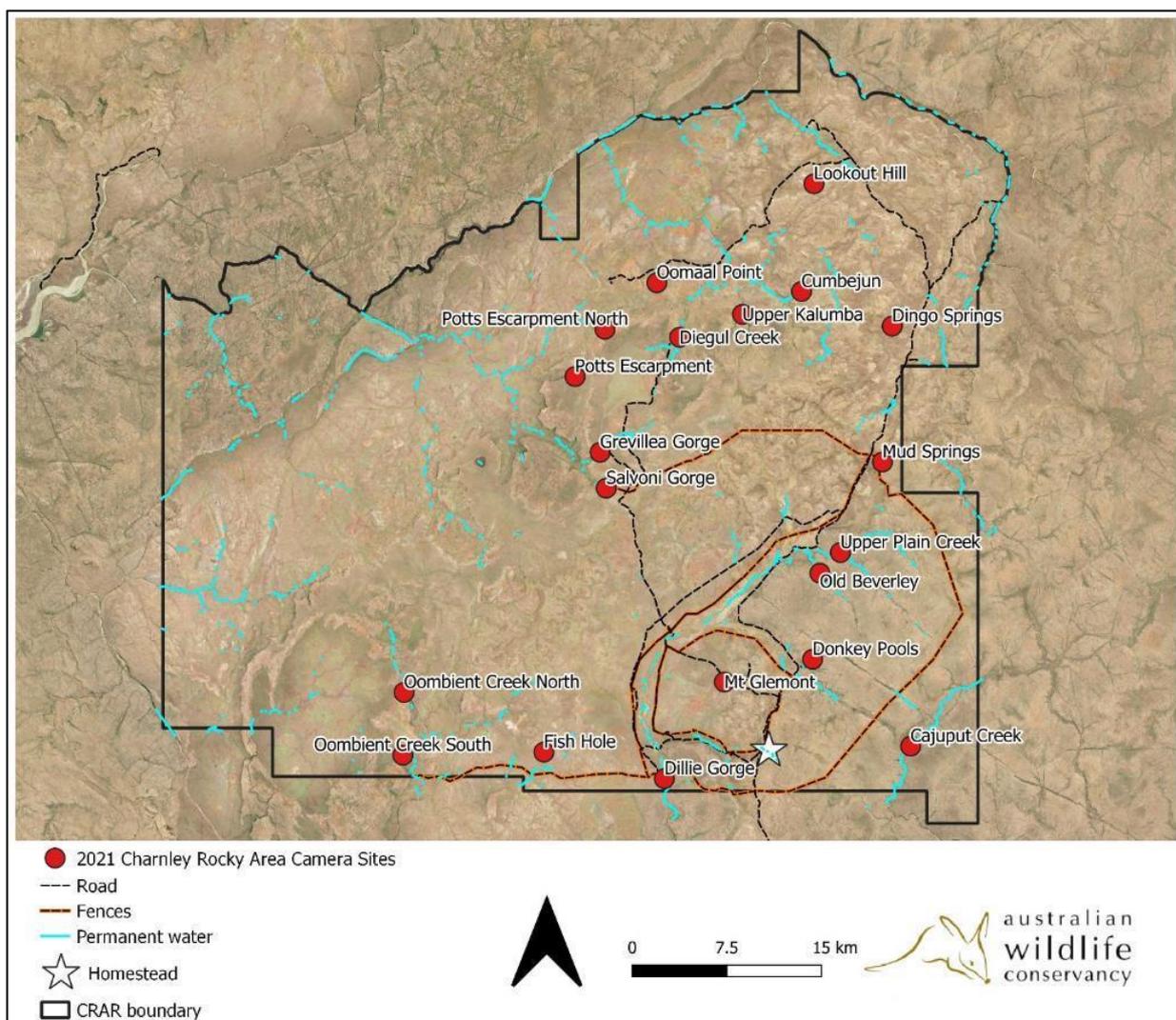


Figure 8. Charnley Rocky Area Camera Array (20 sites) on Charnley River – Artesian Range Wildlife Sanctuary.

Artesian Rocky Area Camera Array

The first standardised Ecohealth Artesian Rocky Area Array was undertaken in the Artesian Range and Sub-Artesian in February-March 2021 and succeeds the more targeted Artesian Northern Quoll Camera Array as

the general surveillance method for indicator assemblages and threats in the region. The Artesian Rocky Area Array is comparable to the established Charnley Rocky Area Camera Array (5 cameras per site) and was designed to assess the persistence of indicator assemblages and threatened and declining fauna (largely mammals) using standardised and repeatable methods. Several species found on CRAR are restricted to the Artesian Range (e.g., Monjon/Nabarlek) and/or are detected in higher abundance (e.g., Bandicoot, Wyulda, Northern Quoll) compared to the other rocky and lowland regions on CRAR.

A total of 12 sites were chosen for Ecohealth monitoring in the Artesian across six different habitat types: Rocky, Palm Woodland, Rocky Gorge, Sub-Artesian, Rainforest, and Charnley River (Figure 9). Note that eight of these sites (excluding Rainforest West and East, and Charnley River West and East) are also surveyed in the Targeted Artesian Northern Quoll Camera Array (Figure 5). Five cameras were deployed at each site for 28 nights, totalling 1,680 trap-nights. All cameras were spaced approximately 100-200 m apart within each site and set 1.5 m above the ground facing downwards at a 45° angle towards a generous smear of bait.

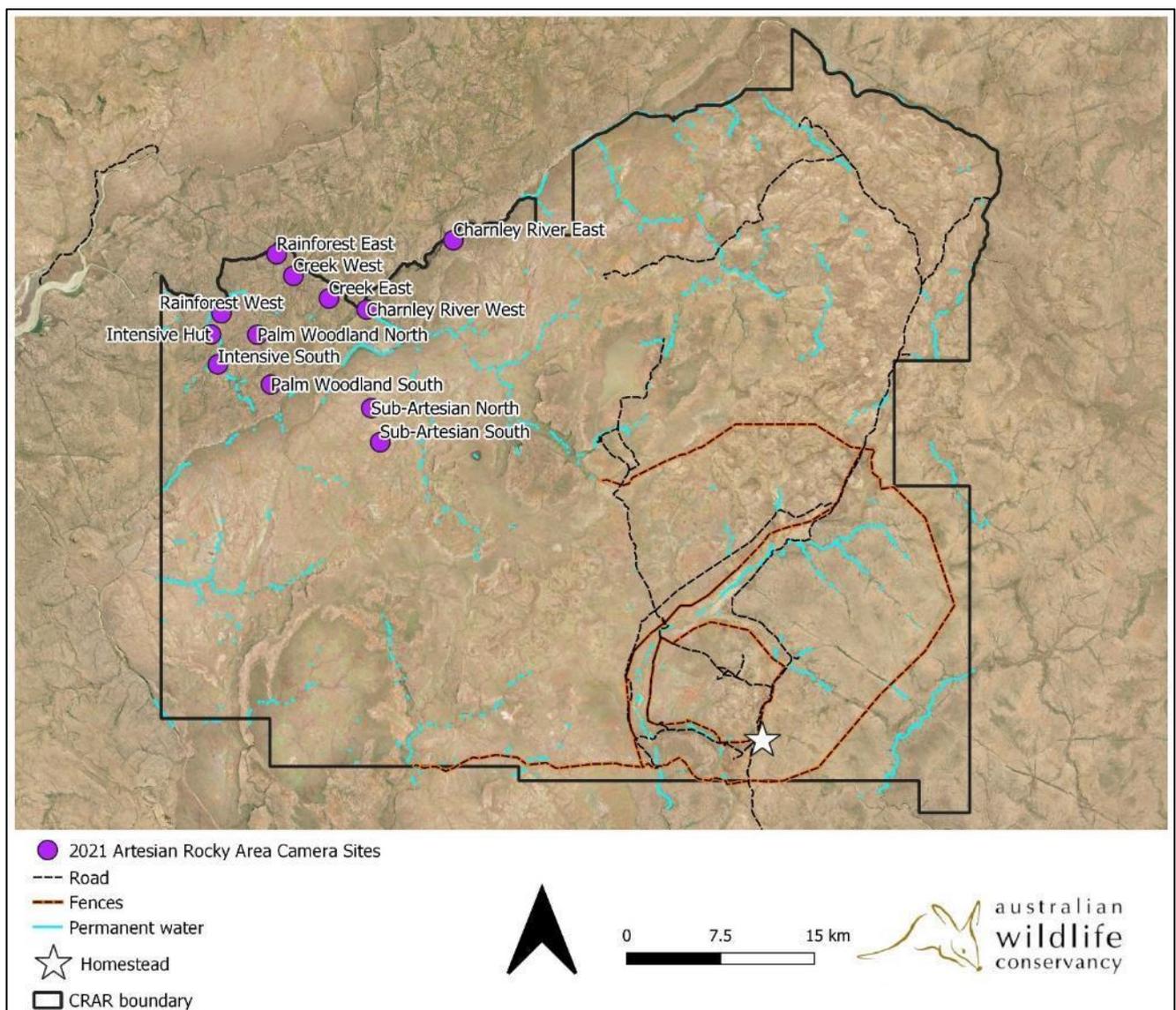


Figure 9. Artesian Rocky Area Camera Array (12 sites) on Charnley River – Artesian Range Wildlife Sanctuary.

Charnley Waterhole/Wetland Camera Array

Waterhole/wetland cameras were deployed at 12 Waterhole, Riparian, or Wetland sites across eastern Charnley in October 2021 (Figure 10). Cameras were set prior to significant rainfall, as this is when fauna are likely to be more restricted to water sources. The 2021 array replicated the locations of all 10 sites in the 2020 Waterhole Camera Array, but the exact locations of each camera at these sites differed, due to differences in the remaining surface water in the late dry season, and changes to the overall aim of the survey. Historically

the Waterhole Array was trialled to monitor finch and quail persistence (tailored camera deployment closer to the ground), however future arrays will be used as part of an ongoing management plan to monitor the persistence of feral pigs on Charnley (as part of the CRAR Feral Pig Management Framework), and other biodiversity indicators and threats not readily detected by other surveys (Table 1, Table 2). Two additional sites were added to the array in 2021 (Lake Gilbert and Lake Doherty) to assess the prevalence of pigs and other feral herbivores in these highland wetlands.

Cameras were deployed the 12 sites for 14 trap nights (five cameras at 10 sites) and three cameras at the two trial sites (Lake Gilbert, and Lake Doherty), totalling 784 trap nights. All cameras were deployed considering the suitability of each site for feral pigs and other biodiversity and threat indicators and the location of permanent water. Unbaited cameras were set adjacent to the water resource (5 – 10 metres away) with a slight angle (around 30°).

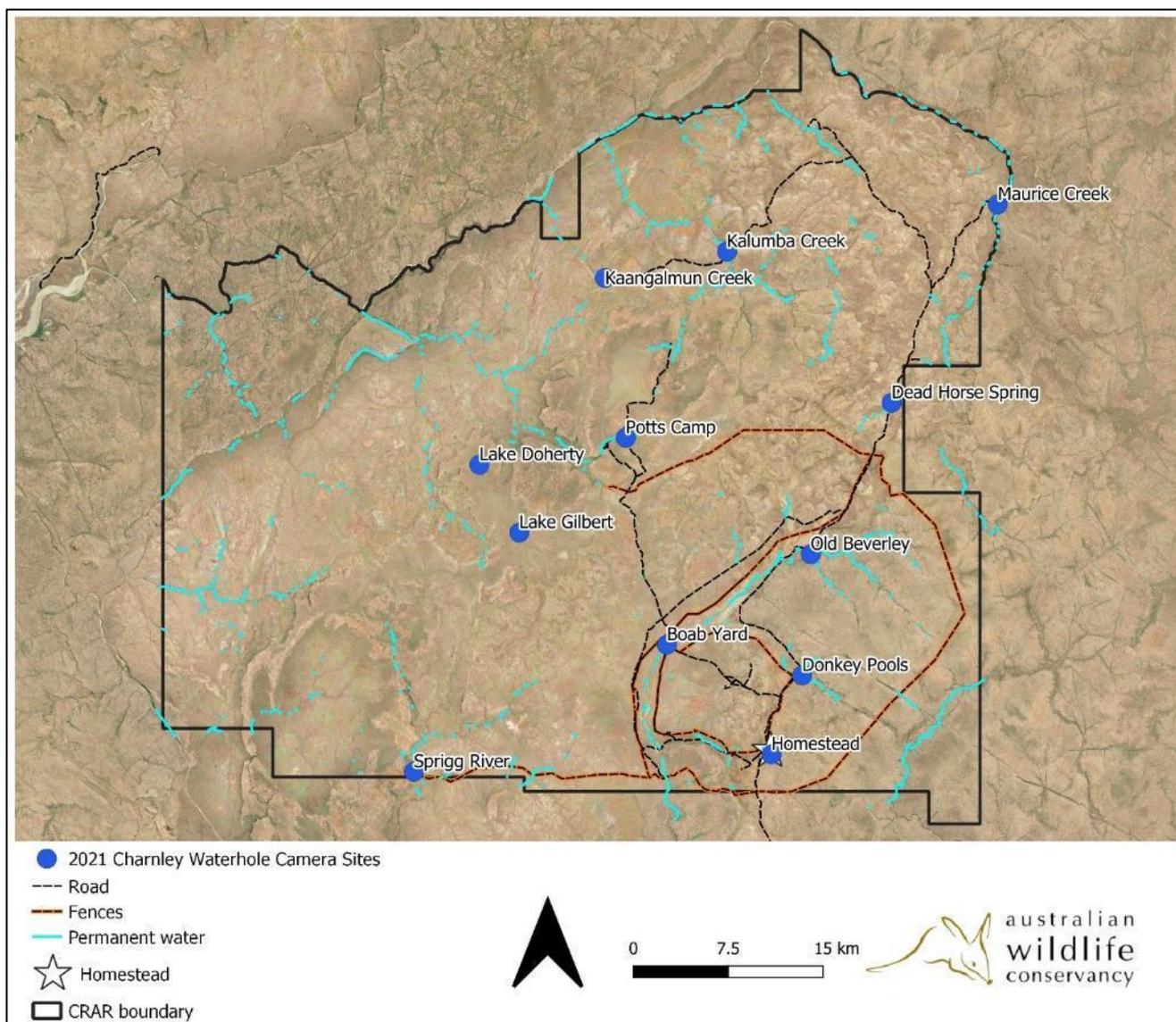


Figure 10. Waterhole/Wetland Camera Array (12 sites) on Charnley River – Artesian Range Wildlife Sanctuary.

Charnley Savanna Diurnal Bird Survey

Each of the 34 Standard Live Trapping sites were surveyed for savanna diurnal birds concurrent to live-trapping on 2-3 consecutive mornings (Figure 6). This survey has been undertaken annually in this standardised manner since 2019. A total of 74 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 (but within the same habitat type). Charnley Savanna Diurnal 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.

Charnley Standard Vegetation Survey

The Standard Vegetation Structure Survey was conducted at each of the 34 Standard Live Trapping sites for the third consecutive year, using three 100 m transects set up within each site (Figure 6). 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 recorded 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 monitor changes in vegetation and habitat structure in major habitat types on CRAR and responses to land management activities and environmental change. In addition, vegetation survey data provides covariates for interpreting Standard Live Trapping data.

Feral Herbivore Aerial Survey

Large, introduced herbivores such as feral cattle, horses (*Equus caballus*), donkeys (*Equus asinus*), 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. 2011a). 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). As such, their impact has been managed and monitored by AWC, particularly in the destocked area of CRAR Wildlife Sanctuary which comprise areas of high ecological significance.

The annual Feral Herbivore Aerial Survey was undertaken in mid-November 2021 based on a slightly revised flight path (revised from 2020 version) to include more of Plain Creek and southeast Charnley (highlighted by white polygon in Figure 11). The exact flight path has varied slightly year to year since 2016, however results are comparable overall, covering the same regions of CRAR. The 2021 survey was undertaken shortly before the feral herbivore aerial cull and prior to significant rainfall on CRAR and covered approximately 420 km of CRAR taking approximately five hours to complete. The standard flight path is flown each year 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 noted whether they were inside or outside a 45° angle from vertical (this gives an 'inside' transect width of 200 m). Cattle is by far the greatest threat on CRAR assessed by this survey, and is also the only large feral observed in high enough abundance to be used to meaningfully calculate estimates. For cattle only, this data generates raw cattle density metrics, from which population and density estimates can be derived by extrapolating cattle density to areas 2 km from permanent water on the property.

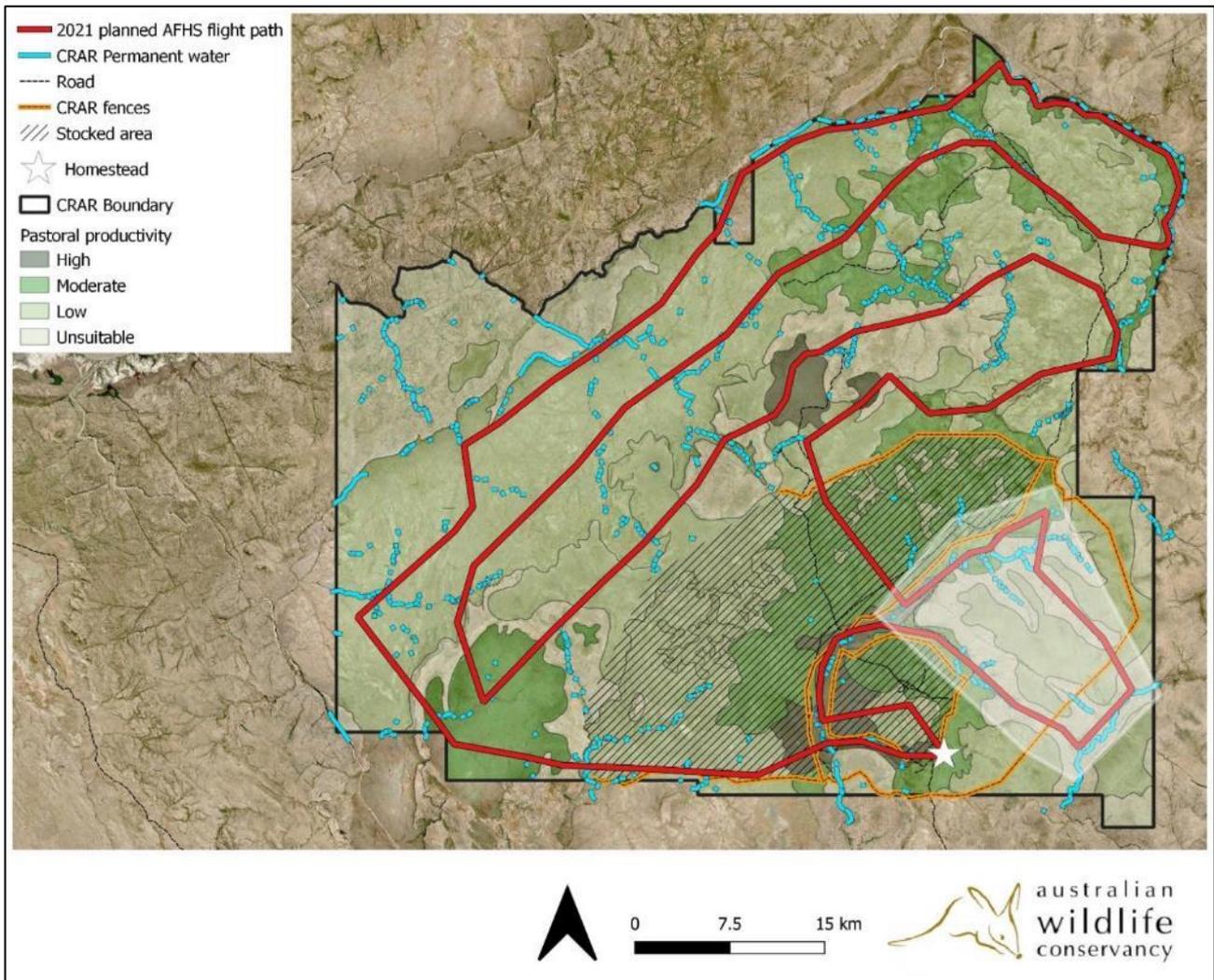


Figure 11. Feral Herbivore Aerial Survey flight path on Charnley River – Artesian Range Wildlife Sanctuary, showing pastoral productivity underlay. The white polygon highlights the addition made to the flight path in 2021 which historically excluded south-east Charnley.

Analysis methods

Most Ecohealth metrics are common across the indicator species and guilds for CRAR Wildlife Sanctuary. Unless noted otherwise in the results section, most metrics are calculated as set out in Table 5 below.

Table 5. Metrics and associated calculations for Charnley River – Artesian Range Wildlife Sanctuary.

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.
Mammals, reptiles	Abundance	Standard Live Trapping Camera traps (only when individuals are identified)	A measure of abundance where individual animals are identified; the number of individuals per 100 TN or per standard	Per 100 trap nights: For individual species: Calculate the average abundance (per 100 TN) for that species across all survey sites and/or within habitat type. Average of: (total number of

Indicator	Metric	Survey data sources	Description	Analysis summary/ calculation
			<p>survey (accounts for survey effort).</p> <p>Involves the number of individuals captured or observed in live trapping data and bird surveys, respectively; and number of individuals, <u>not detections/visits</u>, identified by camera traps.</p>	<p>individuals recorded at survey site / total number of trap nights at each survey site x 100).</p> <p>For guilds: Calculate the average abundance (per 100 TN) of all individuals in the guild across all survey sites and/or within habitat type. Average of: (total number of individuals of the guild recorded at survey site/ total number of trap nights at each survey site x 100).</p> <p>For live trapping, trap nights are only included where a trap type targets the indicator appropriately (see Table 1). For example, funnel trap nights are excluded for small to medium-sized mammal guild, and cage and Elliott traps are excluded for the small reptile guild.</p> <p>Note - when determining live trapping survey effort, although pitfall and funnel traps were each set and checked 5 times per survey (3 morning and 2 evening checks), each trap deployed resulted in 3 sampling units or 'TN' based on trap night convention (for mammal and reptile analyses). Incidentals and recaptured individuals were also removed prior to analyses.</p> <p>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 were removed prior to analyses).</p>
Birds		Charnley Savanna Diurnal Bird Survey		<p>Per standard survey: For guilds: Calculate the no. individuals (abundance) observed per survey morning, and average across all sites and/or within habitat type.</p>

Indicator	Metric	Survey data sources	Description	Analysis summary/ calculation
				Flyovers were excluded from analyses.
Mammals, reptiles, threats	Activity	Camera traps	<p>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 visits by the same individual (i.e., the majority of species cannot be identified to individual animals in camera trap images due to a lack of distinguishing features).</p> <p>In a sequence of images of a single species, a single camera 'visit' is defined as occurring when there is at least a 5 minute period between the species' last capture and subsequent image.</p>	<p>Per 100 trap nights: For individual species: Calculate the average visits (per 100 TN) for that species across all survey sites and/or habitat. Average of: (total number of individuals recorded at survey site / total number of trap nights at each survey site x 100).</p> <p>For guilds: Calculate the average visits (per 100 TN) of all individuals in the guild across all survey sites and/or within habitat. Average of: (total number of individuals of the guild recorded at survey site/ total number of trap nights at each survey site x 100).</p> <p>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 were removed prior to analyses).</p>
Mammals, reptiles, birds	Richness	Standard Live Trapping Survey	<p>A measure of raw species diversity for indicator guilds; average number of species per site or survey</p> <p>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.</p>	<p>Total number of species captured per site averaged across all survey sites/or within habitat.</p> <p>For live trapping incidentals and recaptured individuals were removed prior to analyses.</p>
		Camera trap		<p>Total number of species detected per site averaged across all survey sites.</p> <p>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 were removed prior to analyses).</p>
		Charnley Savanna Diurnal Bird Survey		<p>Total number of species observed during each standard survey averaged across all</p>

Indicator	Metric	Survey data sources	Description	Analysis summary/ calculation
				survey sites and/or within habitat. Flyovers were excluded from analyses.
Feral herbivores, vegetation	Density	Various	The number of detections per unit distance or area, sometimes expressed as proportion of area surveyed.	Generally specific to each metric when used, see additional information on density metrics in results.
Feral herbivores	Population and density estimate	Aerial survey	Estimation of population size and density based on data extrapolation.	Population and density estimates are derived by extrapolating raw count data (cattle observed within 45° towards ground from chopper) to areas 2 km from permanent water on the property following a standard procedure and data assumptions. Estimated head of cattle = raw count / survey area (ha) * area within 2 km of permanent water (ha). Density estimate = cattle head estimate / area within 2 km of permanent water (ha). Based on cattle density estimate.

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. Each scar was attributed by year, month, and season. Fire scars detected from January to July (inclusive) were attributed as 'Early', whereas those detected August to December were attributed as 'Late'. For each year, unburnt areas were created by erasing the recorded fires from the entire boundary area. 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. Detailed methods are provided in Webb et al. (2022).

Results

Threatened and iconic species

Northern Quoll

The endangered (EPBC listed) Northern Quoll is readily detected and monitored by all three of the Ecohealth camera arrays on CRAR (i.e., Artesian Northern Quoll Camera Array, Charnley Rocky Area Camera Array, and Artesian Rocky Camera Array). The Artesian Northern Quoll Camera Array showed an abundance score of 0.8 relative to a consistent average of 1.9 and 2.0 individual quolls per 100 TN during the 2018-2019 and 2019-2020 wet seasons – which translates to a 58% decline from pre cane toad levels (Figure 12, Figure 13). The total number of individual quolls identified in the 2018-2019, 2019-2020, and 2020-2021 wet seasons were

52, 59, and 22, respectively. Occupancy also declined in 2020-2021 (75%), compared to 2018-2019 and 2019-2020 results (both 100%).

The Charnley Rocky Area Camera Array results demonstrated that the activity of Northern Quolls in 2021 (2.64/100TN) has declined compared to 2020 (4.5/100TN). However, the occupancy increased to 30% of the 20 rocky area sites from 20% in 2020, with Northern Quolls recorded at two additional sites in 2021 (Figure 12). The Artesian Rocky Camera Array results showed the activity of quolls to be 4.45/100TN, with detections at 67% of the 12 sites (Figure 12).

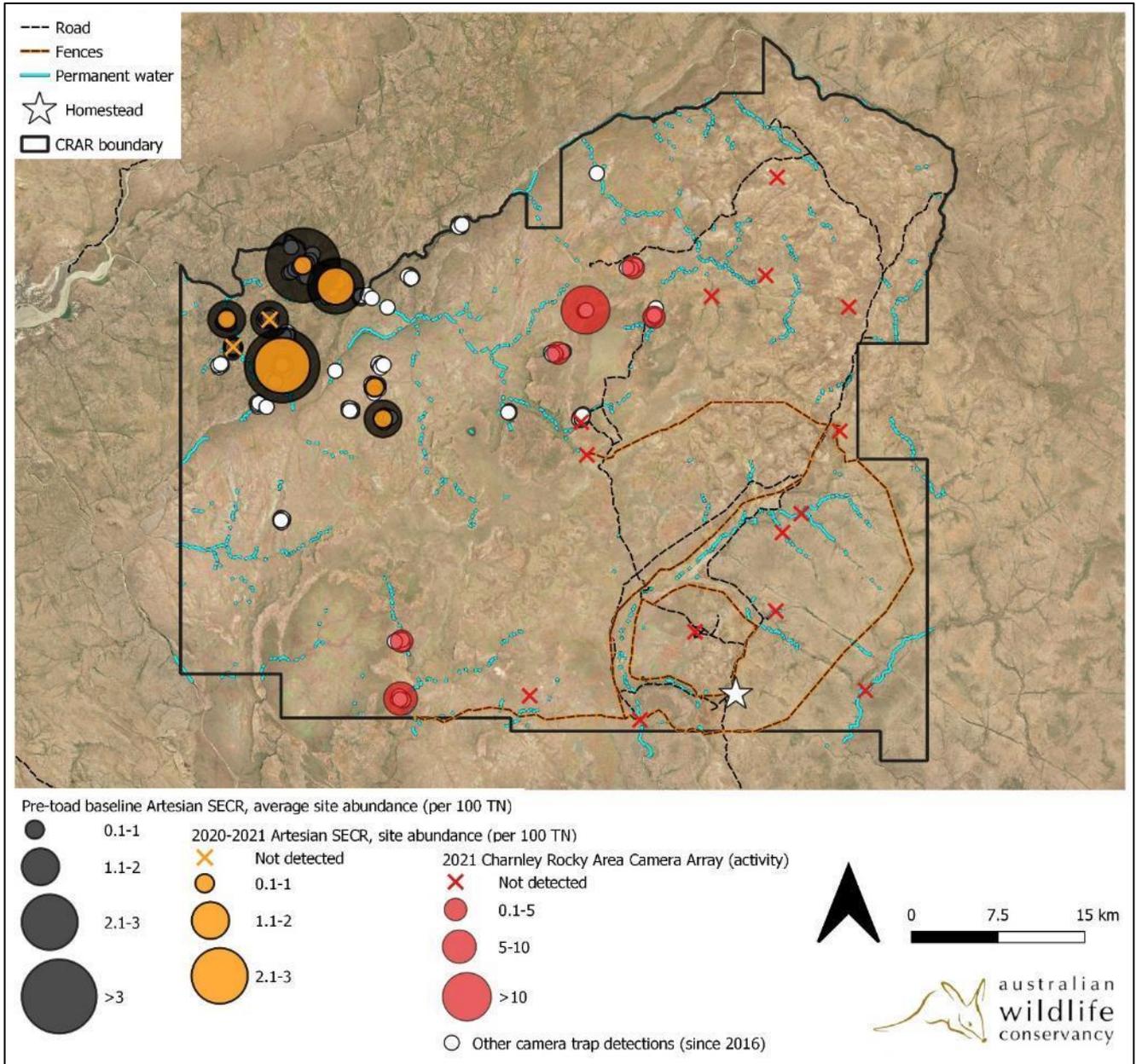


Figure 12. Northern Quoll abundance and activity from the 2021 Artesian Northern Quoll Camera Array and Charnley Rocky Area Camera Array, respectively. Average Northern Quoll abundance per site from the 2018-2019 and 2019-2020 wet season is also presented to visualise the pre-toad baseline in the Artesian Range.

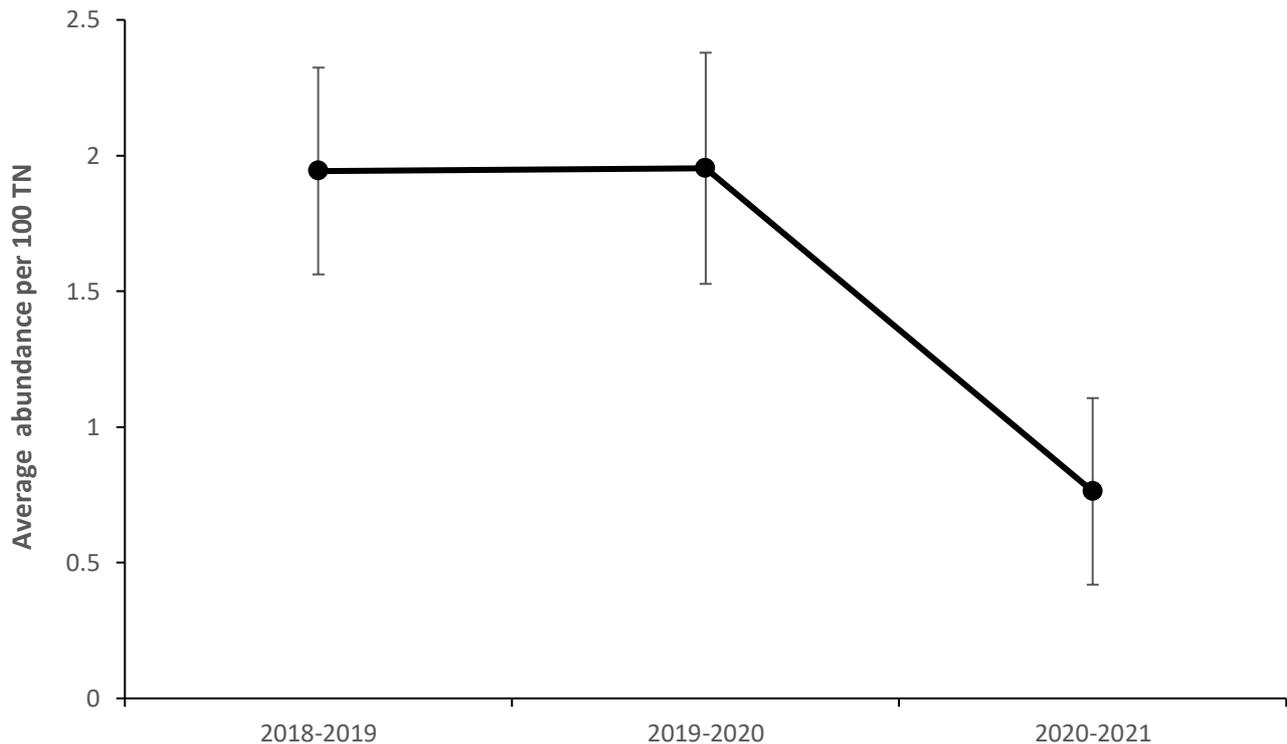


Figure 13. Northern Quoll average site abundance (individuals per 100 trap nights (TN)) in the Artesian Range pre and post cane toad arrival (in 2020) from the Artesian Northern Quoll Camera Array. The analysis included only individual quolls identified within the standard survey period (28 TN) and uncertain identifications (i.e., blurry images of quolls, 2019-2020 – 9 unknown images, 2020-2021 – 1 unknown image) were excluded (error bars represent \pm SE).

Northern Brown and Golden Bandicoots

Northern Brown and Golden Bandicoots (the latter listed as vulnerable, EPBC) are currently monitored by the Charnley Rocky Camera Array and the Artesian Rocky Camera Array and are not readily detected by other established Ecohealth surveys on CRAR Wildlife Sanctuary. Bandicoots have been detected and captured across CRAR since 2014 with most activity and highest occupancy in the Artesian Range (Figure 14). The 2021 Rocky Camera Arrays illustrate their high relative occupancy in the Artesian Range and their occurrence in some refugial rocky areas on Charnley (Table 6, Figure 14). Though both Golden and Northern Brown Bandicoots have been confirmed in the Artesian, only Northern Brown Bandicoots have been confirmed on Charnley and it is unknown if Golden Bandicoots are restricted to the Artesian Range.

To date the only method to distinguish between Northern Brown Bandicoots and Golden Bandicoots is genetic analysis. Recent live trapping in the Artesian Range (February 2021) resulted in 6 bandicoot captures. Follow up genetic analysis confirmed all were Golden Bandicoots, in line with a handful of genetic samples from 2017 and 2018 which confirmed the existence of Golden Bandicoots in the Artesian. Additional targeted camera arrays (planned in 2022) look to further monitor bandicoots and assist in live trapping to clarify the distribution and extent of Golden and Northern Brown Bandicoots.

Table 6. Northern Brown and Golden Bandicoot metrics derived from appropriate 2021 camera surveys on Charnley River – Artesian Range Wildlife Sanctuary.

Indicator	Survey	Metric	Current value	Year	Trend (activity, occupancy)
Northern Brown and Golden Bandicoots	Charnley Rocky Area Camera Array	Activity	0.82	2021	Increase in activity and occupancy compared to 2020 (0.11, 5%).
		Occupancy	10%		
	Artesian Rocky Area Camera Array	Activity	2.11	2021	
		Occupancy	42%		

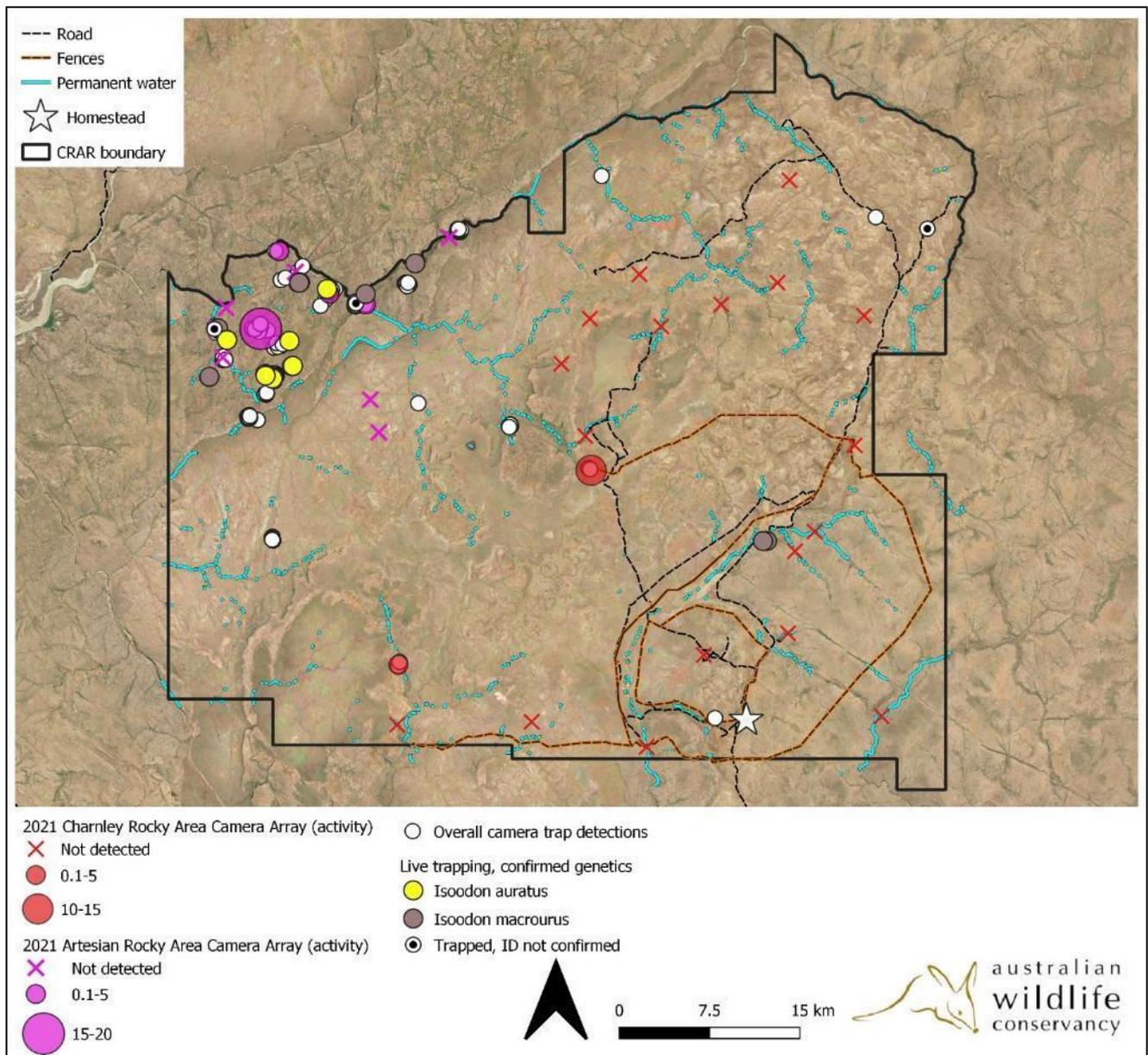


Figure 14. Bandicoot detections in 2021 (red and pink circles) with reference to historic detections (since 2014 – white circles). Golden Bandicoot (yellow dots) and Northern Brown Bandicoots (brown dots) captured during 2021 and historic live trapping that have species confirmed through genetic analysis identification are also shown.

Northern Brushtail Possum

The northern subspecies of Brushtail Possums (*Trichosurus vulpecula arnhemensis*), listed as vulnerable under the EPBC Act, are known to have a very low detectability throughout the Kimberley, and this is also true on CRAR. Most records on CRAR (detected since 2017) are from the basalt-rich hills in the Synnot Valley, termed Sub-Artesian sites, and from the productive riparian strip of northern Kalumba Creek (Figure 15). There are also anecdotal records on Mt Glemont, which, if confirmed would mean that this small refuge may support all three species of possums (Brushtail Possum, Rock Ringtail Possum, *Petropseudes dahli*, and Wyulda).

There is currently no effective Ecohealth survey for long-term monitoring of Northern Brushtails on CRAR, with detections mostly obtained from trial, inventory, and/or non-targeted surveys (which do not reliably detect the indicator). In 2021, there were only two detections of the Northern Brushtail Possum from two separate camera surveys, one individual in southeast Charnley and one at Sub-Artesian South (Figure 15). The Charnley record significantly extends the range of the species on CRAR and suggests that the species likely occurs throughout the property (Figure 15). Arboreal and Lowland Camera Arrays in development aim to enhance detectability and act as the long-term monitoring survey for the threatened indicator, commencing in 2022.

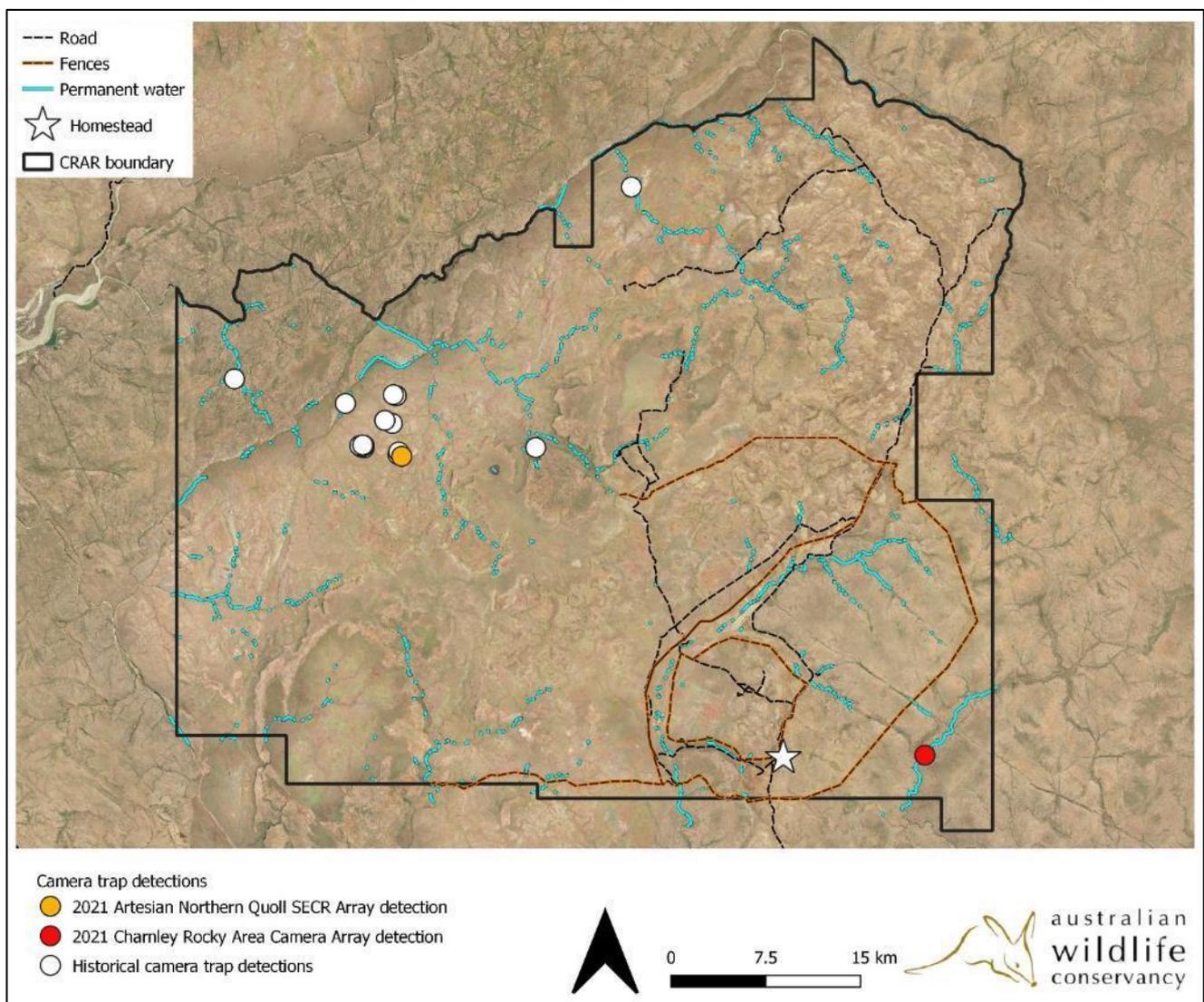


Figure 15. Northern Brushtail Possum 2021 and historical (2018-2020) camera trap detections on Charnley River – Artesian Range Wildlife Sanctuary.

Monjon and Nabarlek

In 2021, Monjon / Nabarlek were detected at half of the Artesian Rocky Area Camera Array sites (50% occupancy, activity 2.2/100 TN; Figure 16). Given the restricted nature of both species and their priority and

threatened status, AWC will develop a Conservation Plan which will include more targeted surveys to enhance monitoring and clarify their individual distributions.

The near threatened Monjon (State listed Priority 4) is an iconic macropod endemic to the far northwest Kimberley, which, on CRAR, is restricted to the Artesian Range with no records in the Sub-Artesian and elsewhere on the property. Although they are likely to be most abundant here, it remains unclear if the Artesian Range comprises solely Monjons, or if the similar in appearance and endangered (EBPC listed) Nabarlek also exists within the CRAR boundary in Artesian Range (Todd 2014). This region of CRAR sits at the southernmost extent of the known Nabarlek distribution. The two species are not readily distinguishable by camera trap images and genetic analysis (via faecal pellets, Todd 2014) would be required to clarify the existence and distribution of Nabarleks on CRAR and neighbouring AWC Partnership Areas.

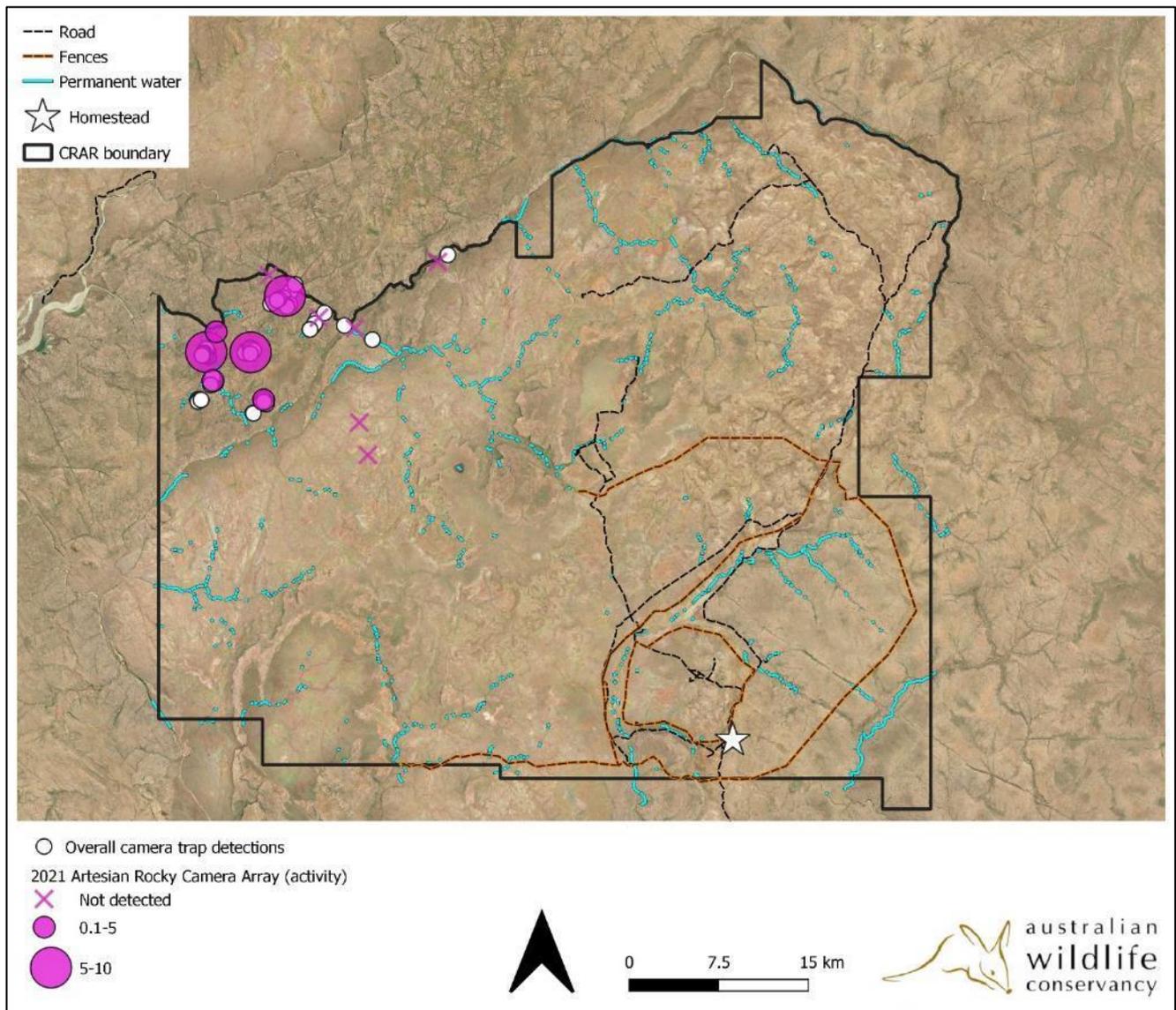


Figure 16. Monjon/Nabarlek camera trap detections since 2017 in the Artesian and recent detections and activity in the 2021 Artesian Rocky Camera Array.

Black Grasswren

The Black Grasswren is a near threatened species (State listed Priority 4) endemic to northwest Kimberley and restricted to the Artesian Range within CRAR. A total of 91 Black Grasswren detections were made during playback surveys along standardised transects in the Artesian Range in 2021. Of the 91, 70 were in response to call playbacks and 21 were additional observations along transects. On average, 10.1 detections were made per site, with 100 % site occupancy recorded (Figure 17). This survey indicates that Black Grasswrens are widespread throughout the Artesian Range. The species was detected only five times by the two 2021 Artesian camera arrays suggesting that camera traps are an ineffective monitoring technique (unless camera

surveys are redesigned/targeted). This was the first standardised playback survey conducted as part of Ecohealth for the iconic Black Grasswren and follows a research project undertaken in the Artesian by Clarke (2014). Note that in some cases, individuals may have been detected at multiple call playback points and as such the data is interpreted as the number of detections (activity), rather than the number of individuals (abundance).

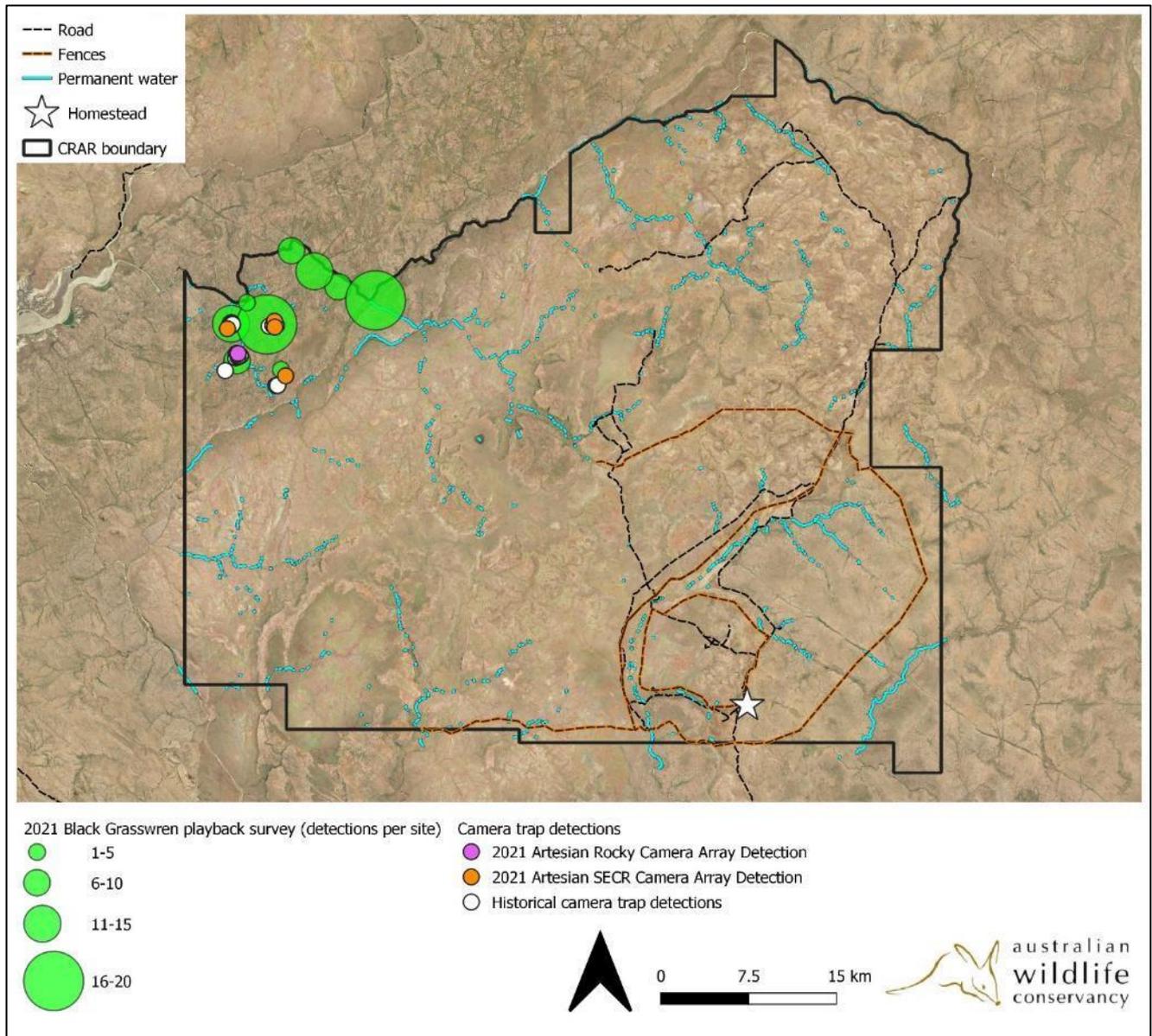


Figure 17. Black Grasswren 2021 playback survey observations and historical camera trap detections in the Artesian Range on Charnley River – Artesian Range Wildlife Sanctuary.

Gouldian Finch

No targeted surveys for Gouldian Finches (*Erythrura gouldiae*; listed as endangered under the EPBC Act) were undertaken on CRAR in 2021 and no individuals were recorded by other surveys. Waterhole cameras and camera traps in general have been unsuccessful in detecting the Gouldian Finch, with the species detected by Granivorous Birds Targeted Survey and Savanna Diurnal Bird Surveys in 2019 and 2020 (almost exclusively at Riparian sites; refer to Sayers et al. 2020 for methods). Gouldian Finches were detected 15 times during the two types of surveys (6/60 Granivorous Birds Targeted Survey and 9/235 Savannah Diurnal Bird Surveys). Despite being detected during in fewer events, more individuals were observed in Granivorous Birds Targeted Surveys (92/148) than in the Savanna Diurnal Bird Surveys (56/148; Figure 18). In 2020, only 24 individuals were observed at 2 Granivorous Birds Targeted Surveys sites (occupancy 5.5%). Although Granivorous Birds Targeted Surveys are currently the best method to detect Gouldian Finches, the survey is unlikely to continue

in its current form as the method only provides a crude measure of species persistence. Additional surveys and revised metrics for this threatened species will be developed under a Conservation Plan, guided by historical sightings.

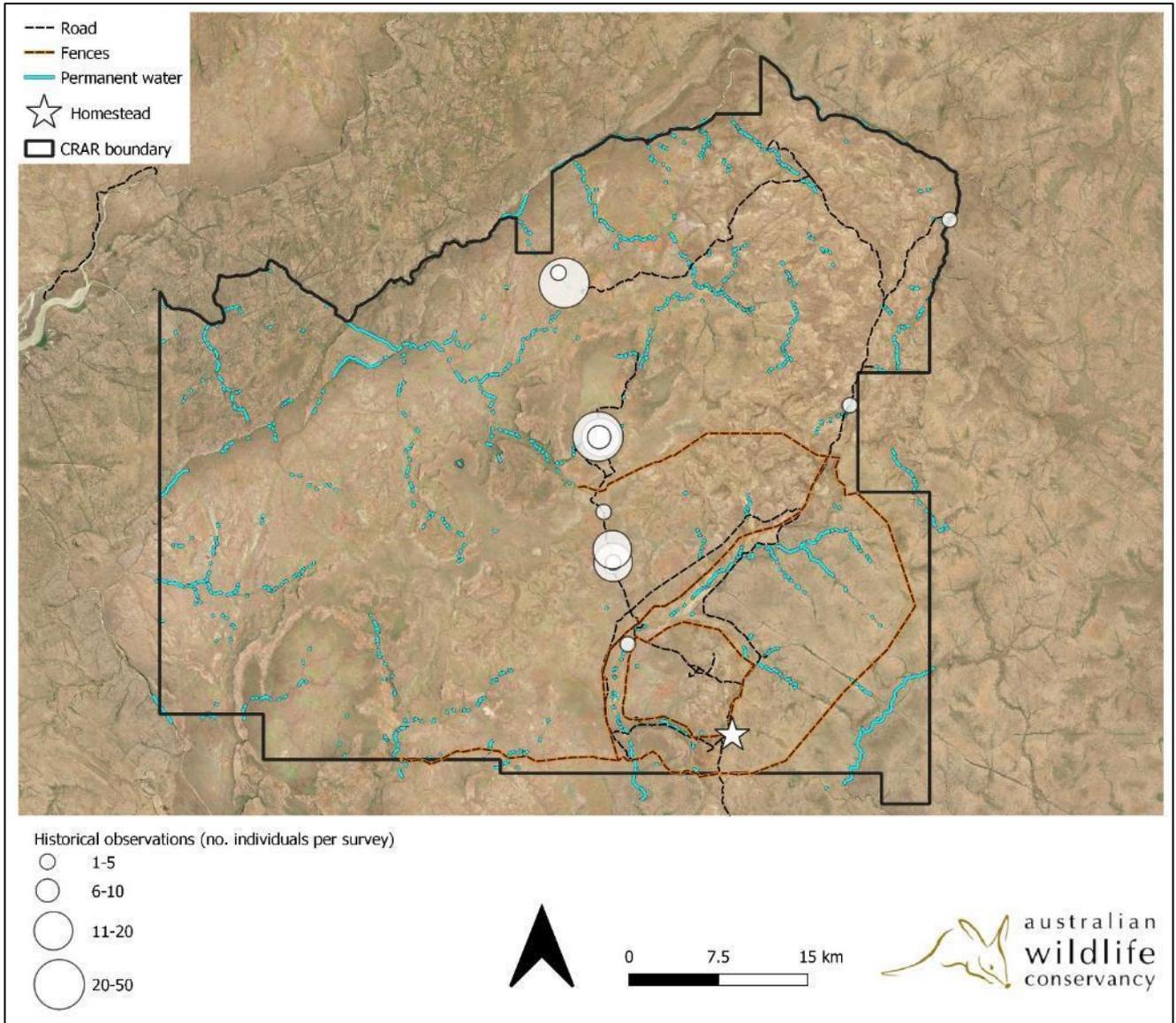


Figure 18. Gouldian Finch historical (2019 – 2020) observations on Charnley River – Artesian Range Wildlife Sanctuary (Observational Waterhole Surveys and Savanna Diurnal Bird Surveys combined).

Water monitors and Yellow-spotted Monitor

No targeted camera surveys were undertaken in 2021 for water monitors (threatened status currently under review by Australian Government) or the Yellow-Spotted Monitor (*Varanus panoptes*). In 2022, a new Varanid Camera Array will be used to monitor varanid species most at risk from cane toads (Ujvari and Madsen 2009, de Laive et al. 2021). Across camera surveys that were undertaken in 2021 (Figure 19), the Charnley Rocky Area Array detected Mitchell’s Water Monitor (*V. mitchelli*) twice, and Merten’s Water Monitor (*V. mertensi*) twice, in addition to individual detections by the Waterhole/Wetland Camera Array. The Yellow-spotted Monitor was detected 3 times by the Artesian Northern Quoll Camera Array and once by the Charnley Northern Quoll Targeted Research Survey, a survey that was conducted for an independent research project on the persistence of Northern Quolls in central and eastern Charnley.

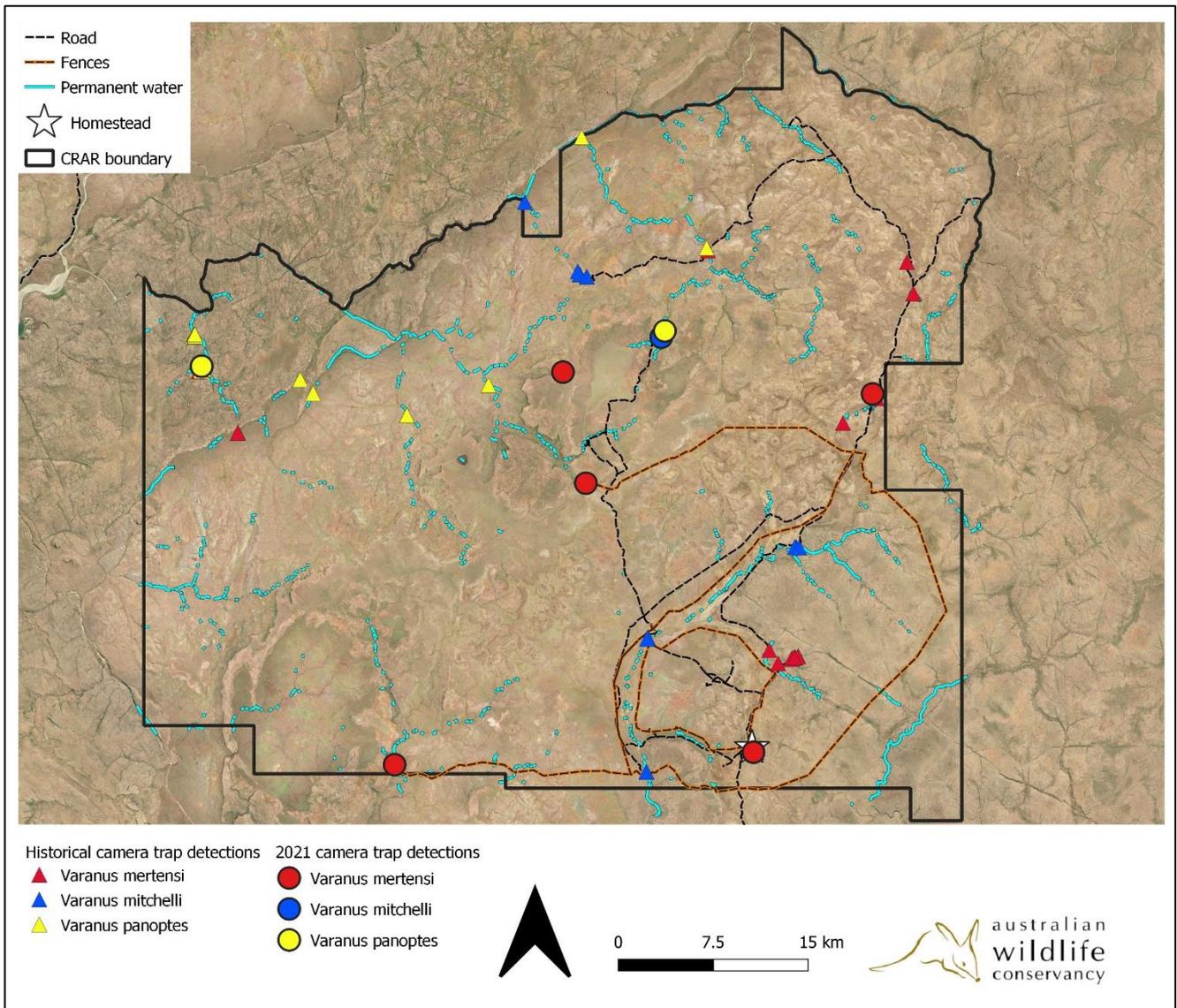


Figure 19. Water monitor and Yellow Spotted Monitor detections during 2021 camera surveys and historical detections on Charnley River – Artesian Range Wildlife Sanctuary.

Assemblages and surveillance species

Mammals

Thirty-one native mammals (and 5 introduced mammals) are known to, or likely to, occur on CRAR Wildlife Sanctuary, excluding the 24 species of bats in the order of Chiroptera which are currently not surveyed in CRAR Ecohealth. Of the 31 native mammals, 24 were recorded in Ecohealth Surveys in 2021 (including threatened and/or iconic mammals detailed above) with no new mammals confirmed on CRAR. An additional five native mammal species were recorded in 2021 by incidental observations, four of which were bat species (Black Flying Fox, *Pteropus alecto*, Orange Leaf-nosed Bat, *Rhinioncteris aurantia*, Little Broad-nosed Bat, *Scotorepens greyii*, and Common Sheath-tailed Bat, *Taphozous georgianus*) and the other the Savanna Glider (*Petaurus ariel*).

Mammal species (outside Chiroptera) which were not detected in 2021 but have been confirmed on CRAR previously, were the Grassland Melomys (*Melomys burtoni*), and the Red-cheeked Dunnart (*Sminthopsis virginiae*). Species which were not detected in 2021 but are likely (or very likely) to occur on CRAR are the Central Pebble-mouse (*Pseudomys johnsoni*), Long-haired Rat (*Rattus villosissimus*), and the Stripe-faced Dunnart (*Sminthopsis macroura*). Many of these species not detected (or not detected through Ecohealth

surveys) are cryptic, restricted in distribution and habitat on CRAR, and/or require more targeted monitoring to assess their persistence.

Small lowland mammals

In 2021, all six members of the small lowland mammal guild were trapped within the Standard Live Trapping survey (84 individuals). This guild showed a significant increase in abundance and richness compared to 2019 and 2020, being comparable to 2016 and 2017 richness, but not in abundance (Figure 20, Figure 21). This was likely associated with the 2020-2021 above average wet season and increases in vegetative ground cover and resources. Overall, there was a doubling in the averages per site for the guild abundance (116% increase) and richness in 2021 compared to 2020. Both 2018-2019 and 2019-2020 were below average wet seasons, which likely contributed to the substantial drop in guild abundance and richness observed in 2019 and 2020. On average, Blacksoil sites in 2021 comprised the highest levels of small mammal abundance and richness. When looking at individual species within the guild, all species apart from the Delicate Mouse (*Pseudomys delicatulus*) recorded an increase or remained stable in abundance and occupancy compared to 2019 and 2020 levels (Figure 22, Figure 23). The Delicate Mouse is common throughout north and northeast Australia, and this species may decline under reduced habitat disturbance as planigale numbers increase.

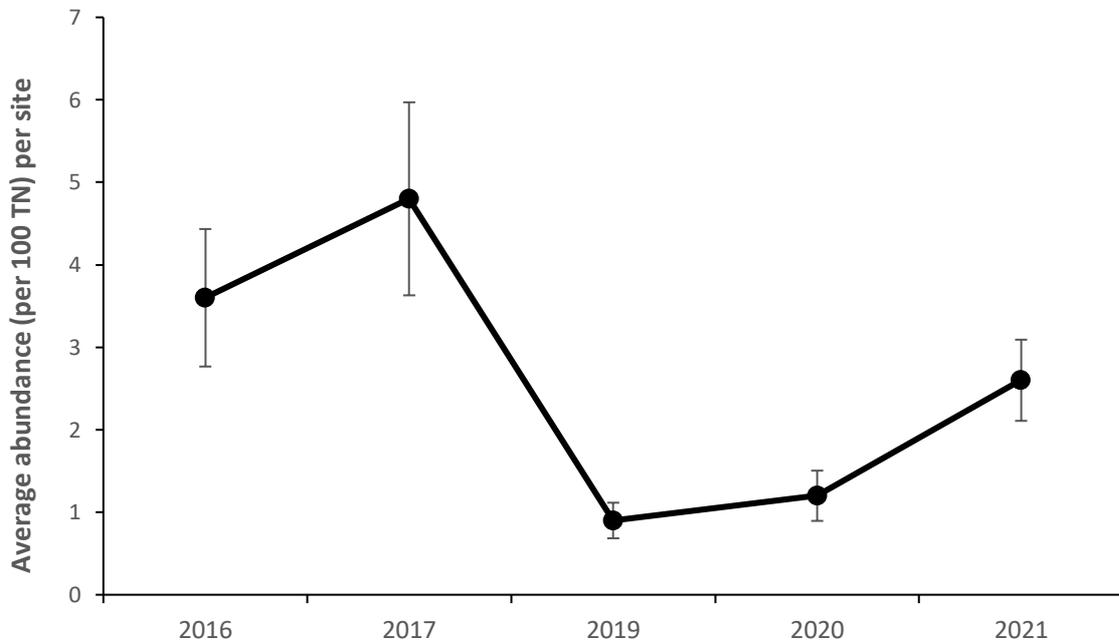


Figure 20. Overall average small mammal guild abundance (individuals per 100 TN) per site from Standard Live Trapping Surveys on Charnley between 2016-2021 (error bars represent ± SE).

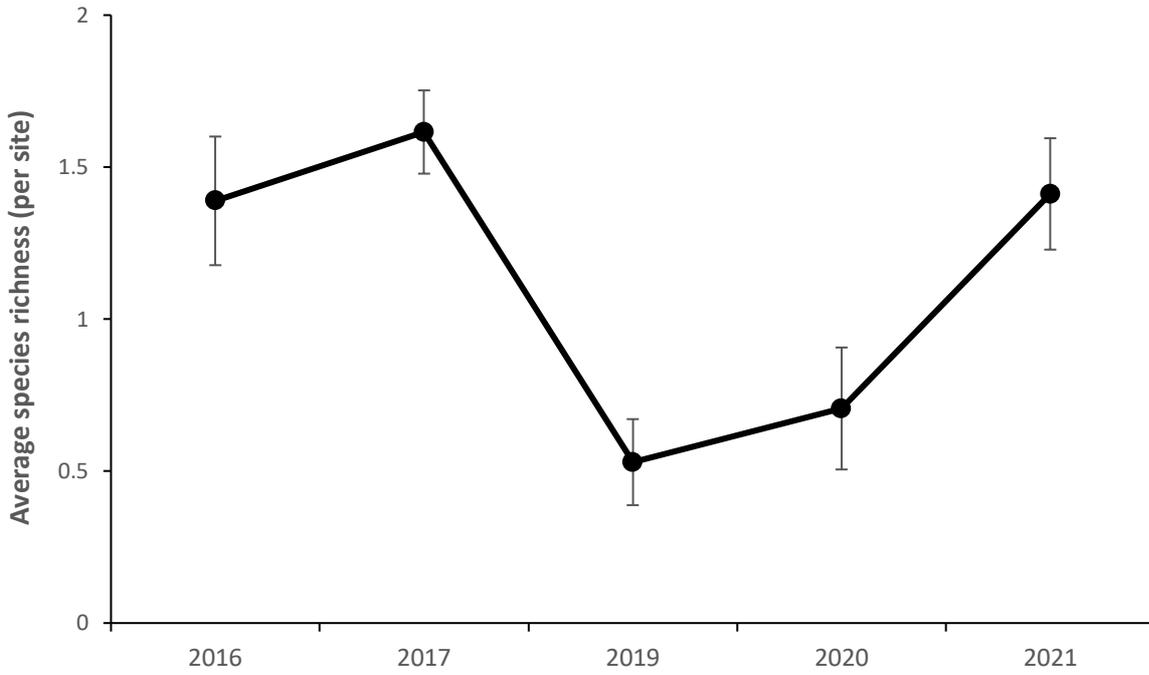


Figure 21. Overall average small mammal guild species richness, per site, from Standard Live Trapping Surveys on Charnley between 2016 – 2021 (error bars represent \pm SE). No surveys were completed in 2018.

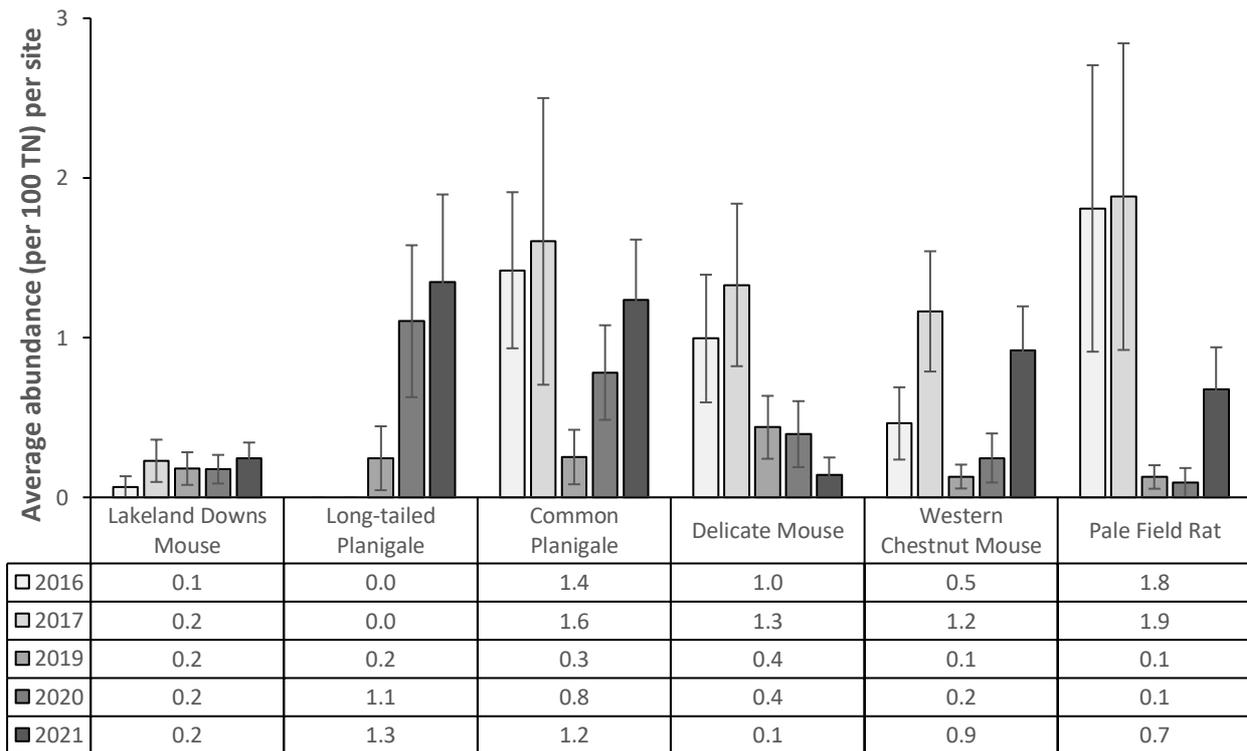


Figure 22. Average small lowland mammal species richness (individuals per 100 TN) per site, from Standard Live Trapping surveys on Charnley 2016 – 2021 (error bars represent \pm SE). Note that the individual appropriateness of trap types for particular species is accounted for in survey effort (i.e., TN)

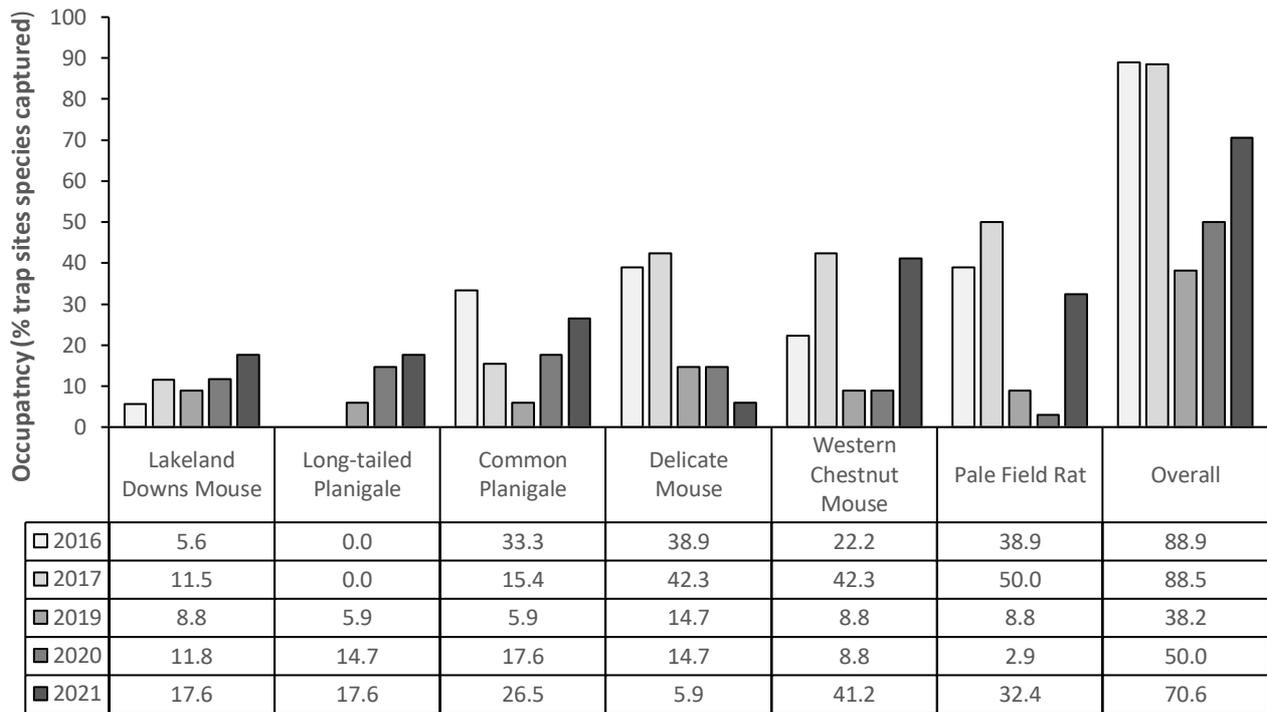


Figure 23. Small lowland mammal species site occupancy from Standard Live Trapping surveys on Charnley between 2016 – 2021. No surveys were completed in 2018.

Small-medium rocky mammals

In the 2021 Charnley and Artesian Rocky Camera Arrays, all eight rocky mammal species expected to occur in these rocky habitats were detected. These included seven in the small-medium rocky mammal guild (dasyurids, rodents) and the Echidna (*Tachygllossus aculeatus*) and excludes other grouped mammals such as macropods, arboreal mammals, and dingoes (*Canis lupus dingo*) outlined elsewhere. Five species in the small-medium rocky mammal guild were detected on Charnley in 2021, the Northern Quoll, Ningbing False Antechinus (*Pseudantechinus ningbing*), Pale Field Rat (*Rattus tunneyi*) / Western Chestnut Mouse (*Pseudomys nanus*), Common Rock Rat (*Zyzomys argurus*), and the Kimberley Rock Rat (*Zyzomys woodward*). Seven species in the small-medium rocky mammal guild were detected in the Artesian in 2021 - the Northern Quoll, Rakali (*Hydromys chrysogaster*), Golden-backed Tree Rat (*Mesembriomys macrurus*), Ningbing False Antechinus, Pale Field Rat / Western Chestnut Mouse, Common Rock Rat, and the Kimberley Rock Rat. The Artesian Rocky Area Array showed higher species richness for the small-medium rocky mammal guild compared to the Charnley Rocky Area Array. Activity was considerably greater on Charnley in large part due to higher Common Rock Rat activity. Interestingly, there was an increase in species richness and activity on Charnley between 2020 and 2021 (Table 7).

Table 7. Small-medium rocky mammal metrics derived from 2021 Artesian Rocky Area and Charnley Rocky Area Camera Arrays.

Indicator	Survey	Metric	Current value	Year	Trend (activity, occupancy, richness)
Rocky small-medium sized mammals					
Small to medium rocky mammal guild (dasyurids, rodents)	Charnley Rocky Area Camera Array	Activity	136.3	2021	Increased activity and richness compared to 2020 (117.11, 1.5).
		Richness	2.25		
	Artesian Rocky Area Camera Array	Activity	23.1	2021	No comparable survey.
		Richness	3.41		

Indicator	Survey	Metric	Current value	Year	Trend (activity, occupancy, richness)
Echidna	Charnley Rocky Area Camera Array	Activity Occupancy	0.54 55%	2021	Decreased activity and increased occupancy compared to 2020 (0.61, 40%).
	Artesian Rocky Area Camera Array	Activity Occupancy	0.12 17%	2021	No comparable survey.
Kimberley Rock Rat	Charnley Rocky Area Camera Array	Activity Occupancy	0.11 10%	2021	Detected at 2 sites in 2021, and 1 site in 2020 (0.07, 5%).
	Artesian Rocky Area Camera Array	Activity Occupancy	5.7 83%	2021	No comparable survey.
Ningbing False Antechinus	Charnley Rocky Area Camera Array	Activity Occupancy	0.61 30%	2021	Increased activity and occupancy compared to 2020 (0.18, 20%).
	Artesian Rocky Area Camera Array	Activity Occupancy	0.06 8%	2021	No comparable survey.

Macropods

All six macropod species known to occur on CRAR (Monjons and Nabarleks are currently grouped) were detected in 2021, and all species within the large macropod guild were detected by the Charnley Water/Wetland Camera Array (Table 8). The Short-eared Rock Wallaby (*Petrogale brachyotis*) was widespread across both Charnley and Artesian Rocky Camera Arrays.

Table 8. Macropod metrics derived from 2021 Artesian Rocky Area, Charnley Rocky Area, and Charnley Waterhole/Wetland Camera Arrays.

Indicator	Survey	Metric	Current value	Year	Trend (activity, occupancy)
Macropods					
Large macropod guild (Agile Wallaby, Antilopine/Common Wallaroo, Northern Nail-tail Wallaby)	Charnley Waterhole/Wetland Camera Array	Activity Richness	32.4 1.08	2021	No comparable survey.
Short-eared Rock Wallaby	Charnley Rocky Area Camera Array	Activity Occupancy	14.1 70%	2021	Decreased activity compared to 2020 (23.5, 70%).
	Artesian Rocky Area Camera Array	Activity Occupancy	2.3 67%	2021	No comparable survey. Most active at Charnley River sites.

Arboreal mammals

All five arboreal mammal species known to occur on CRAR were detected in 2021 (including the Northern Brushtail Possum). Both the Golden-backed Tree-rat and Wyulda, now restricted and/or endemic to

northwest Kimberley, were readily detected on cameras across the Artesian Range (Table 9). To date Golden-backed Tree-rats have not been detected outside the Artesian Range on CRAR. Conversely, Wyulda (a highly frugivorous species) are found outside the Artesian in a few refugial sites on Charnley within rocky gorges characterised by rainforest and vine thicket with high availability of fruiting trees. Rock Ringtail Possums are most frequently detected at Mt Glemont (an isolated volcanic outcrop) with an additional detection at Dille Gorge in 2021. This is the first detection of Rock Ringtails outside of Mt Glemont with no records in the Artesian Range. The planned Charnley Arboreal Camera Array will likely enhance the detectability of the Savanna Glider, and possibly Rock Ringtail, and Wyulda, and if so will be used to monitor these indicators going forward, complementing the Charnley and Artesian Rocky Area Camera Arrays.

Table 9. Arboreal mammal metrics derived from 2021 Artesian Rocky Area and Charnley Rocky Area Camera Arrays.

Indicator	Survey	Metric	Current value	Year	Trend (activity, occupancy)
Arboreal mammals					
Savanna Glider	-	Activity	-	-	One new incidental record on Charnley in 2021.
		Occupancy	-	-	
Rock Ringtail Possum	Charnley Rocky Area Camera Array	Activity	0.43	2021	Increase in detection and occupancy compared to 2020 (0, 0%).
		Occupancy	10%		
Wyulda	Charnley Rocky Area Camera Array	Activity	1.46	2021	Increase in activity and decrease in occupancy compared to 2020 (0.89, 10%).
		Occupancy	5%		
	Artesian Rocky Area Camera Array	Activity	7.66	2021	No comparable survey.
		Occupancy	75%		
Golden-backed Tree-rat	Artesian Rocky Area Camera Array	Activity	2.15	2021	No comparable survey.
		Occupancy	67%		

Predators

Dingos are currently assessed by three surveys on CRAR, all of which are restricted to distinct habitats: the Charnley Rocky Area Camera Array and Artesian Rocky Area Array are located in the rocky terrain of Charnley and dissected gorges of the Artesian, respectively, and the Charnley Waterhole/Wetland Camera Array surveys along the lowland riverine regions of Charnley. The Charnley Rocky Area Camera Array showed a decline in occupancy (from 75% to 45%) and activity (from 2.25 to 1.2) compared to 2020, and the 2021 Artesian Rocky Area Array confirms the historically low presence in the rugged and structurally complex Artesian Range (Activity=0.38, Occupancy=25%) compared to rocky and lowland areas on Charnley (Table 10). Interestingly, the lowland Charnley Waterhole/Wetland Camera Array showed very high activity (7) and occupancy (75%) of dingos compared with the other two Surveys. Dingo occupancy has previously been shown elsewhere to decrease with increased terrain ruggedness with a preference for flat, lowland areas (Stobo-Wilson et al., 2020).

Table 10. Predator metrics derived from 2021 Artesian Rocky Area and Charnley Rocky Area Camera Arrays.

Indicator	Survey	Metrics	Current value	Year	Trend (activity, occupancy)
Predators					
Dingo	Charnley Rocky Area Camera Array	Activity	1.2	2021	Decrease in activity and occupancy compared to 2020 (2.25, 75%).
		Occupancy	45%		

Indicator	Survey	Metrics	Current value	Year	Trend (activity, occupancy)
	Charnley Waterhole/Wetland Camera Array	Activity	7.0	2021	No comparable survey.
		Occupancy	75%		
	Artesian Rocky Area Camera Array	Activity	0.38	2021	No comparable survey.
		Occupancy	25%		

Birds

Overall, 101 native bird species were recorded by 2021 Ecohealth Surveys (i.e., Diurnal Bird Surveys and camera trap surveys), from 198 species known or likely to occur on CRAR. An additional 32 bird species were recorded in 2021 by incidental observations (21) and trial surveys (11), including cryptic, nocturnal, specialised, and/or seasonal bird species (e.g., Rainbow Pitta, *Pitta iris*; Grebes, Hawk-owls, Spotted Night Jar, *Eurostopodus argus*; Cuckoos) not readily monitored by established surveys. This leaves a minimum of 65 species not detected in 2021 but have been confirmed or are likely to occur on CRAR - species which require more targeted surveys and/or the sanctuary is at the edge of their known range. Several bird species were observed incidentally on CRAR in 2021 for the first time and are now listed as confirmed (including Star Finch, *Bathilda ruficauda*; Green Pygmy Goose, *Nettapus pulchellus*; and Hoary-headed Grebe, *Poliiocephalus poliocephalus*).

Savanna diurnal bird guild

In 2021, Standard Diurnal Bird Surveys at Standard Live Trapping sites detected 1,468 individual birds comprising 68 species (out of a total of 102 species recorded over three years at Standard Live Trapping sites; excluding fly overs), corresponding to an average of 19.8 individuals and 8.0 species per survey, which was similar to 2019 and 2020 metrics (Figure 24 and Figure 25). Lowland savanna bird metrics have been relatively stable over the past three years despite significant variation in wet season conditions over this period (Figure 3).

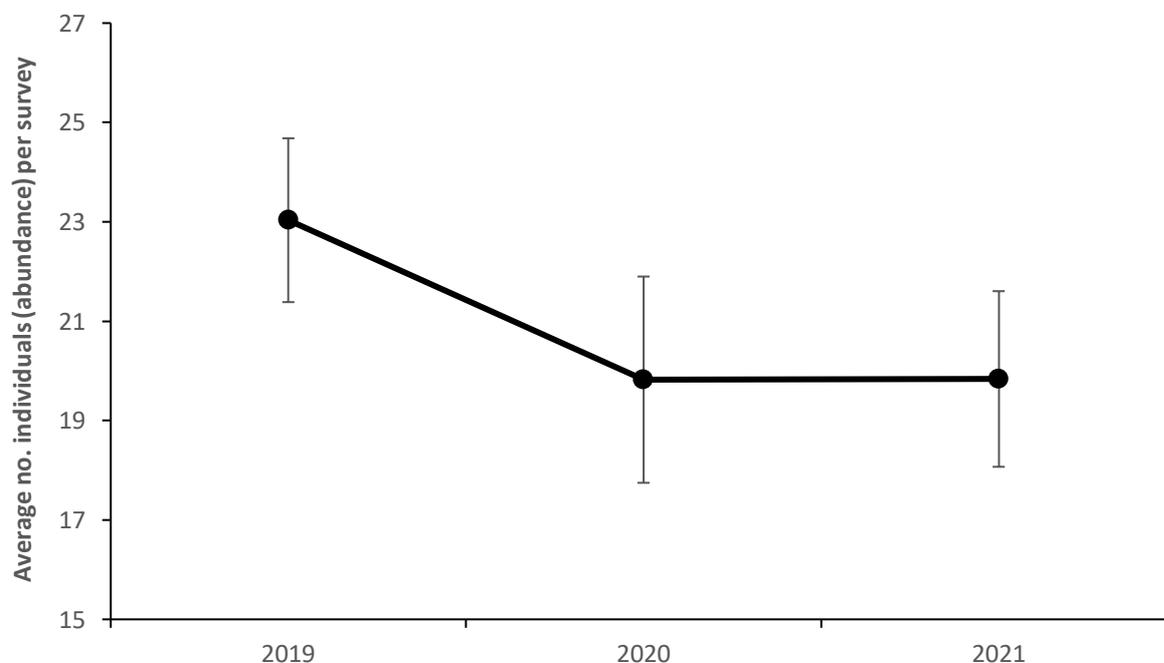


Figure 24. Overall average abundance (individuals per survey, excluding fly overs), from 2019-2021 Savanna Diurnal Bird Surveys on Charnley (error bars represent \pm SE).

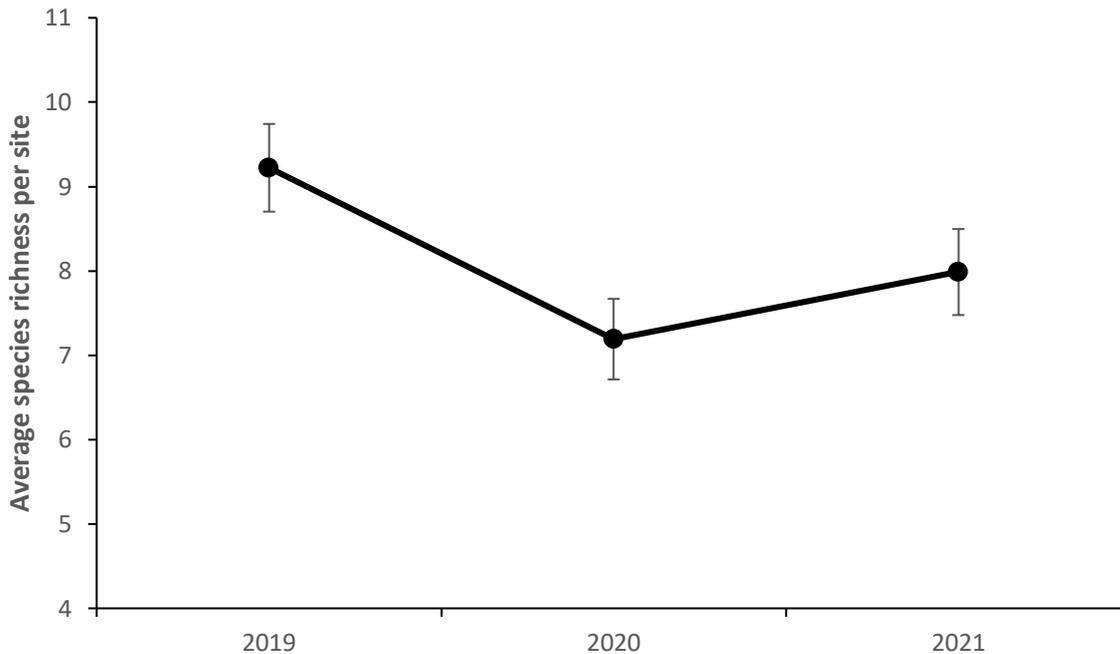


Figure 25. Overall average savanna diurnal bird species richness, per survey (fly overs excluded), from 2019 – 2021 Savanna Diurnal Bird Surveys on Charnley (error bars represent \pm SE).

Reptiles

In total, 46 native reptile species were recorded in 2021 by Ecohealth Surveys, from 120 species known or likely to occur on CRAR. An additional 20 reptile species were recorded in 2021 by incidental observations, particularly geckos (e.g., genus *Gehyra*) and snakes, taxa which are not readily detected or captured by established surveys. Notable incidental observations include the cryptic Rough-scaled Python (*Morelia carinata*) in the Artesian Range, and a juvenile Kimberley Death Adder (*Acanthophis cryptamydros*, listed as vulnerable by IUCN) at Mount Glemont. This leaves a minimum of 54 reptile species which were not detected in 2021 but have been confirmed or are likely to occur on CRAR - species which require more targeted surveys and/or the sanctuary is at the edge of their known range. Several reptile species were detected for the first time on CRAR in 2021. The Northern Savannah Two-pored Dragon (*Diporiphora sobria*) and Kimberley Dtella (*Gehyra kimberleyi*) were identified in 2021 live trapping on Charnley and added to the CRAR species list. Furthermore, the Northern Dtella (*Gehyra australis*) was identified on CRAR during spotlighting in the Artesian Range.

Small lowland reptiles

In 2021 Standard Live Trapping, 194 small reptiles were trapped comprising 23 species as part of the savanna lowland small reptile guild (12 skinks, 3 dragons, 5 geckos, 1 flap-footed lizard, and 2 small snakes, excluding non-target large brown snakes and varanids), out of 46 species historically captured in live trapping since 2016. Given geckos and flap-footed lizards have historically been captured in low numbers by live-trapping surveys on Charnley, they have been combined with skinks and dragons to form a larger lowland small reptile guild. Metrics of abundance and richness increased in 2021, from 2020 but were similar to 2019 metrics (Figure 26, Figure 27). The lower abundance in 2020 may have been due to the two prior below average wet seasons, contrasting with the increased 2020-2021 wet season.

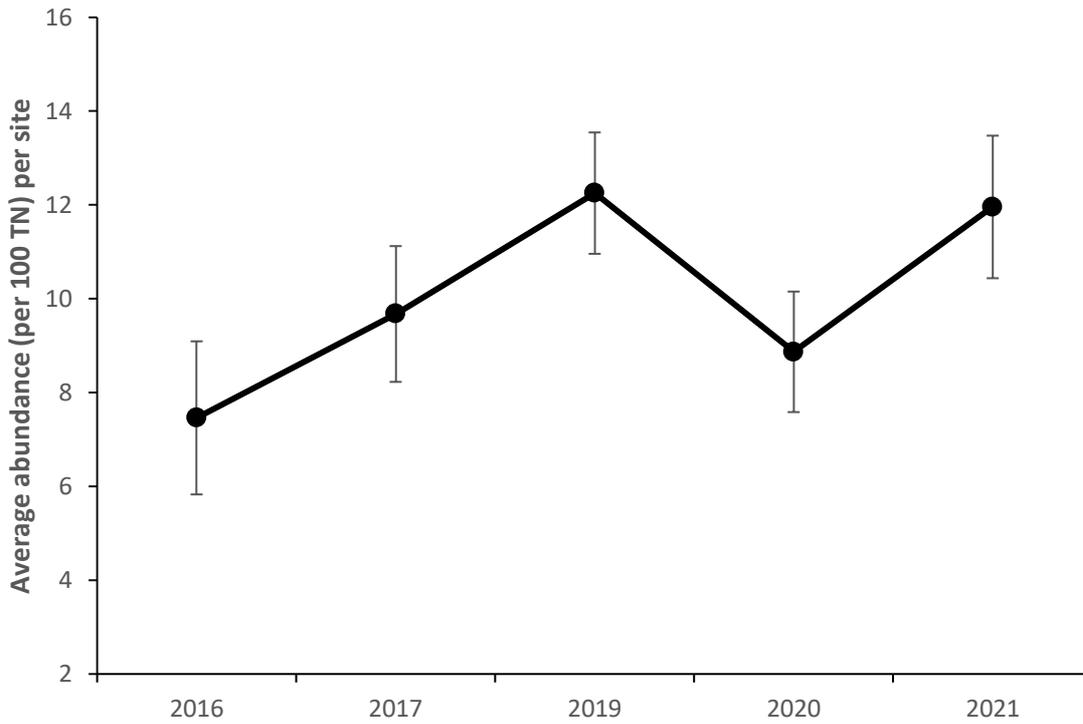


Figure 26. Overall average reptile abundance (per 100 TN) per site from Standard Live Trapping surveys on Charnley between 2016 – 2021 (error bars represent \pm SE). No surveys were conducted in 2018.

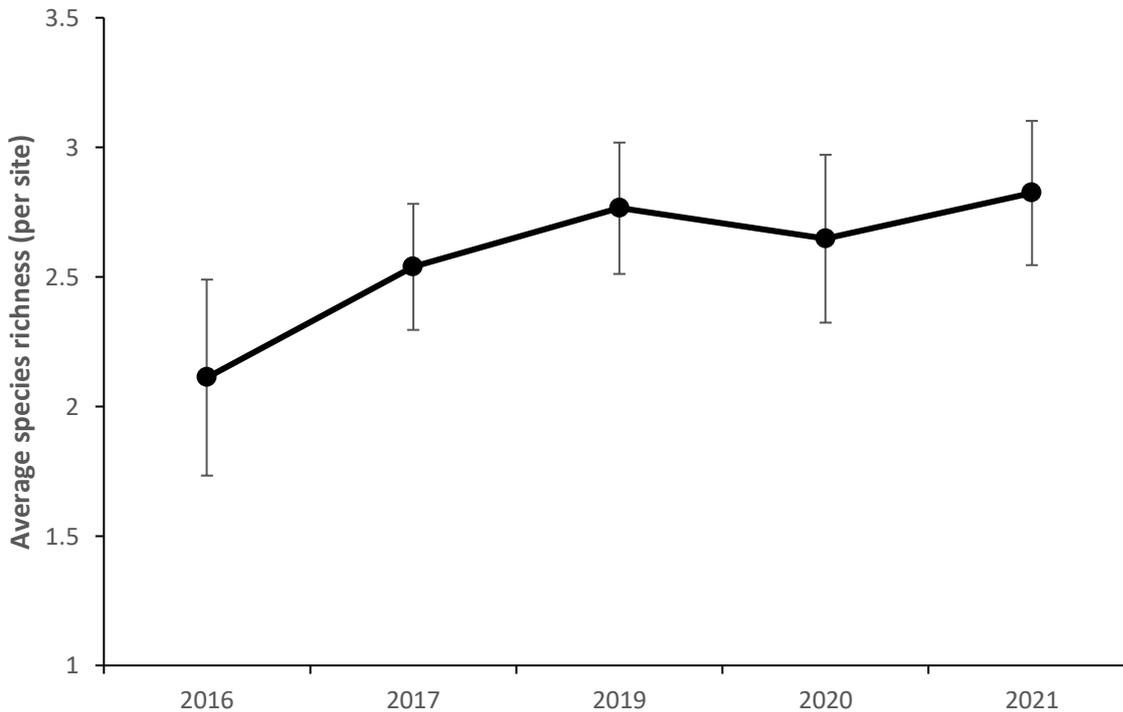


Figure 27. Overall average reptile species richness per site from Standard Live Trapping surveys on Charnley between surveys on Charnley between 2016 – 2021 (error bars represent \pm SE). No surveys were conducted in 2018.

Large reptiles

All 10 species of varanid confirmed on CRAR were detected in 2021 Ecohealth Surveys. Varanids represent a diverse and important group of native predators and face significant threat of decline from the introduced cane toad. Varanids on CRAR are categorised as follows: water monitors (Merten’s Water Monitor, and

Mitchell’s Water Monitor), rock monitors (Black-palmed Rock Monitor, *Varanus glebopalma*; Kimberley Rock Monitor, *Varanus glauerti*; and Spiny-tailed Monitor, *Varanus acanthurus*), and arboreal monitors (Spotted Tree Monitor, *Varanus scalaris*, and Black-headed Monitor, *Varanus tristis*). The Yellow-spotted Monitor, Storr’s Monitor (*Varanus storri*) and Gould’s Monitor (*Varanus gouldii*) are currently not assigned to a guild. Currently rock monitors are the only group effectively monitored by established surveys on CRAR (i.e., the Charnley Rocky Area Camera Array, and Artesian Rocky Area Camera Array); there are plans to develop more targeted surveys for other monitors, particularly water monitors and the Yellow-spotted Monitor, most at risk of decline.

Rock monitors showed higher activity and richness in the Artesian compared to Charnley (Table 11). Promisingly, there was also a large increase in activity and richness in 2021 on Charnley compared to 2020 (Table 11). All three species of rock monitor were detected by the two Rocky Area Arrays surveys in 2021.

The Northern Blue-tongue’s threatened status is currently under review by the Commonwealth Government and we have identified it as a species to watch and, thus, will develop targeted monitoring. This large skink was detected three times by the Artesian Rocky Area Array, 6 times by the Artesian Northern Quoll Camera Array, once in the 2021 trial of Artesian Live Trapping, and only once outside the Artesian in 2021 in the Charnley Northern Quoll Targeted Research Survey.

Table 11. Large reptile metrics derived from appropriate surveys for Charnley River – Artesian Range Wildlife Sanctuary.

Indicator	Survey	Metric	Current value	Year	Trend (abundance, occupancy, richness)
Large reptiles					
Rock monitor guild (Black-palmed Rock Monitor, Kimberly Rock Monitor, and Spiny-tailed Monitor)	Charnley Rocky Area Camera Array	Activity	2.21	2021	Large increase in activity, occupancy, and richness compared to 2020 (0.86, 0.6).
		Richness	1.15		
	Artesian Rocky Area Camera Array	Activity	5.48	2021	No comparable survey.
		Richness	1.92		
Northern Blue-tongued Skink	-	Activity	-	2021	Detected 10 times in the Artesian and once at Oombient Creek.
		Occupancy	-		

Vegetation

In 2021, the proportion of vegetation ground cover (tussock, hummock, low shrubs <140cm) increased across all habitat types (Table 12, Figure 28). The increase in this metric contributed to an overall increase in total ground cover (leaf litter, vegetation ground cover and elevated dead debris combined). This increase is likely associated with above average 2020-2021 wet season rainfall - the first above average since 2017-2018 (Figure 3). Conversely, canopy cover and woody debris have remained steady for the past 3 years. Vegetation and structural variables vary considerably across habitat type – variation which is likely to influence faunal composition, richness, and abundance. For example, Blacksoil and Riparian sites on average comprise the greatest proportion of vegetative ground cover (Table 12).

Table 12. Vegetation and habitat structure metrics at Standard Live Trapping sites from 2019-2021 on Charnley. Note bare soil and rock also recorded along each transect account for the remaining total ground cover %.

Habitat type	Year	Leaf litter cover %	Vegetation ground cover %	Total ground cover % (<140 cm)	Canopy cover % (>140 cm)	Woody debris (records per 100 m)
Blacksoil	2019	9	75	85	2	0.0
	2020	25	58	83	0	0.0
	2021	2	86	88	0	0.0
	Average	12	73	85	1	0.0
Riparian	2019	27	59	87	37	3.1
	2020	32	56	88	42	2.7
	2021	6	92	98	43	3.3
	Average	22	69	91	41	3.0
Sandseep	2019	44	46	91	48	4.3
	2020	38	50	88	50	5.1
	2021	11	83	95	53	5.7
	Average	31	60	91	50	5.0
Woodland	2019	35	40	75	34	2.3
	2020	29	47	76	35	2.3
	2021	7	89	96	35	1.8
	Average	24	59	82	35	2.1

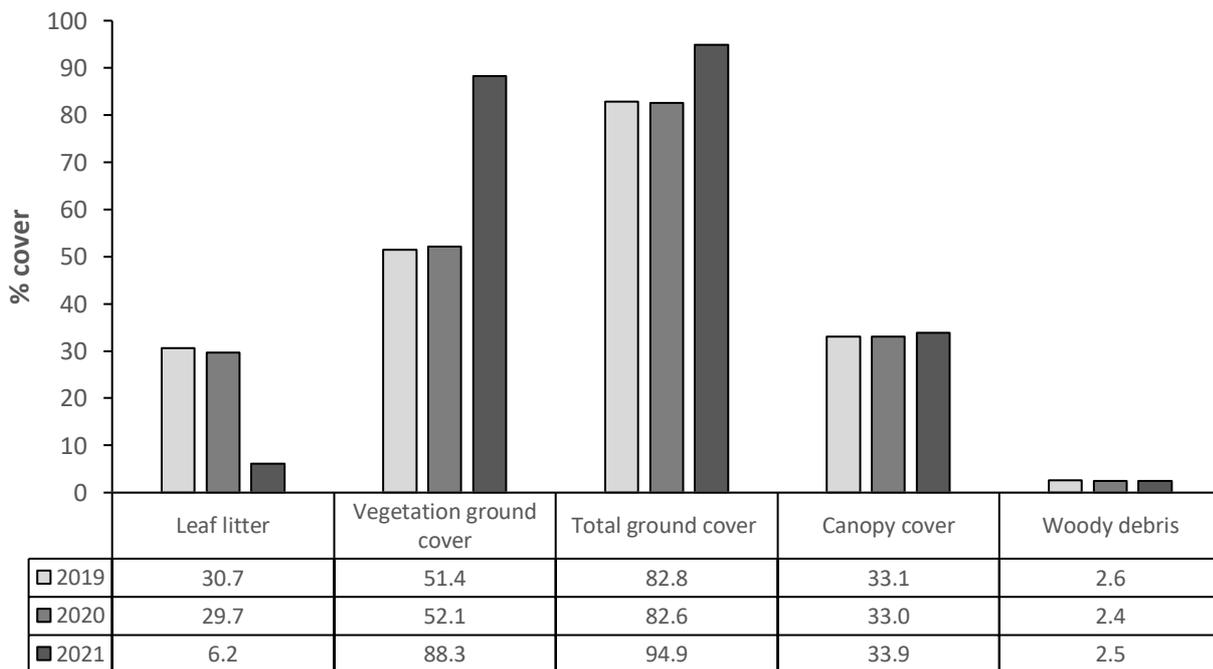


Figure 28. Vegetation and habitat structure metrics across all Standard Live Trapping sites (habitat types combined) from 2019 to 2021. Note that all metrics apart from woody debris are the proportion (%) of transect 1 m point measurements for which that metric was recorded, whereas woody debris is records per 100 m given it was surveyed continuously along each transect.

Threat indicators

Feral cats

Feral cats were detected by the 2021 Charnley Rocky Area Camera Array and the 2021 Waterhole/Wetland Camera Array with 40% and 75% occupancy and activity scores of 1.9 and 3.2 respectively (Figure 29). There was a considerable reduction in site occupancy and activity in the rocky areas of Charnley when compared to 2020 results (75% occupancy; 1.96 /100TN). Cats were not detected in the Artesian Range by the Artesian Rocky Area Array but were detected at Sub Artesian North and South (Figure 29). Historically, feral cats have rarely been detected in the Artesian Range despite significant camera trap effort. As such, it is assumed that they are present at extremely low density in the region (Hohnen et al. 2016b). A redesigned Predator Camera Array aims to enhance AWC’s monitoring of feral cats in eastern Charnley in 2022.

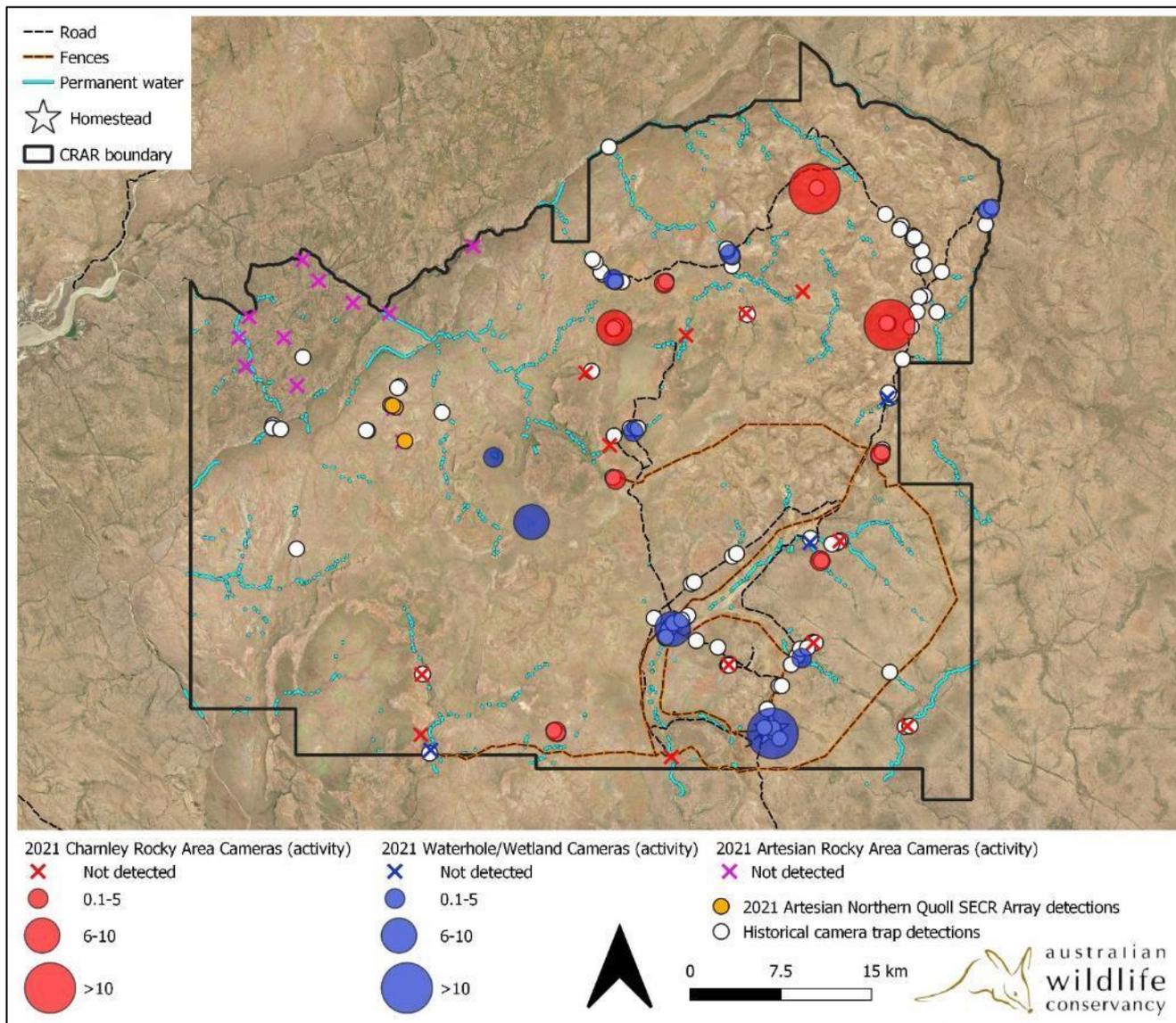


Figure 29. Feral cat detections from multiple 2021 camera surveys (including no detections) including historical detections since 2017.

Feral cattle

Feral cattle remain a significant threat on CRAR Wildlife Sanctuary through grazing and reducing habitat availability (Legge et al. 2011a, 2019). A total of 544 head of cattle were observed in the destocked area during the 2021 Aerial Feral Herbivore Survey (Table 14, Figure 30). Note that 27 cattle were removed on the Munboon Plateau and surrounds by the Department of Biodiversity, Conservation and Attractions (DCBA) just prior to the survey which may have reduced the number of cattle recorded in this region. In 2021, there was an increase in raw cattle density (1.4 head / km surveyed) compared to 2020 (0.7 head / km), with 2021

density comparable to 2019 and 2018 levels (Table 14). The reduction in cattle numbers and density relative to the 2016 survey can be attributed to the completion of the stock lease fence by Mount House and the mustering of cattle in the destocked region. Following the 2021 survey, the annual aerial cull in November-December resulted in the removal of 781 cattle on CRAR.

Note that density and population estimates derived from extrapolating data to unsurveyed areas within 2 km of permanent water sources are currently in development, with initial density estimate provided for 2021 (Table 14). Cattle were also readily detected by the Waterhole/Wetland Camera Array with activity of 157.9/100 TN and an occupancy of 83%, with all camera sites located outside the destocked area.

Table 13. Summary of Feral Herbivore Aerial Survey results on Charnley River – Artesian Range Wildlife Sanctuary since 2016.

Measure	2016	2018	2019	2020	2021
Cattle count in destocked area (and within 45°)	673 (NA)	519 (NA)	482 (286)	240 (182)	544 (440)
Cattle density in destocked area (head / km surveyed)	1.9	1.5	1.3	0.7	1.4
*Cattle density estimate (head / ha within 2 km of permanent water on CRAR, based on population estimate)	NA	NA	TBD	TBD	0.08

*Cattle population and density estimate methodology is under revision

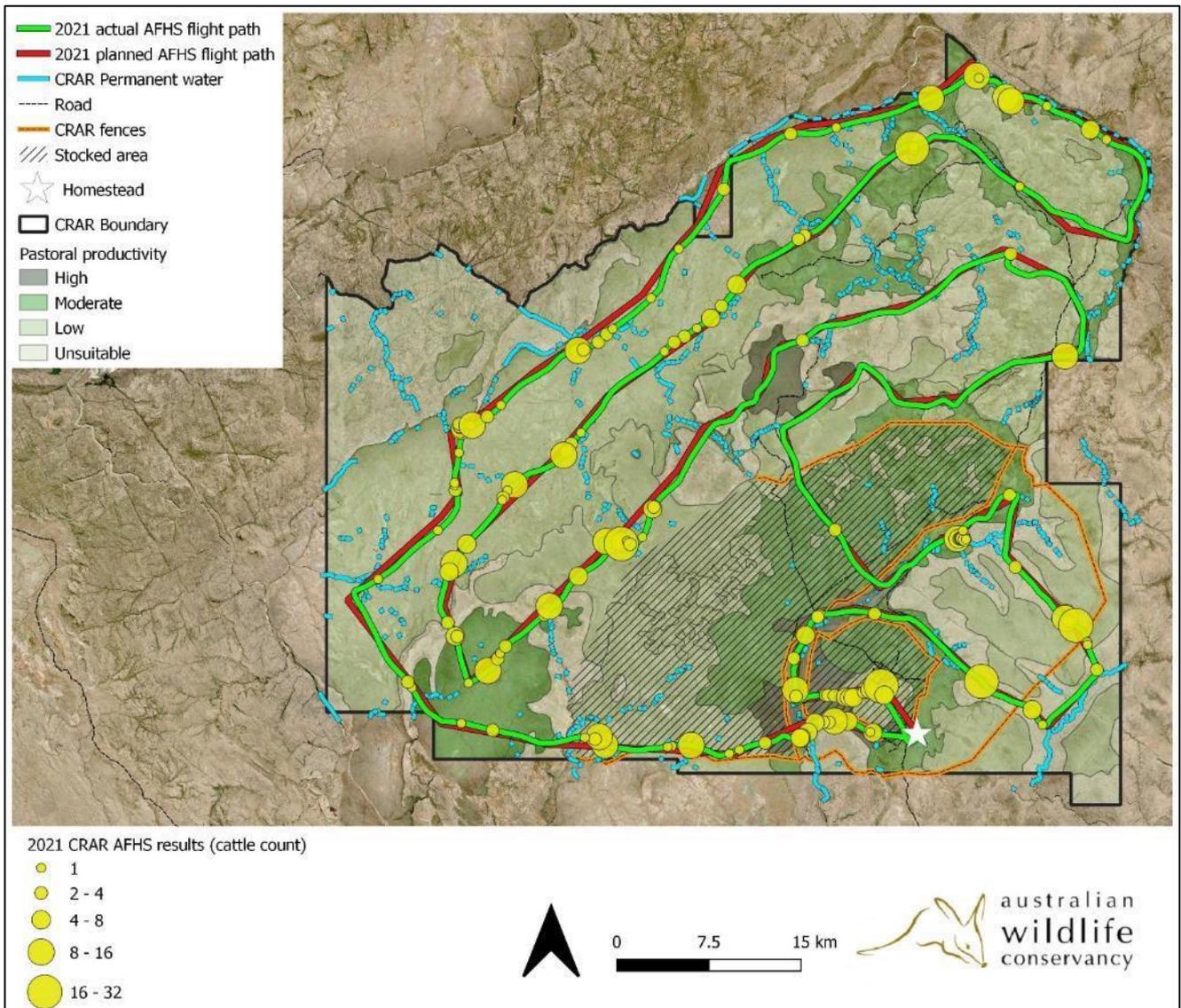


Figure 30. Feral Herbivore Aerial Survey 2021 results showing the distribution and abundance of cattle on Charnley River – Artesian Range Wildlife Sanctuary along the 438 km transect flown. This survey was conducted after the annual muster by Mount House.

Donkeys, horses, and pigs

Donkeys, horses, and pigs were not observed in the 2021 Aerial Feral Herbivore Survey and have rarely been observed by previous aerial surveys (Table 14). Pigs are known to be especially difficult to detect from the air and are more readily detected by camera traps. Pigs and donkeys were only detected by the 2021 Waterhole/Wetland Camera Array, with pigs detected at one third of waterhole sites (33% occupancy, 11.8/100 TN activity; Figure 31). Donkeys were detected at Lake Gilbert (8% occupancy, 1.2/100 TN activity) and no horses were detected by any camera array. In addition to camera trap detections, pig damage was also observed during trial wetland and waterhole condition assessments at several sites in 2021 where they were not detected by cameras.

Table 14. Summary of Feral Herbivore Aerial Survey results on Charnley River – Artesian Range Wildlife Sanctuary since 2016.

Measure	2016	2018	2019	2020	2021
Overall donkey count	1	0	3	0	0
Overall horse count	0	0	0	0	0

Measure	2016	2018	2019	2020	2021
Overall pig count	3	0	0	0	0

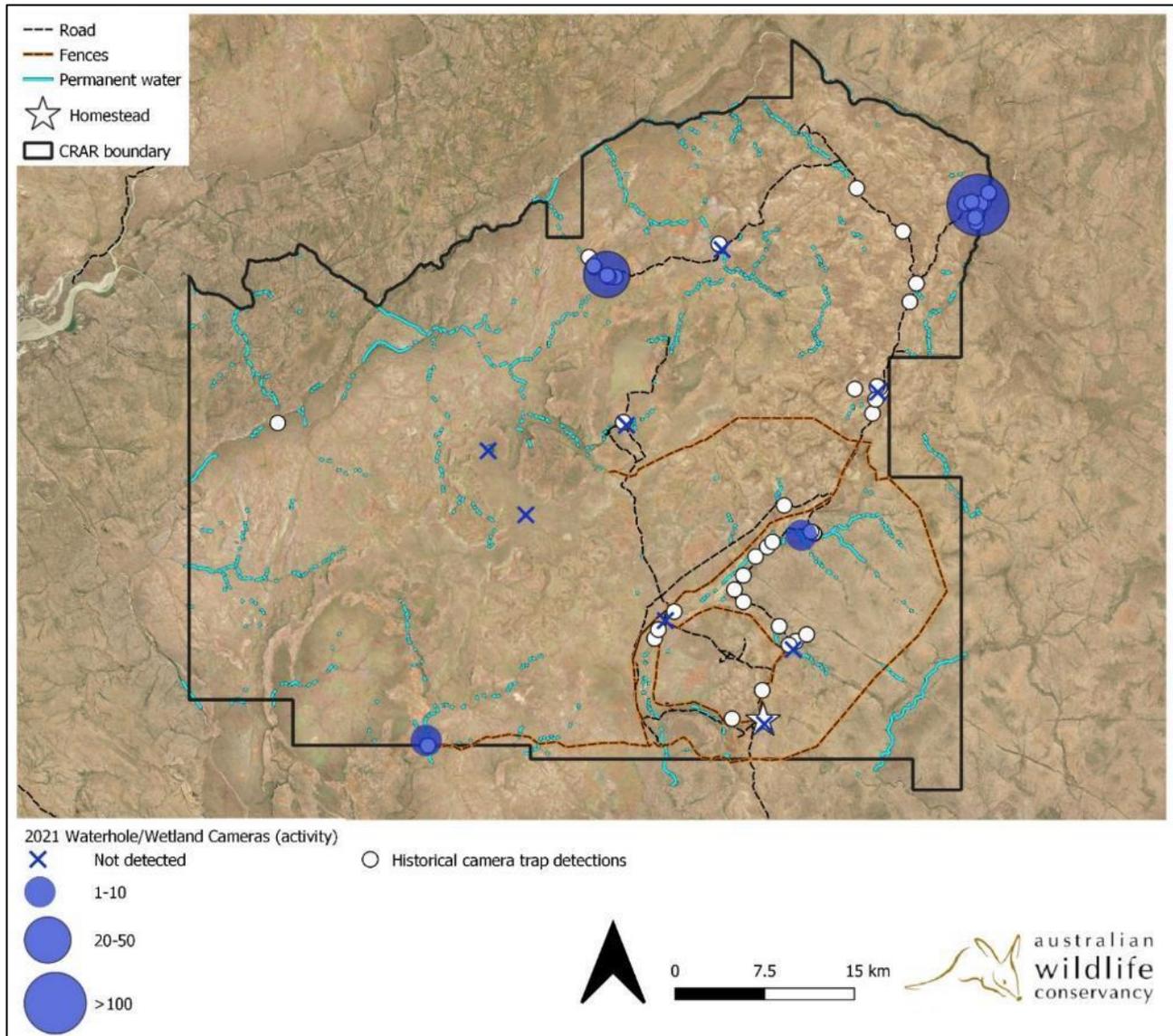


Figure 31. Feral Pig detections (activity) in 2021 from the Waterhole/Wetland Camera Array on Charnley River – Artesian Range Wildlife Sanctuary also showing historical camera trap detections (since 2019).

Cane toads

Prior to the 2020-2021 wet season, cane toads had not been detected in the Artesian Range, including during the 2018-2019 and 2019-2020 wet season when intensive camera surveys were undertaken. Both camera surveys undertaken in the wet season of 2020-2021 (in addition to spotlighting), detected cane toads in the Artesian Range for the first time (Figure 32). As a result, it is inferred that cane toads now cover 100% of CRAR Wildlife Sanctuary as of late 2020.

The advancing cane toad front has been tracked across the central Kimberley by AWC since 2015 (Figure 32). Monitoring for cane toads on Charnley began in 2017, with the first detections from the dry season of 2018 in the northeast and southeast of Charnley. During the 2018-2019 wet season, cane toads moved through central Charnley. As of February 2020, the toad front appeared to be at the base of the Artesian Range, with toads presumably moving through the southern Synnot Valley. From there they infiltrated the Artesian Range in 2020 where they were readily detected on camera traps during the 2020-2021 wet season for the first time.

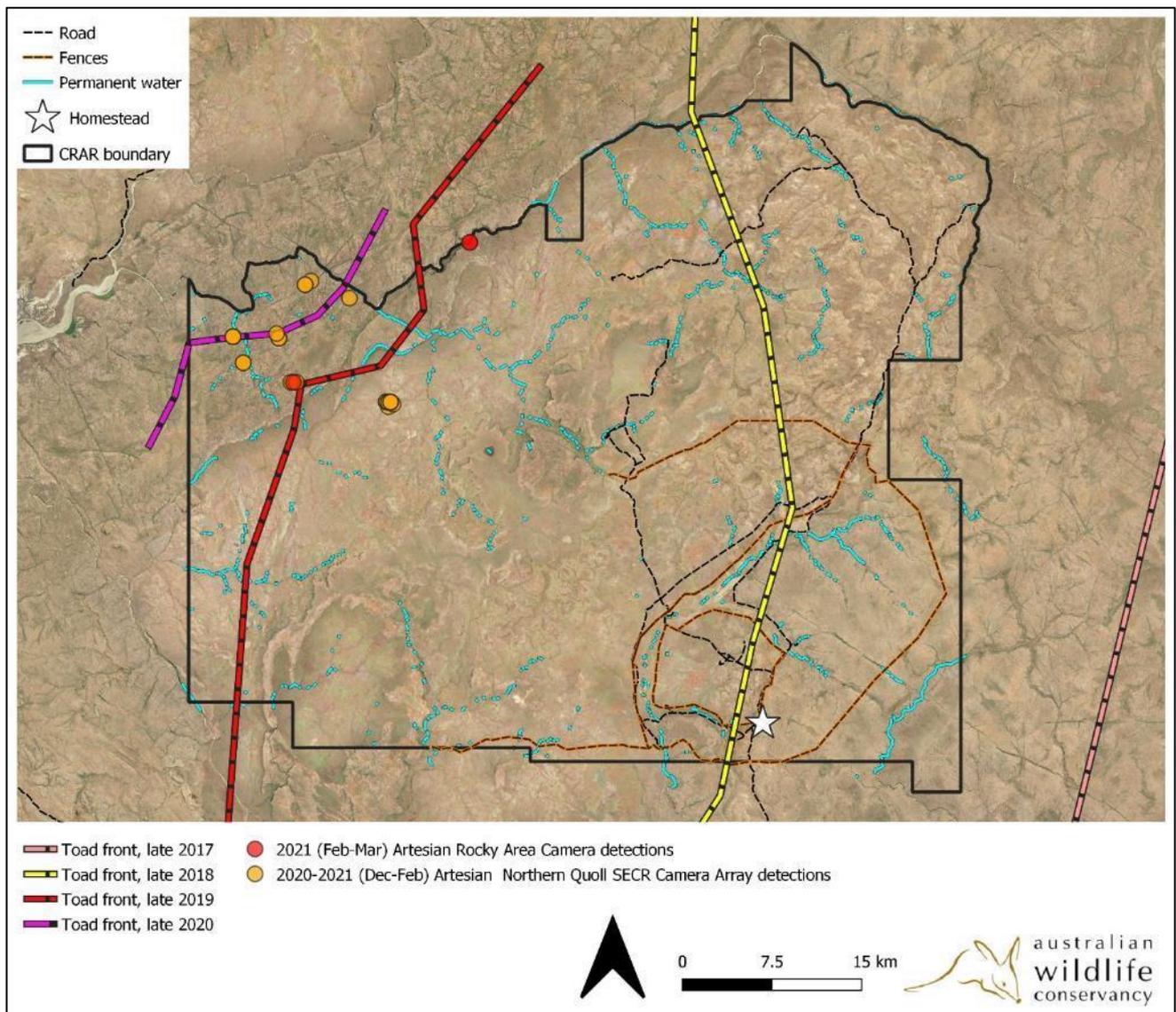


Figure 32. Map of the inferred advancement of the cane toad front from 2017 to late 2020 showing the first cane toad camera detections in the Artesian Range during the 2020-2021 wet season.

Weeds

No targeted weed surveys were undertaken in 2021. A Property Weed Management Strategy is under development.

Fire

The 2021 fire analysis showed that the prescribed burning program on CRAR has changed fire patterns, with all 2021 metrics showing an improvement (in most cases, a major improvement) from the baseline periods prior to and during AWC fire management (Table 15). The total area burnt in 2021 was 33% of the property compared to a mean of 56% in the baseline period - the total area burned in 2021 matched the 33% target in the 2021 Burn Plan. Furthermore, only 7% of the property in 2021 was impacted by more intense late dry season (LDS) fires (Figure 33), which is below the post-Ecofire program mean of 17% and substantially below the pre-Ecofire mean of 45%. This is also lower than the 8-10% LDS target anticipated in the 2021 Burn Plan. There is also a clear trend of decreasing distance to long-unburnt areas: from 2002-07, average mean and maximum distances were 6.3 and 17.6 km respectively, while for 2010-21, the corresponding average distances were 1.7 and 8.4 km. These changes and trends can be expected to have a range of positive consequences for biodiversity (Radford et al. 2015).

Table 15. Metrics and outcomes of 2021 fire management on Charnley River – Artesian Range Wildlife Sanctuary.

Metric	Baseline average 2000/02-2007	AWC management average 2008/10-2021	2021 result	Trend (AWC vs baseline)	Trend (2021 vs baseline)
Area burnt by early dry season (EDS) fire (%)	11	22	25	↑	↑
Area burnt by late dry season (LDS) fire (%)	45	17	7	↓	↓
Total area burnt (%)	56	38	33	↓	↓
Modal frequency of fires in last 8 years	5	-	3	-	↓
Modal frequency of LDS fires in last 8 years	4	-	0	-	↓
Area of long-unburnt vegetation (3+ years since fire) (%)	3	14	27	↑	↑
Mean distance to unburnt vegetation (km)	2.4	1.0	0.7	↓	↓
Mean distance to long-unburnt vegetation (km)	6.3	1.7	0.9	↓	↓
Mean distance to vegetation long-unburnt by LDS fire (km)	5.3	1.2	0.8	↓	↓

Notes:

Area-base metrics are expressed as % of the 300,059 ha sanctuary, 'long unburnt' refers to vegetation that had not been burnt in at least the last 3 years.

Baseline values for annual metrics are the average for years prior to full implementation of fire management by AWC on CRA: i.e., 2000-07 for annual metrics, and 2002-08 and for 3-year metrics.

AWC management values for metrics are the average for years during which AWC has implemented fire management on CRAR: i.e., 2008/10-2021.

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 ↓).

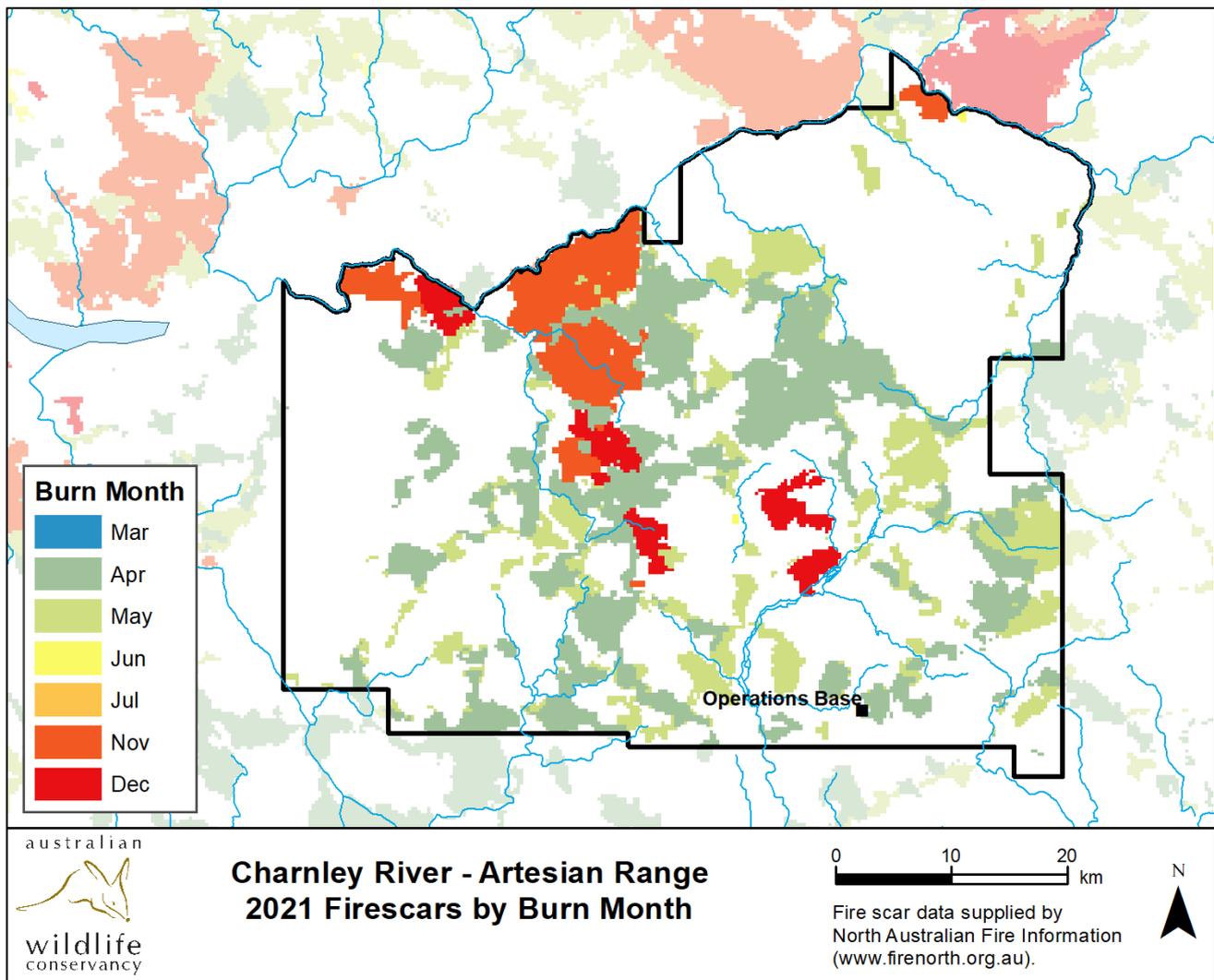


Figure 33. Map of fire scars by month on CRAR in 2021, with November and December the result of LDS unplanned fires which impacted central and eastern sections of the Artesian Range, eastern Sub-Artesian, and western sections of the Synnot Range. Ecological Priority Zone 1 sites were impacted, however, EDS scars, LDS suppression, and an above average wet season all combined to reduce LDS fire extent.

Discussion

The 2021 Ecohealth Report is the result of considerable survey effort in 2021. A total of 4,071 live trap nights, 8,586 camera trap nights, 448 km of transects, and 74 bird surveys were conducted as part of Ecohealth, with additional trial, inventory, and opportunistic surveys also taking place in 2021, outlined in survey reports. A total of 193 vertebrate species were detected by Ecohealth Surveys, and a total of 259 species were recorded when incidental observations and trial surveys were accounted for. Following an above average wet season for the first time in three years, the results of the 2021 Ecohealth Program showed evidence of a rebound in some biodiversity metrics on CRAR. Nonetheless multiple threats continue to put pressure on CRAR wildlife, threats which AWC will continue to monitor closely and aim to reduce and/or eliminate through science-informed conservation land management.

Against the backdrop of ongoing and widespread decline and extinction of Australian mammals since European settlement (Woinarski et al. 2011, 2015, Ziemnicki et al. 2015), and major gaps in biodiversity monitoring across Australia (Legge et al. 2018), it is critical that AWC enhances monitoring efforts for threatened and iconic species – including ground-dwelling critical weight range mammals. Some notable results from ongoing threatened species monitoring on CRAR include the persistence of the Northern Quoll in different regions of the property. Despite the incursion of the cane toad in eastern and central Charnley in 2018-2019, in 2021 Quolls still occupy several refugial sites in complex rocky habitat, particularly along the Munboon Escarpment, and gorges and outcrops of the Synnot Range. The status and viability of these

progressively isolated populations will continue to be monitored by AWC. The 2020-2021 wet season was particularly significant for the Northern Quoll in the Artesian Range, with the cane toad infiltrating the region from early 2020. Cane toads were detected for the first time in the region during the 2020-2021 wet season, whilst the abundance of Northern Quolls at standard monitoring sites in 2021 was shown to decline relative to the pre-toad levels. This provides initial evidence of a population decline linked to the cane toad invasion as inferred elsewhere across Northern Australia (Burnett 1997, Ziembicki et al. 2013), including AWC's Mornington Sanctuary. Given the complexity of Artesian Range terrain and the absence of feral cats in the region (unlike central and eastern Charnley), it is likely that Northern Quoll populations will persist in this region, with follow up monitoring planned in 2022 to assess population status.

Northern Brown and Golden Bandicoots (the latter listed as vulnerable) remain a key target complex for monitoring on CRAR. Surveys in 2021 illustrated the high relative occupancy of bandicoots on the Artesian Range and their occurrence in some refugial rocky areas on Charnley. Though both Golden and Northern Brown Bandicoots have been confirmed on the Artesian, only Northern Brown Bandicoots have been confirmed on Charnley and it remains unknown if the Golden Bandicoot is restricted to the Artesian Range. Additional targeted camera arrays and live trapping is planned to further monitor Bandicoot species, clarify species distribution and extent, and identify source populations of Golden Bandicoot for translocations to parts of its former range.

Other notable threatened species detections on CRAR include the detection of the Northern Brushtail Possum in southeast CRAR. This record significantly increases the known range of the threatened subspecies on CRAR, historically detected in western Charnley, particularly in the Sub-Artesian. The Northern Brushtail, like several other threatened and iconic species (e.g., Water Monitors), are not effectively monitored by current surveys and require additional targeted surveys which will be developed under Conservation Plans going forward.

The year 2021 saw an increase in biodiversity metrics for several surveillance assemblages - including a doubling in the abundance and richness of the small lowland mammal guild, likely associated with the above average wet season and an increase in resources and vegetative ground cover. Of the six species comprising the guild, all but one, the Delicate Mouse, showed an increase or remained stable in abundance and occupancy, with the Delicate Mouse showing a continual decline since 2017. The Delicate Mouse has been shown to be more abundant at sites characterised by higher disturbance (i.e., stocked sites and sites with higher fire prevalence) – indicating that this species declines under reduced habitat disturbance as planigale and other small mammal numbers increase (Radford et al. 2015, Legge et al. 2019). Overall results also show that the Artesian Range continues to be a stronghold for a number of Kimberley endemics that have declined elsewhere in their range (i.e., central and eastern Charnley) including the Monjon/Nabarlek, Golden-backed Tree Rat, Wyluda, Golden Bandicoots, and Kimberley Rock Rat.

Other notable findings for surveillance assemblages include a large increase in the activity, occupancy, and richness of the Rock Monitor Guild compared to 2020 on Charnley, with all 10 species of varanid confirmed on CRAR also detected in 2021 surveys, in the presence of toads. Larger-bodied reptile predators such as varanids, which prey on the toxic amphibian, are particularly vulnerable to population decline (Ujvari and Madsen 2009, Pearson et al. 2014). The small lowland reptile guild also showed a slight increase in abundance and richness relative to 2020. Small lowland reptile trends appear to be not as closely aligned with annual rainfall, compared with small lowland mammals, which show a more apparent association with rainfall.

Cattle and feral pigs were pervasive on CRAR, and are significant threats to the ecosystems and wildlife of CRAR by reducing habitat availability (Legge et al. 2019, Mihailou and Massaro 2021). As confirmed by the Aerial Feral Herbivore Survey and the Waterhole/Wetland Camera Array, cattle continue to reside throughout the destocked areas of the wildlife sanctuary, at similar levels since 2018, despite management input. An increase and targeted concerted effort will be made to remove cattle from sensitive and ecological priority areas and maintain and repair fence lines particularly in the early dry season to limit cattle escaping from the leased stocked area. There are also plans to install additional exclusion fencing around sensitive ecosystems on CRAR, including wetlands such as Lake Gilbert and Lake Doherty. Pigs were found to occupy one third of the waterhole and wetland sites monitored in 2021. This survey was used to target some control measures in 2021 and will continue to inform the Feral Pig Management Strategy on CRAR, which aims to suppress pig numbers and reduce their damage to riparian and wetland habitats.

Both cane toads and feral cats remain significant direct threats to CRAR wildlife. Cane toad distribution now covers 100% of CRAR Wildlife Sanctuary which likely occurred from early 2020. The status and decline of species most at risk to toad toxin across the entire property will continue to be assessed. Interestingly, cat detectability remains extremely low in the Artesian Range with no detections by camera traps in 2021. Feral cats remain pervasive, however, in the Synnot Range, and the grassy plains and rocky outcrops of eastern Charnley likely due to the lower habitat structural complexity of these regions (Stobo-Wilson et al., 2020). With no effective method to eliminate cats from the landscape, AWC continues to indirectly counter cat predation by improving habitat condition through the Ecofire program. Fire regimes have improved markedly on CRAR since AWC management, and this has likely had a positive impact on native flora and fauna. For example, increasing the amount of, and decreasing the distance to, unburnt (and long unburnt) vegetation, provides protection from feral predators for ground-dwelling mammals and birds that forage in recently burnt areas and shelter in long-unburnt vegetation (Legge et al. 2008). Furthermore, reducing high intensity fires, and increasing habitat heterogeneity (pyrodiversity) and long-unburnt vegetation enhances the establishment of mature denning and fruiting trees, and the health of grassland species, which many species depend on for sustenance (Hohnen et al. 2015, 2016a, Weier et al. 2018). 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.

Ecofire and Ecohealth Programs will continue to be implemented in 2022 and beyond on CRAR Wildlife Sanctuary. Looking ahead, several new or redesigned standardised surveys to improve the monitoring of assemblages and threats are planned from 2022, including the Charnley Bandicoot Lowland Camera Array (and live trapping), Charnley Arboreal Mammal Camera Array, Charnley Varanid Camera Array, and Charnley Predator Camera Array. Additional targeted surveys for threatened and iconic species will also be developed in coming years - aligned with species Conservation Plans under development. This may include, for example, the continuation of the Charnley Northern Quoll Targeted Research Survey which was trialled in 2021 as part of the Northern Quoll Persistence Research Program.

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