Western Shield Monitoring Results: Mammals — trapping transects and camera monitoring to December 2022



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PARKS AND WILDLIFE SERVICE
western shield

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Contents

Acknowledgements

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Summary

Western Shield (WS) aims to recover and sustain wild populations of Western Australian native fauna through broadscale introduced predator management. To support this, fauna populations and introduced predators are monitored to determine the efficacy of WS management. Monitoring results are presented below on four native mammal species — koomal (*Trichosurus vulpecula hypoleucus*), woylie (*Bettongia pencillata*), chuditch (*Dasyurus geoffroii*) and quenda (*Isoodon obesulus*), for the period 1996 to 2022. In addition, preliminary information on two additional species, quokka (*Setonix brachyurus*) and black-flanked rock-wallaby (BFRW: *Petrogale lateralis lateralis*) is provided along with summaries of introduced predator activity at targeted sites.

A total of 32 sites were monitored for native fauna using mark-recapture methods in 2022. Of these 29 sites were monitored using WS cage trapping methods[1], and three sites using Thomas traps set to target either quokka or black-flanked rock-wallaby. Targeted camera monitoring (occupancy) or point count monitoring was also conducted at 15 sites specifically for quokkas, at two sites for black-flanked rock-wallaby and at 22 sites for predators[2].

The number of sites monitored using mark-recapture methods has declined since 2015 and this continues to have significant impacts on WS's ability to effectively report on population trends for focal species. It is important that at a minimum, monitoring data is collected from those sites recommended in the *Western Shield Monitoring Plan 2021 – 2024*. Of the 29 sites monitored using cages in 2022, two sites were newly established in 2022, four sites are outside of the WS footprint and will act as reference sites in long-term analysis, resulting in just 23 long-term monitored sites monitored in 2022 within the baited footprint, compared to 41 in 2010.

The relative abundance of woylies remained within anticipated natural variation in 2022 at most of the primary strongholds, however the species distribution has remained low, with only 34% of sites recording the species in the period 2018 – 2022, compared to 47.2% between 2002 and 2006. Further management efforts are likely to be required to ameliorate threatening processes at some locations to facilitate improvements in the woylie distribution and population size.

Occupancy modelling of standard cage monitoring indicates that chuditch expanded their area of occupancy in the period 1996 – 2018. However, from 2019 the number of sites recording chuditch in standard cage monitoring declined substantially. The implementation of chuditch specific monitoring at 11 sites in 2022 recorded eight sites with chuditch present, six of which are long term monitoring sites under WS or district programs. Capture rates of chuditch at all six of these long term WS sites were substantially higher using chuditch specific methods than that recorded in standard WS monitoring and ongoing monitoring of these sites using these modified methods will improve our capacity to understand population trends for this threatened species into the future.

Koomal continue to be the most commonly recorded species at WS cage trapping transects. However, the relative abundance of the species at key sites continues to demonstrate declines. At a state level, occupancy modelling using presence/absence of koomal in cages suggests declining trends in the periods 2010 – 2013 and 2015 – 2017. There has been a slight upward trend in occupancy in recent years.

There has been a substantial increase in occupancy of quenda at monitoring sites from 2021 to 2022, contrasting with the declining trend from 1996 – 2020. External factors such as changes in rainfall may influence the density and hence detectability of this species. The ongoing low captures of the species

[1] Noting that although they use WS methods some sites are monitored under district programming.
[2] Districts have indicated that additional sites were monitored however the details were not available for this report.

using WS cage monitoring methods suggests that it will be important to consider alternative monitoring methods to determine trends at the population level.

Quokka monitoring is largely conducted under district programs. Only one site has collected long-term mark-recapture monitoring. This population continues to show positive trends, with abundance increasing in recent years. Monitoring of black-flanked rock-wallabies indicates positive population trends with either increasing abundance or point counts across most sites including the population translocated to Kalbarri National Park. The only exception to this appears to be Cape Le Grand.

A total of 22 sites are now monitored for introduced predators on an annual basis as part of WS or associated programs. Information gathered from sites indicates that fox activity is suppressed in baited areas compared with non-baited control sites. This is particularly evident at sites with regular baiting throughout the year, emphasising the importance of the maintenance of ground baiting transects at sites particularly those with low frequency aerial baiting (i.e., less than 6 events/annum). Further examination of data on feral cat activity is required to inform the management of this species more effectively across a range of biomes.

Introduction

Western Shield (WS) aims to recover and sustain wild populations of Western Australian native fauna threatened by foxes and feral cats through broadscale introduced predator management. Currently, the primary method used to manage foxes and feral cats is landscape scale deployment of toxic baits with the aim of reducing predation pressure on native wildlife in managed areas. In some circumstances, baiting is complemented with other management actions such as trapping and/or fencing to provide additional protection to vulnerable species. Translocations (i.e., wild to wild and captive managed to wild) may also occur to augment conservation efforts for some species.

To assess the effectiveness of introduced predator management, WS monitors native fauna populations (Figure 1). To date, this monitoring has targeted populations of fauna in the south-west of the state. This monitoring assumes that if WS management is effective, populations of native mammal species sensitive to feral cat and/or fox predation will be maintained or improved at these sites provided no other threatening process is impacting the monitored species.

Monitoring targets four native mammal species (primary species). These are koomal, also known as common brush-tailed possum (*Trichosurus vulpecula hypoleucus*), woylie (*Bettongia pencillata*), chuditch (*Dasyurus geoffroii*) and quenda (*Isoodon obesulus*). These species are medium-sized mammals that are known to respond positively to introduced predator management and are relatively easily captured using simple cage trapping techniques. State level summaries are presented for each species for the period 1996 to 2022 and include WS data and district programs that employ WS cage monitoring methods. Where possible, additional data collected from other DBCA projects that monitor quokka or black-flanked rock-wallabies have been included to provide information on the response of native species to management in areas where the four primary species are either sparse or absent.

Commencing in 2015, camera monitoring has been implemented across a broad range of habitats. Where available, results from camera monitoring have been presented providing information on threatened species, foxes and feral cats. This data will be vital in providing more comprehensive information on species distribution and the activity of feral predators relative to different baiting regimes in the long-term.

Unless otherwise stated, information presented in this report is based on raw data. Updates to the 2017 modelling will be conducted once two years of data from the *Western Shield Monitoring Plan 2021 – 2024* (Department of Biodiversity, Conservation and Attractions 2021) have been collected. The modelling will assist in understanding the significance of population fluctuations of the four primary species and will incorporate explanatory covariates (e.g., fire, temperature, vegetation health, habitat fragmentation, rainfall, etc) that may impact on the trajectory of populations of native fauna.

State summary: Distribution and relative abundance of key species in the south of the state

Standard WS monitoring uses cage traps lured with universal bait (i.e., peanut butter mix with oats and sardines). Cages are set every 200 m along unsealed tracks and typically set for four nights. Trap effort varies at each location (see Appendix 1 for details for each site). All data presented below has been standardised relative to trap effort to enable effective comparison between sites. A total of 29 sites were monitored using cage traps in 2022 (Figure 1), six greater than in 2021 and 30% less than in 2010 (Figure 2). This trap effort continues to be lower than the minimum of 36 recommended under the Western Shield monitoring plan (Department of Biodiversity, Conservation and Attractions 2021). Four of the 29 sites monitored in 2022 are control sites (i.e., outside of the WS management area — Moore River[3], Nambung, Porongorups, and Stene), providing information on fauna populations in areas with no active DBCA fox or feral cat management.

Camera monitoring for predators involves the use of automated wildlife cameras set to take three images per trigger. Camera locations are chosen using a random point generator for each site with a minimum distance of 1.5 km between each point (for details on camera monitoring methods see Drew (2018)). The number of cameras at each location varies according to district capacity or project (see Appendix 1 for details). Data collected from predator cameras provides information on the effectiveness of different bait prescriptions. In addition, targeted camera monitoring has been used at several sites to monitor for threatened species. Cameras at these sites are placed in habitat areas most likely to support the target species. Sites with active camera monitoring in 2022 are highlighted in Figure 1, noting that some sites are monitored through district or third-party programs (e.g., Project Numbat, Numbat Taskforce, etc.). Modelling has not been completed for camera data and all figures on fox and feral cat activity are based on raw camera detections.

Occupancy modelling (presence/absence) using the unmarked program (Fiske and Chandler 2011) in R (R Core Team 2020) was used to model long term trends for the four primary WS species across 43 of the most frequently monitored sites (cage monitoring only: 1996 to 2022). The sites included in the analyses and methods used are provided in Appendix 3.

[3] Moore River has a 6.7 km tethered Probait transect. The majority of the monitoring is conducted away from the ground baiting transect.

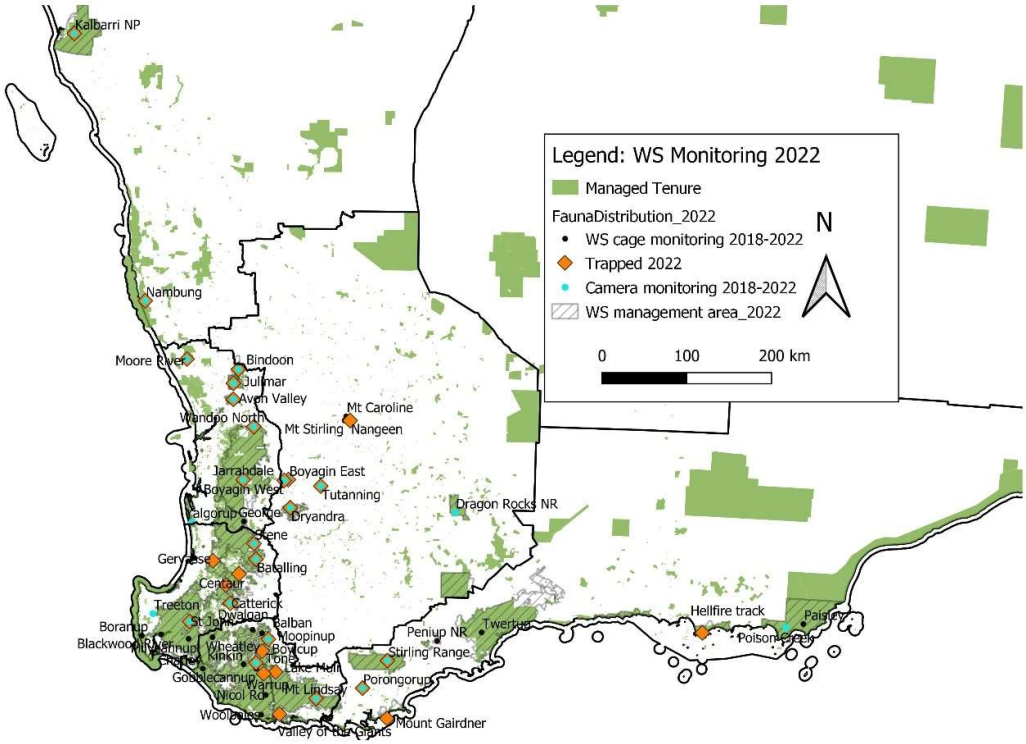

Figure 1: Map indicating the distribution of monitoring sites across the south of the state. Sites marked with an orange diamond were monitored with traps in 2022, black dots are sites that have been monitored at least once in the last five years and light blue dots indicate active camera monitoring in 2022. Note some of the sites indicated are not official WS sites but use the same or very similar methods. Monitoring at Kalbarri, Mt Caroline, Mt Stirling, and Nangeen use Thomas traps, trapping at Gervasse uses both cage and Thomas traps.

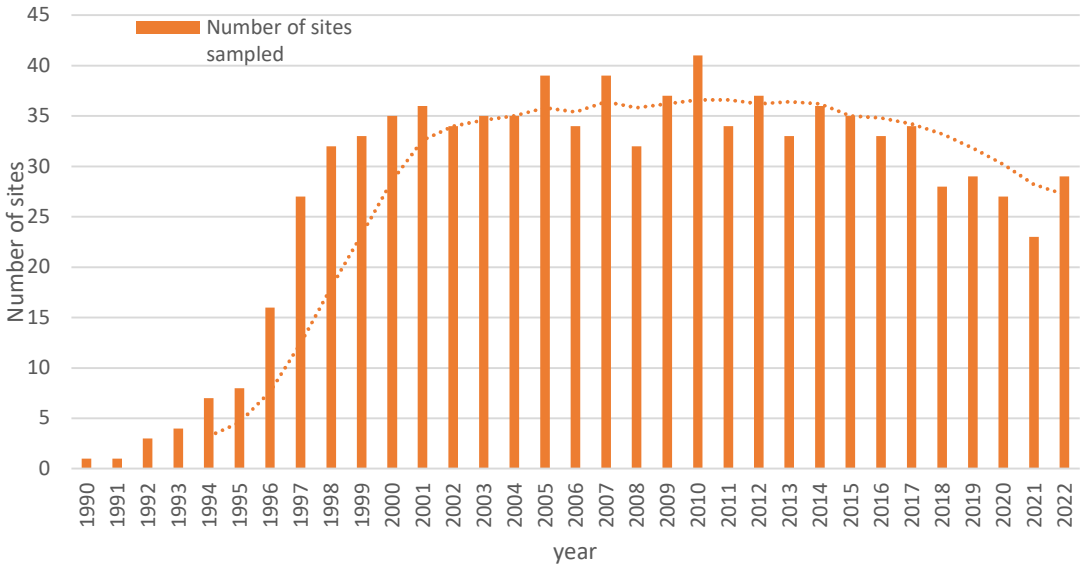

Figure 2: Number of sites monitored using WS standard cage monitoring methods each year. The dotted line represents the average number of sites monitored every five years.

Woylie

The number of sites where woylies were captured in WS or associated district cage trapping has steadily declined since the early 2000s, with only 34% of sites monitored 2018 – 2022 (N = 38 sites monitored) recording woylies. This compares to 42.5% of sites in the period 2012-2016 (N = 37 sites monitored) and 47.2% between 2002 and 2006 (N = 41 sites monitored). Occupancy modelling[4] indicates that overall woylie distribution has declined in the period 2013-2022 (Figure 3) and occupancy levels remain lower than that recorded at the commencement of Western Shield.

A total of 10 sites recorded woylies in 2022 using standard WS cage trapping. This is one less than in 2021. Notably woylies were captured in cage traps at Tutanning in 2022 for the first time since 2010. Woylies had not been detected in cages at this site since 2010, although they had been detected at this site on camera. Five sites recorded woylies on camera between 2018 – 2022. A total of 15 sites detected woylies in cage or camera monitoring in 2022 (

Figure 4).

Figure 5 summarises the relative abundance of woylies over time at key cage monitoring sites. Numbers decreased slightly at Boyagin East and West and Dryandra in 2022, and remained steady or increased at Batalling, Boyicup, Centaur, Moopinup, and Warrup (

Figure 5).

[4] Occupancy modelling using the "unmarked" package: Models for data from unmarked animals in R with up to four visits per secondary survey and up to two per primary survey for each site each year.

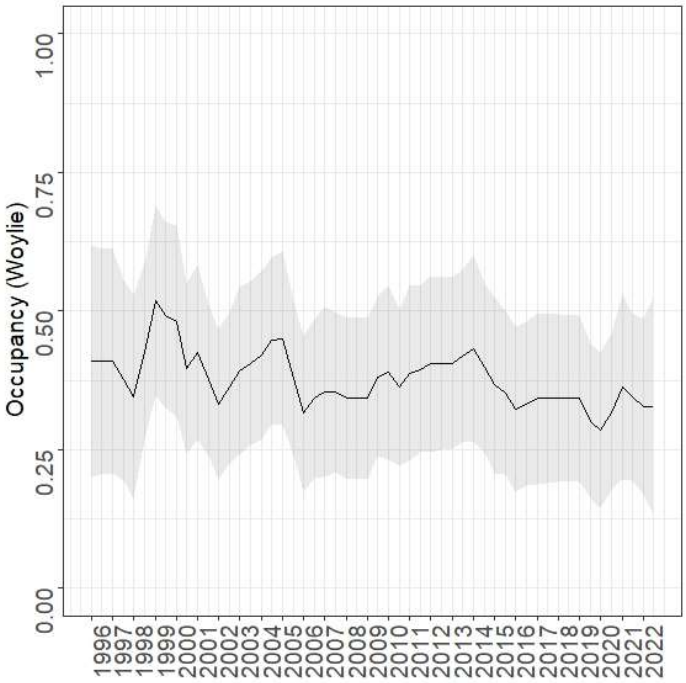

Figure 3: Modelled occupancy of woylies based on cage monitoring at WS monitoring sites (N = 43) 1996 – 2022 (x-axis = Year). Grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data. Larger confidence bounds usually reflect periods of lower trap effort.

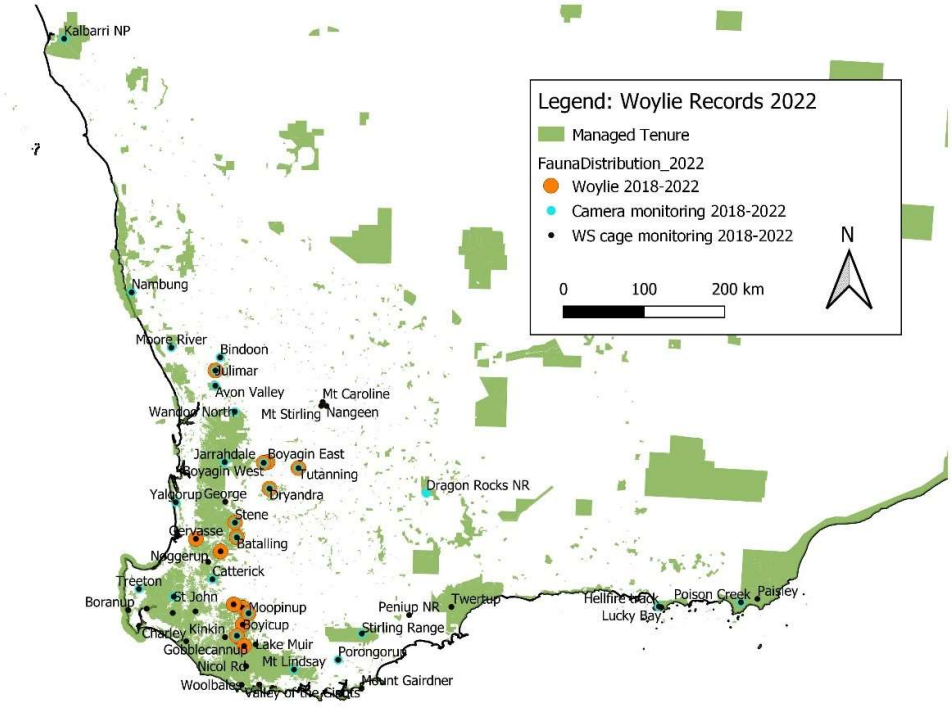

Figure 4: Sites where woylies were captured in cage trapping or noted on camera monitoring 2018 – 2022 (orange dots). Black dots indicate sites that were monitored at least once between 2018 and 2022 using WS cage monitoring methods and blue dots using automated wildlife cameras.

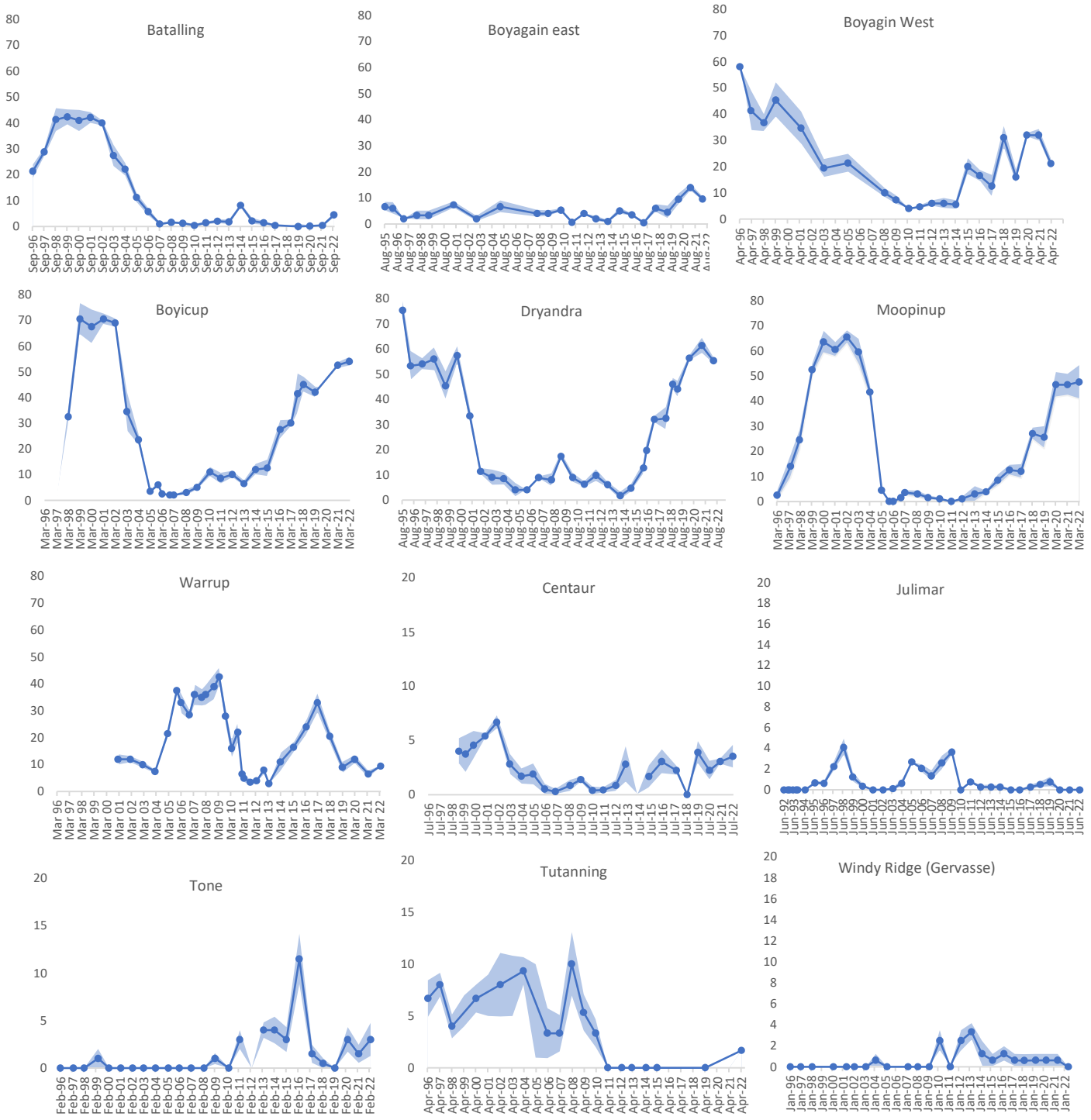

Figure 5: Average daily capture rates of woylies at key woylie sites in the south-west of WA. Blue shading indicates the standard error. Note: the scale is adjusted for high and low capture sites and care should be taken when comparing figures. Boyagin East to Warrup are high performing sites, Centaur to Windy Ridge, low performing sites.

Chuditch

Overall, there has been an increasing trend in the number of sites where chuditch have been detected in cages (1996 – 2019). However, from 2019 onwards there has been a concerning decline in the number of sites recording this species (Figure 6). This decline stabilised in 2021-2022.

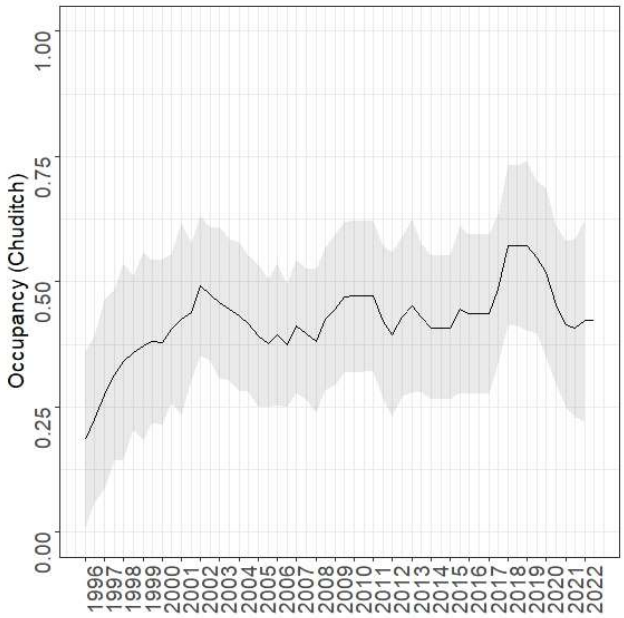

Figure 6: Modelled occupancy of chuditch at WS cage monitoring sites (N=43) 1996 – 2022 (x-axis=Year). The grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data — this usually reflects periods of lower trap effort.

A total of 14 sites recorded chuditch using WS cage methods in 2022, one more than in 2021, noting that one of the sites was monitored for the first time in 2022 as a non-baited reference site. Chuditch were also detected at Kalbarri National Park and St Johns (Sunklands, Blackwood District) on cameras, bringing the total number of sites recording the species as part of standard WS monitoring in 2022 to 16. In the period 2018 – 2022 chuditch have been recorded on camera and/or in WS cages at 27 locations (Figure 7), noting that this excludes the data from targeted chuditch monitoring sites which use different methods. The relative abundance of chuditch captured at a site level using WS methods remains low (

Figure 8).

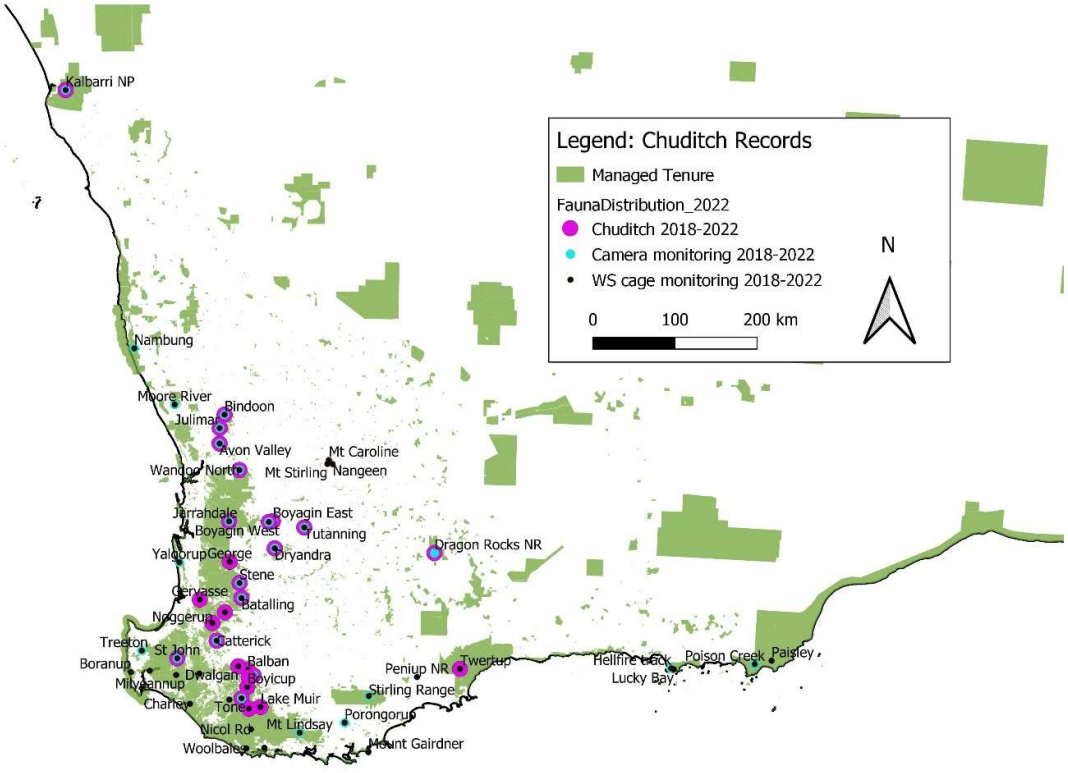

Figure 7: Sites where chuditch were captured in cage trapping or detected on camera monitoring 2018 – 2022 (pink dots). Black dots indicate sites that were monitored at least once between 2018 and 2022 using WS cage monitoring methods and blue dots using automated wildlife cameras. Note that this data excludes targeted chuditch sites (see Chuditch specific monitoring for further details).

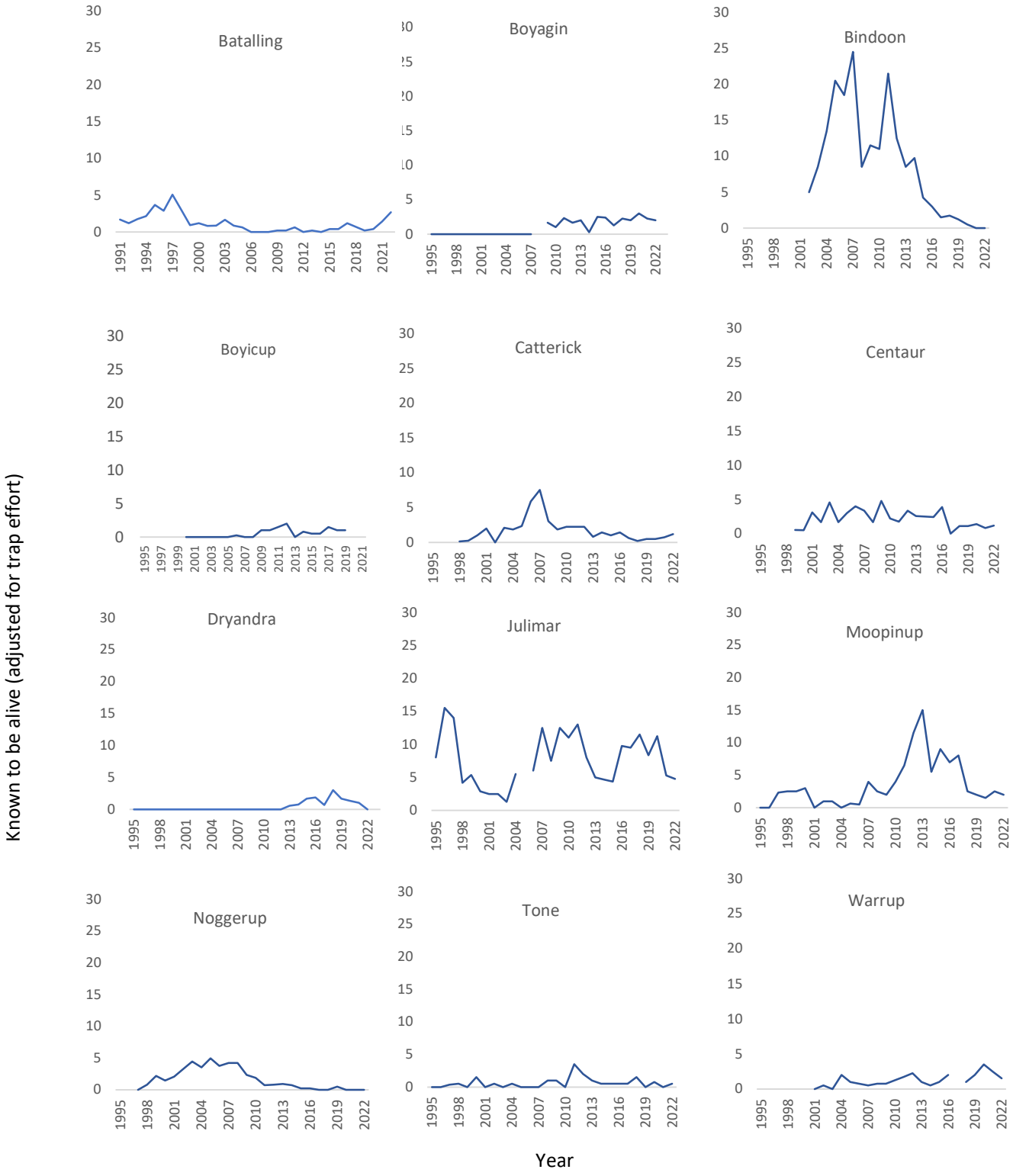

Figure 8: Known to be alive (KTBA) adjusted for trap effort (y-axis) of chuditch across WS and district monitoring sites, where chuditch are regularly captured. X-axis = year. Note that the number of animals recorded in each year will be adjusted based on captures in subsequent trapping events. This data excludes chuditch specific monitoring.

Chuditch specific monitoring

Funding received through DBCA Regional Priorities, Alcoa Foundation, and Taronga Zoo was used to continue chuditch specific monitoring in 2022. This is a collaborative project between Biodiversity and Conservation Science, Conservation and Ecosystem Management and Regional and Fire Management Services (2020 – 2022). Chuditch specific monitoring was conducted at 10 sites in 2022 and additional data was collected by Australian Wildlife Conservancy as part of a translocation and the data was shared with DBCA (Figure 9). Cage traps were lured with chicken and cages were set every 500 m along unpaved tracks near or along WS transects. Trapping was conducted February to July 2022.

Chuditch were captured at eight of the 11 sites surveyed: Ravensthorpe/Cocanarup, Tone-Perup, Dryandra, Batalling, Jarrahdale, Centaur, Catterick and Julimar[5]. Ravensthorpe and Centaur yielded the lowest captures with a success rate of 0.9 % and 1 %, respectively. Dryandra and Julimar yielded the highest chuditch capture rates at 15 % and 13.5 %, respectively (Figure 10). Sites with the lowest captures (Ravensthorpe, Centaur, Jarrahdale and Catterick) were newly established, and some had not been monitored for fauna in recent years. Repeated surveys may result in an increased capture rate due to trap habituation.

No chuditch were captured in cages or on camera at Peak Charles, Ex Jaurdi Station or Helena and Aurora Ranges, suggesting that the species either occurs at densities below detectable levels or is absent from the area. Camera monitoring will be implemented in 2023 at both locations to assess if the species is still present at these sites. Chuditch specific monitoring will be repeated in 2023 at all sites which recorded chuditch in 2022 and will also be established at three new sites (N = 12, 2023).

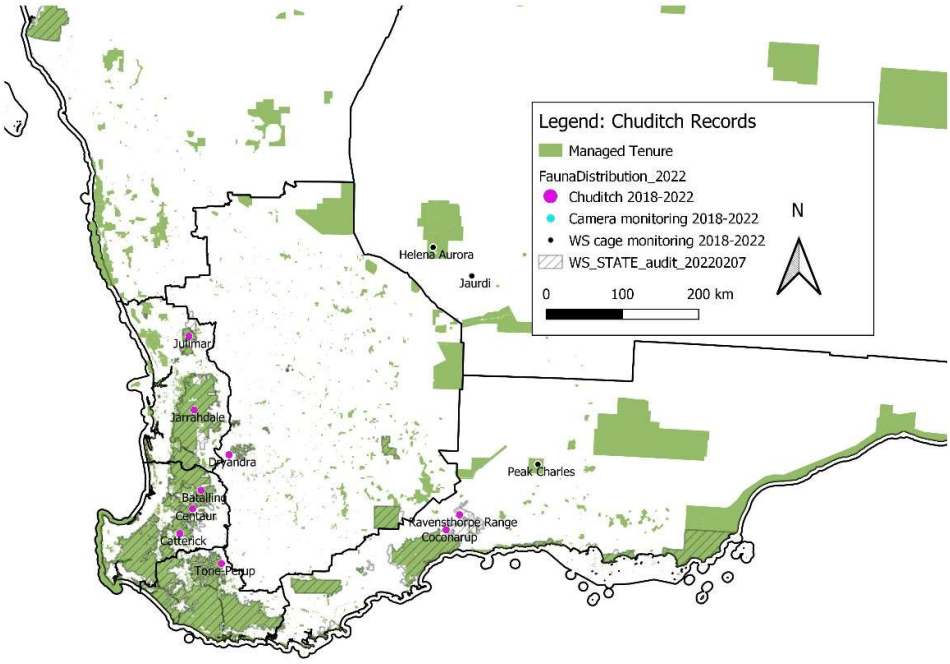

Figure 9: Location of chuditch specific monitoring sites surveyed in 2022, pink dots indicate sites where chuditch were detected.

[5] Julimar trapping was conducted by AWC and the data kindly shared with Western Shield.

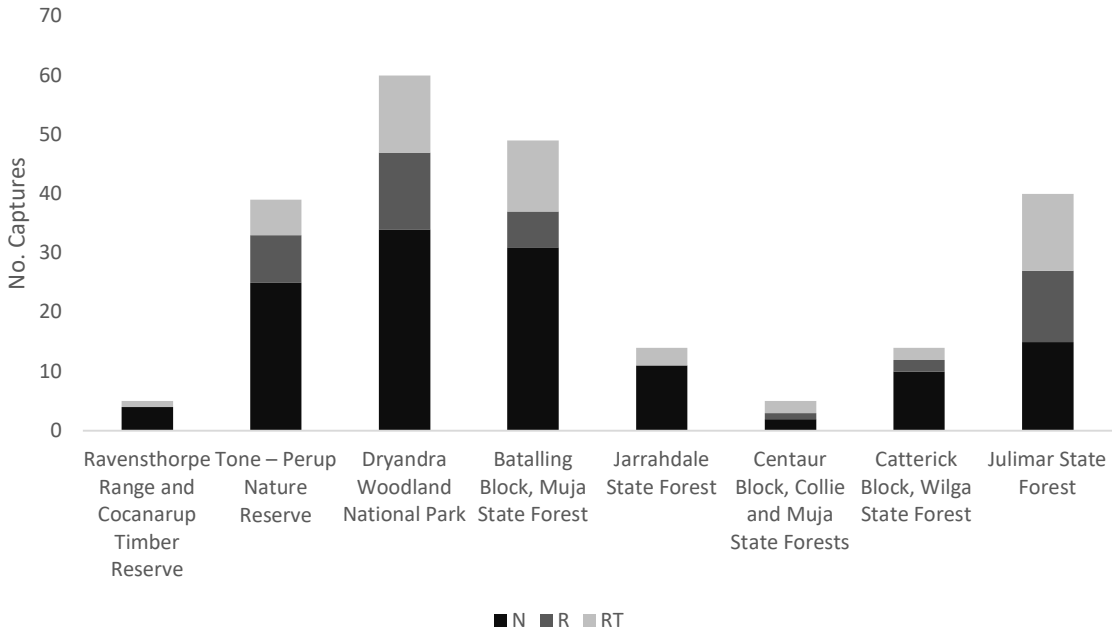

Figure 10: Number of chuditch captured in each location. Recaptures are important for population density estimates. New (N) = never been captured, Recapture (R)= captured in a previous-session/year (R) and Retrap (RT) retrapped same-session/year. Note that Jarrahdale and Ravensthorpe had not been recently trapped and therefore recaptures were highly unlikely.

Koomal

Koomal are the most frequently captured medium-sized marsupial in WS cage trap monitoring. The number of sites where this species was detected increased rapidly after the introduction of fox baiting in the mid-1990s and by the early 2000s over 70% of monitored sites recorded this species (Figure 11). However, between 2006 and 2013 occupancy of this species has steadily declined. There has been recovery in recent years however occupancy again declined in 2022. This may relate to reduced monitoring of some sites, reflected in the larger confidence bounds in 2022.

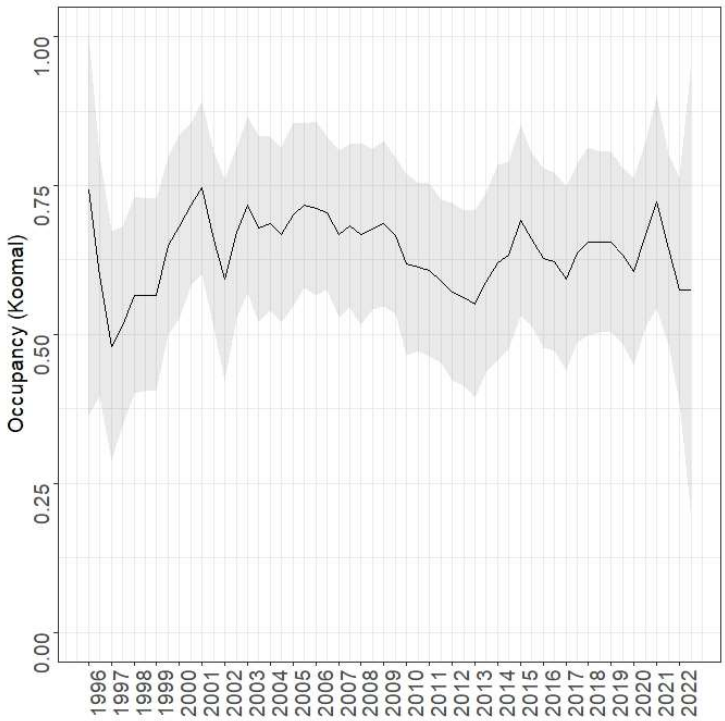

Figure 11: Modelled occupancy of koomal based on cage monitoring at WS monitoring sites (N = 43) 1996 – 2022 (x-axis = Year). Grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data — this usually reflects periods of lower trap effort. Note that in 1996 only a single site was monitored.

Several sites that had not recorded koomal in cage monitoring did record the species on camera in 2022 e.g., Yalgorup, and Walyunga (both baited as part of WS) suggesting that although the species persists at these sites, densities are likely very low. Koomal were also identified on camera at Dragon Rocks and in three non-baited controls, Porongorups, Treeton, and Stene (Figure 12). Data from camera monitoring indicates that although koomal persist at sites without active cat or fox management, koomal detections are significantly lower at these sites compared to baited areas (Figure 13).

Koomal relative abundance

The number of koomal known to be alive has declined at most monitored sites, except for Warrup (

14). It is probable that observed declines in their abundance at Boyicup, Dryandra and Moopinup may be a result of higher capture rates of woylies, which has resulted in fewer traps being available for koomal (Figure 15). Data indicates that once woylie captures start to exceed 35 – 40% of captures, koomal capture rates start to decline. Camera monitoring at Dryandra has suggested that koomal detections although variable over time have not declined in the period 2015 – 2022 (Figure 16). Therefore, it is likely that the downward trend in cage capture rates at Dryandra does not reflect a true decline in the species. However, observed declines in captures of koomal at sites which have low captures of other species (e.g., Stirling Range, St Johns, Tone, see Figure 14) are of concern as they are likely representative of a population decline of koomal at these locations.

Notably, koomal does remain the most common mammal species recorded at most cage monitored sites. Declines in this species are likely indicative of possible declines in rarer species that have similar threats.

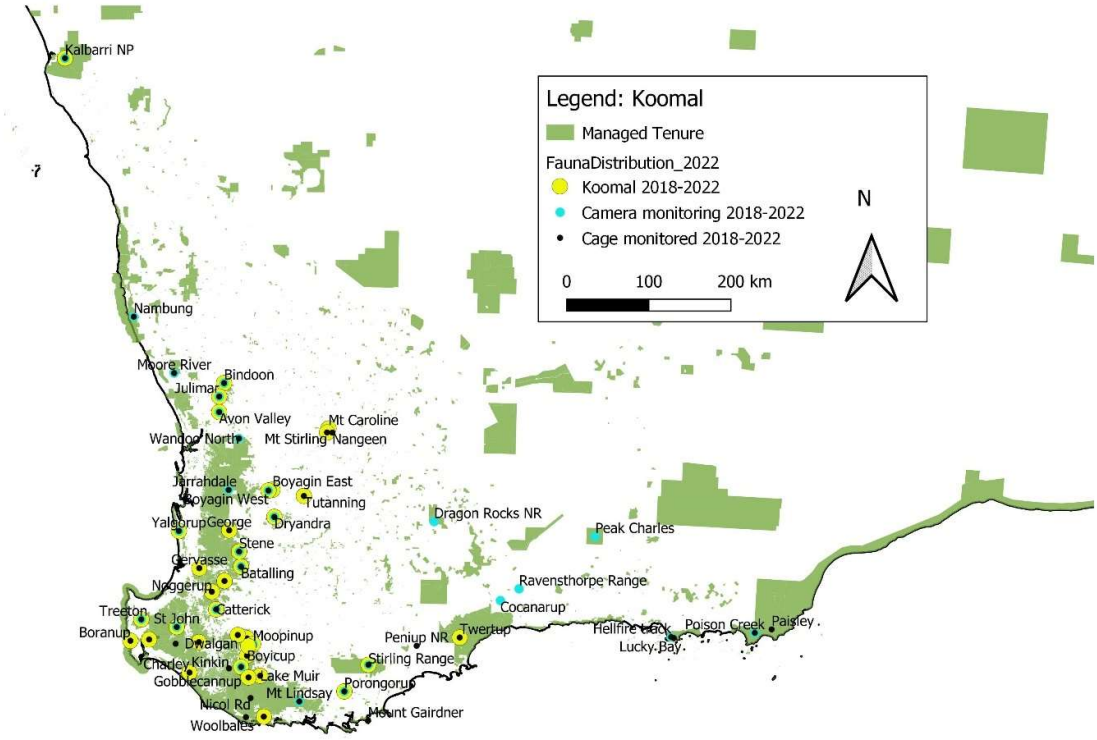

Figure 12: Sites where koomal were captured in cage trapping or detected on camera monitoring 2018 – 2022 (yellow dots). Black dots indicate sites that were monitored at least once between 2018 and 2022 using WS cage monitoring methods and blue dots using automated wildlife cameras.

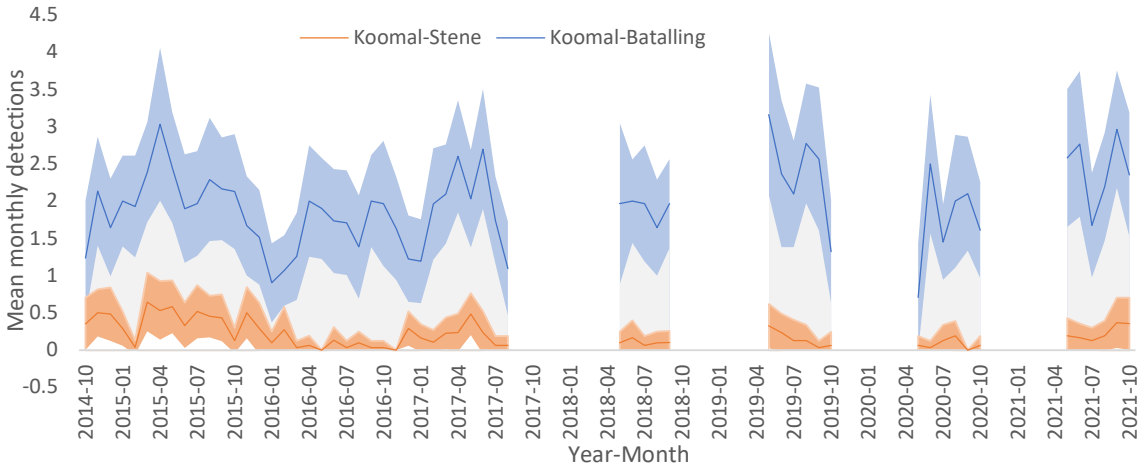

Figure 13: Mean monthly detections of Koomal on camera at Batalling (4 x aerial Probait events/annum) and Stene (no current fox or feral cat management).

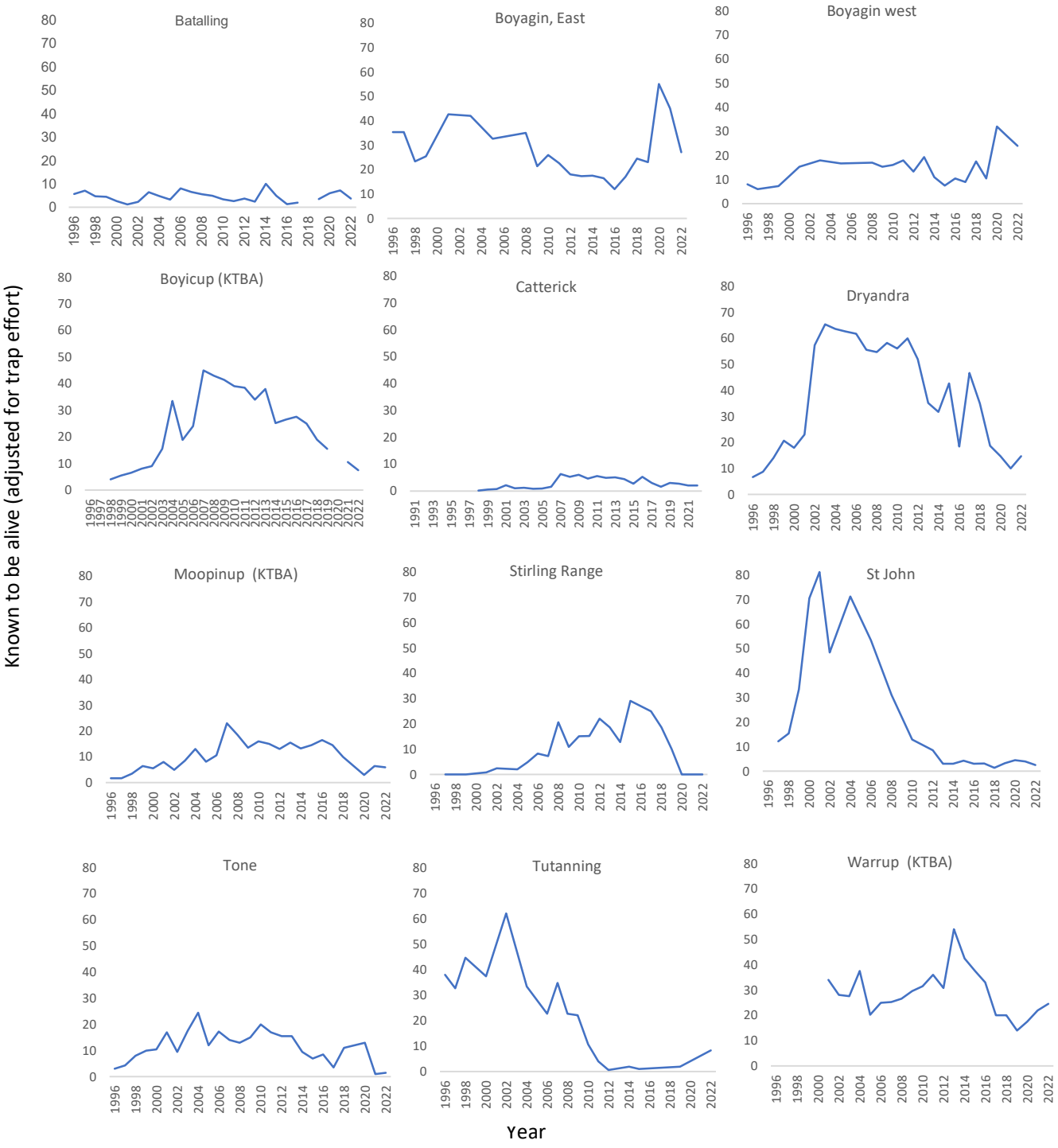

Figure 14: KTBA (adjusted for trap effort; y-axis) for koomal at selected WS sites (x-axis = year). Note only 12 sites with the highest captures are included.

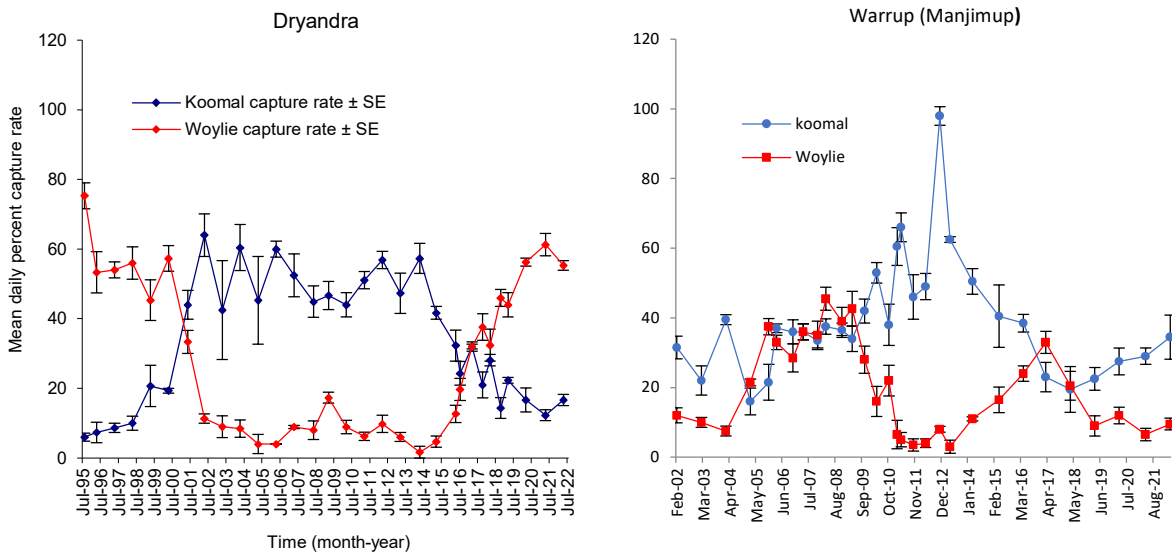

Figure 15: Changes in captures of koomal relative to captures of woylies at Dryandra main block and Warrup (Manjiump cell). Error bars = standard error.

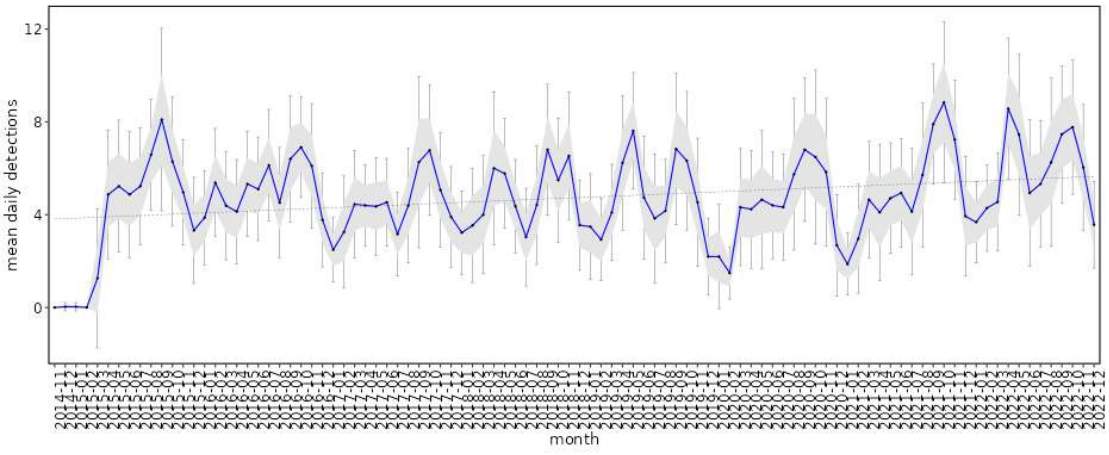

Figure 16: Mean daily detections of Koomal at Dryandra 2014 – 2022.

Quenda

From 1996 to 2019, the general trend has been a decline in the number of sites in which quenda have been detected (Figure 17), with occupancy at its lowest in 2013 and 2019. A substantial increase in occupancy in recent years (2020 – 2022: Figure 17) may relate to improved rainfall across the south-west. Reproductive output in the species is strongly linked to increasing photoperiod and rainfall, with litter sizes often reduced in drought periods (Copley et al. 1990). Successful recruitment has been linked to the quality of the habitat and the abundance of food supply, with dense understorey habitat and supply of subterranean food resources important for successful recruitment and dispersal (Department of Environment and Conservation (NSW) 2006), both of which are linked to rainfall and the local fire regime. Detailed analyses are still to be conducted to help understand the possible determinates of variations in quenda occupancy across the south-west of WA.

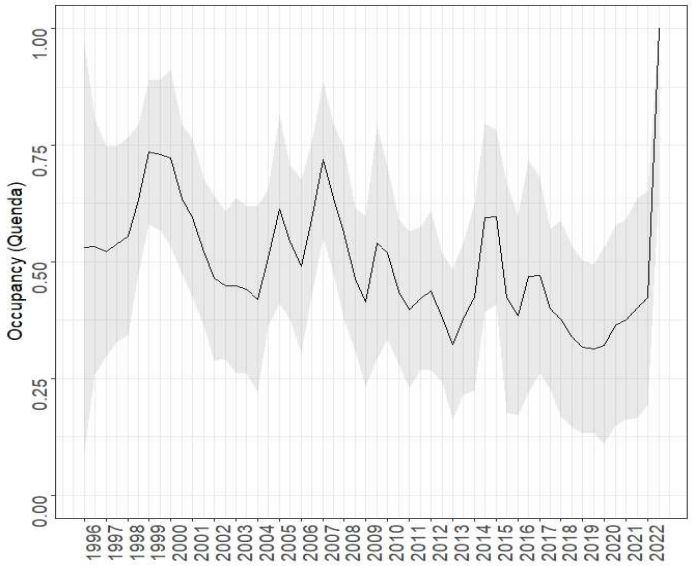

Figure 17: Modelled occupancy of quenda based on cage monitoring at WS monitoring sites over time (N=43). Grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data — this usually reflects periods of lower trap effort. Note that in 1996 only a single site was monitored.

Camera monitoring identified quenda at St Johns and three non-baited control sites, Stene, Treeton, and Porongorups, bringing the total number of sites with quenda present to 13 of the 30 sites sampled (29 cages and cameras and one quokka monitored site) in 2022 and 29 of the 52 sites sampled in the last five years (Figure 18). No quenda were detected on cameras at Moore River, or at the non-baited control sites: Nambung and Wandoo.

The relative abundance of quenda at monitored sites has remained low since the early 2000s (Figure 19) and capture rates are too low for detailed mark-recapture analyses. However, notably a change in lure from apples only to apples dipped in peanut butter occurred at Quokka Swamp from 2019 and capture rates of quenda increased substantially 2019 to 2022 (Figure 19: Quokka Swamp). It is possible that the change in bait has improved the quenda detection at Quokka Swamp compared to other sites. This suggests that to adequately sample this species more species-specific monitoring may be necessary.

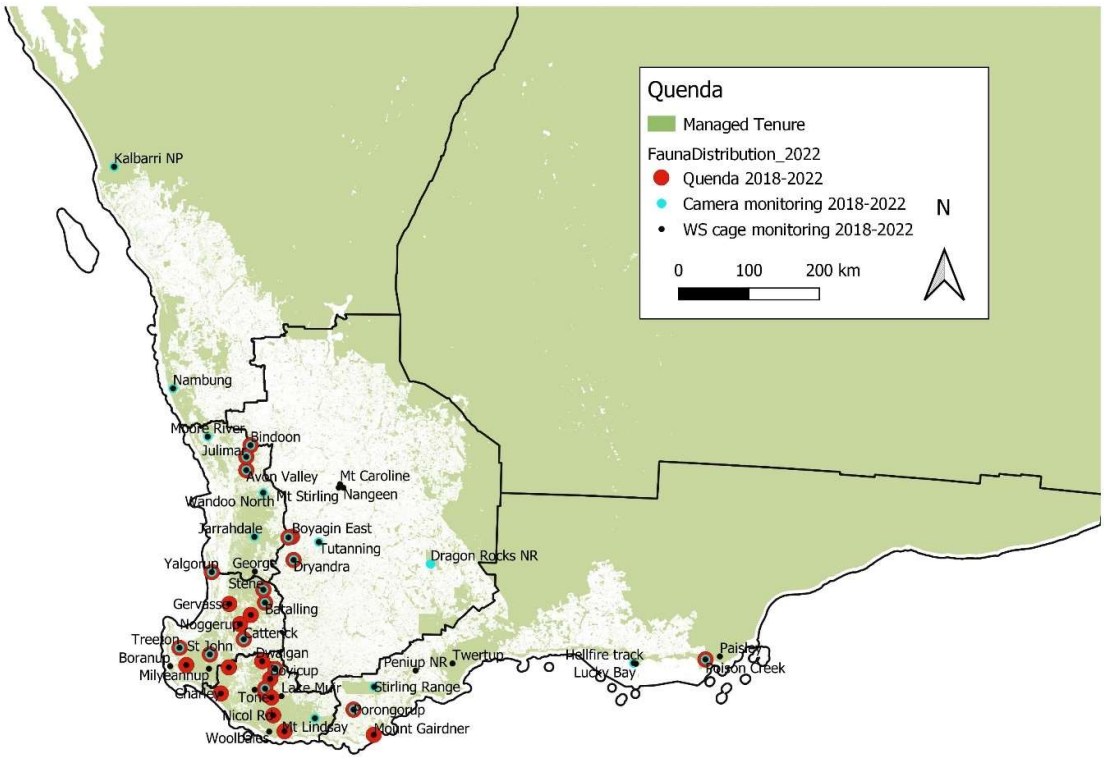

Figure 18: Sites where quenda were recorded in cage trapping using WS methods, quokka monitoring or camera monitoring 2018 – 2022 (red dots). Black dots indicate sites that were monitored at least once between 2018 and 2022 using cage trapping and blue dots camera monitoring.

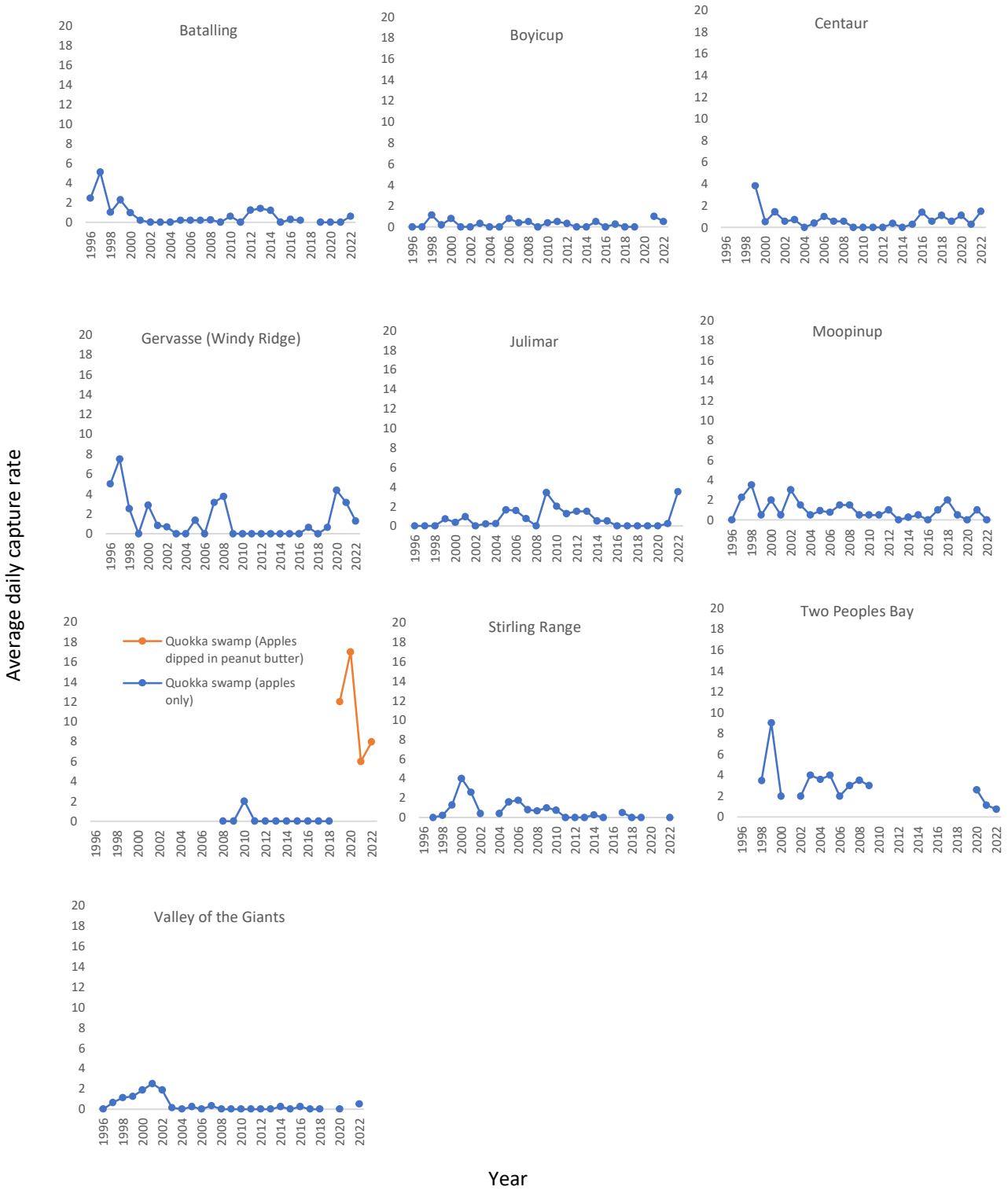

Figure 19:Average daily capture rates at selected sites with frequent captures of quenda across the south-west of Western Australia. Quokka Swamp uses Thomas traps rather than cages and in 2019 implemented a change of bait (orange line) to better target quokkas, this may have also increased quenda captures.

Quokka

Quokkas are known to occur in several WS cells on the mainland. Data is usually collected as part of planning for prescribed burns or other management activities and to date has only been implemented under WS in three districts. Ideally standardised monitoring should be implemented across the quokka's mainland range. Below is a summary of data provided through the quokka recovery team, together with any quokka records from WS or district predator monitoring. It is noted that some sites may have conducted targeted quokka monitoring but not reported this monitoring if quokka were not detected. Camera monitoring for the species was reported for 14 sites between 2021 and 2022 and identified quokka at 10 locations (Table 1). Notably the record at Mt Lindesay is the most eastern record for Frankland District since 1975.

In addition to the 10 camera locations, quokka were also captured at two mark-recapture monitoring sites in 2022 (one Thomas trapping, one cage trapping), resulting in the species being recorded at a total of 15 sites between 2018 and 2022 (Figure 20).

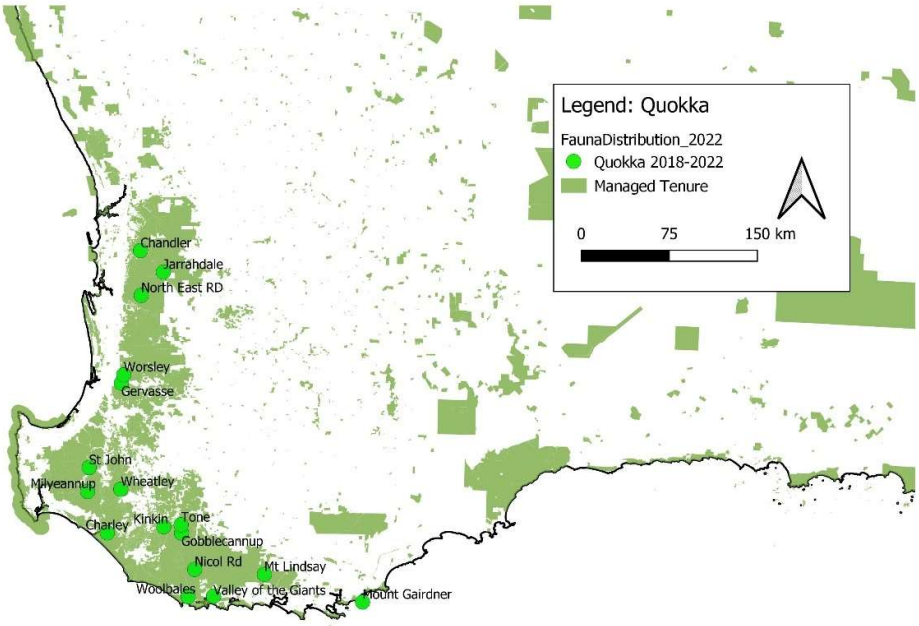

Figure 20: Sites where quokka were captured in traps or on camera 2018 – 2022 (green dots). Monitoring for quokka is limited and generally targeted to likely habitats. Ad hoc monitoring is associated with known disturbance events, such as prescribed burns.

Table 1: Summary of quokka records using camera monitoring in the south-west of WA in 2022.

WS cell	Location (monitoring type)	Number of cameras active (trap nights)	Monitoring Period	Number cameras recording quokkas
Perth Hills	Amphion	1 (48)		0
Perth Hills	Hollyoak — North east Rd (ad hoc)	7 (462)	21/2/2022 – 27/04/2022	2
Perth Hills	Inglehope (ad hoc)	1		0
Perth Hills	Jarrahdale (Chandler- ad hoc)	4 (220)	03/03/2022 – 27/4/2022	2
Shannon	Gobblecannup (targeted)	50	February 2022	7
Denbarker	Mt Lindesay (targeted)	10	13/5/2022 – 13/6/2022	1
Sunklands	Milyeannup (targeted)	10 (700)	4/3/2021 – 13/5/2021	5
Shannon	Tone (predator)	10 (870)	17/5/2022 – 12/08/2022	6
Stirlings	Bluff knoll	tbc	2021	tbc
Perth Hills	Serpentine pipehead dam	1	tbc	0
Sunklands	St Johns (predator)	15 (2251)	26/5/2022 — 6/10/2022	3
Perth Hills	Tumlo	3 (369)	14/01/2022 – 18/5/2022	0
Walpole	Valley of the Giants	10 (410)	17/5/2022 – 27/06/2022	4
Donnelly	Wheatley (targeted)	50	April 2022	6

tbc= to be confirmed

Results from targeted quokka trapping at Gervasse suggests that from the mid-1990s to 2014 there was a general decline in the relative abundance of quokkas at this location, however in recent years the population appears to have increased (Figure 21), noting there was a change in the lure from apples only to apples dipped in peanut butter from 2019.

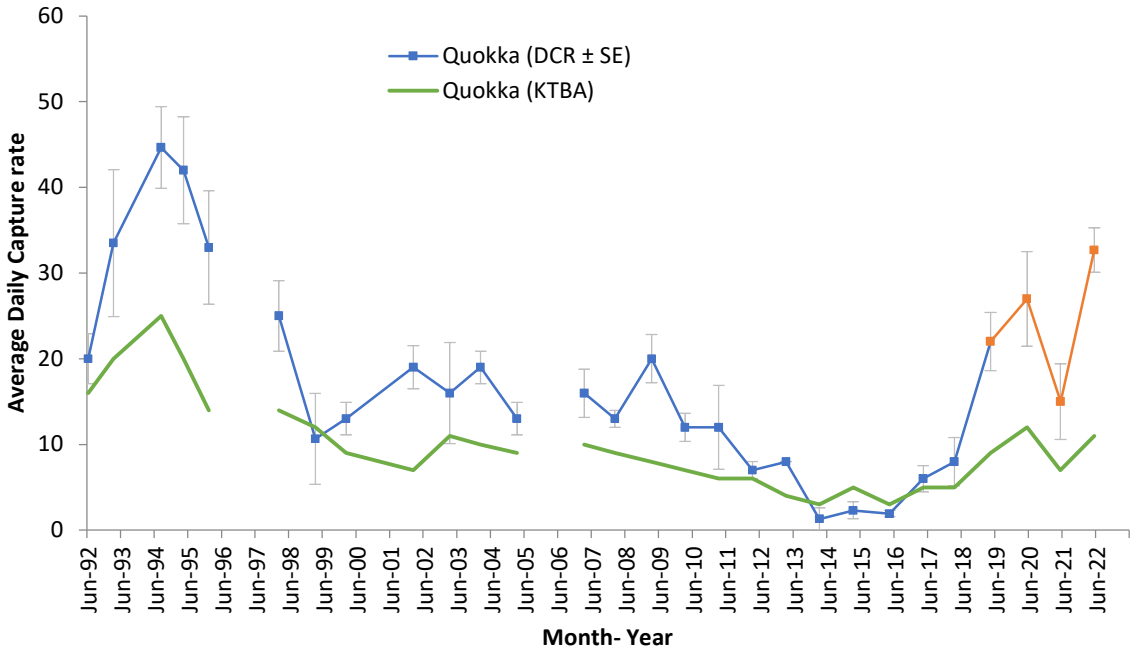

Figure 21: Relative abundance of quokkas (blue line) and known to be alive (KTBA: green line) at Gervasse (quokka swamp), Wellington National Park. Error bars = standard error. Note a change in bait from apples to apples dipped in peanut butter in 2019 (denoted by orange line).

Black-flanked rock-wallaby (*Petrogale lateralis lateralis)*

Populations of black-flanked rock-wallaby (BFRW) are currently monitored under various district programs across Western Australia (). Monitoring at the Cape Range cell (Pilbara), Central Wheatbelt sites (Wheatbelt), Avon Valley National Park (Perth Hills) and Kalbarri gorges (Midwest) is conducted using both cameras and Thomas traps (Table 2). Camera monitoring has also been established at Durba Hills and the Calverts in the Pilbara, and at Cape Le Grand and Salisbury Island (South Coast).

It is highly likely that populations at Avon and Walyunga are either extinct or functionally extinct (i.e., only one animal has been recorded). Monitoring at Avon Valley National Park has only recorded a single animal in the period 2017 – 2022 while no animals have been recorded at Walyunga in recent years (Table 2).

Population modelling indicates that the fenced population at Nangeen is at or close to carrying capacity with an estimated 120 – 170 individuals (Figure 23: Povh et al., 2023, draft). The populations of BFRW at Kalbarri have increased from 12 captured individuals in 2020 to 44 animals in 2022. Many of the captured females were carrying pouch young and there appears to have been some expansion of the population beyond the original translocation sites. This together with several new animals (not previously marked) suggests the population has established well.

Populations at Cape Range are either increasing or relatively stable (Figure 24 and Figure 25). Notably, camera monitoring at Cape Le Grand has indicated a reduction in BFRW activity from 2017 (Figure 26).

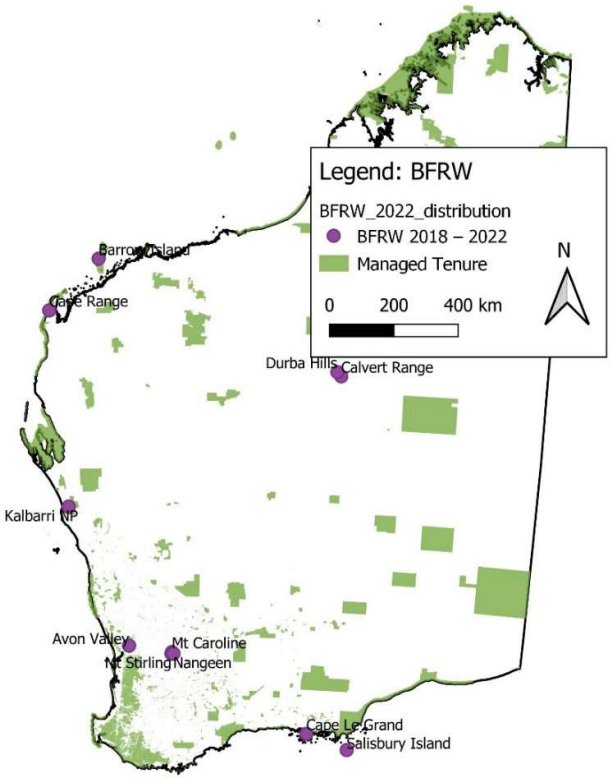

Figure 22: Sites where black-flanked rock-wallabies were recorded during targeted monitoring 2018 – 2022 (purple dots) on DBCA managed lands. Note that monitoring for black-flanked rock-wallabies is targeted to known habitats.

Table 2: Summary of recent BFRW monitoring at sites with active predator management.

Location	*Monitoring type*	*Years*	*Summary*
Avon Valley	Camera	2021	One individual recorded.
Barrow Island	Sight surveys	2022	46 individuals noted in 2022.
Mt Caroline	Thomas	2021	Trap success rates indicate the population is increasing.
Mt Stirling	Thomas	2018	Nine individuals KTBA, population increasing.
Nangeen	Thomas	2022	See Figure 23, population stabilising, but likely close to carrying capacity. Estimated to be 120-170 individuals.
Sales/Gundaring	Thomas	2018	37 individuals KTBA, population increasing.
Durba Hills (translocated population)	Cameras	2019-2021	26 cameras were deployed in 2019. Closure of remote communities due to COVID prevented 2020 check. Some cameras were still active in 2021 resulting in 898 camera-trap nights. Cameras were serviced in June 2021. Classifications are still to be finalised. Camera images in 2021 contained male and female rock-wallabies. There were also images of females with pouch young and young-at-heel. Classifications still to be finalised.
	Thomas		Trapping in August 2021 captured 7 individuals.
Kalbarri	Cameras and Thomas	2020 — 2022	2020 (Thomas): 12 individuals KTBA at Hawks Head, six of the seven females had pouch young. 1 male at Z-Bend. Camera image analysis still to be completed. 2022 (Thomas): 44 individuals. Many females carrying pouch young (total of 307 trap nights including Fourways, Hawks Head, Z-bend and skywalk).
Cape Le Grand	Cameras	2021	Figure 23; Camera monitoring indicates decline in activity since 2015.

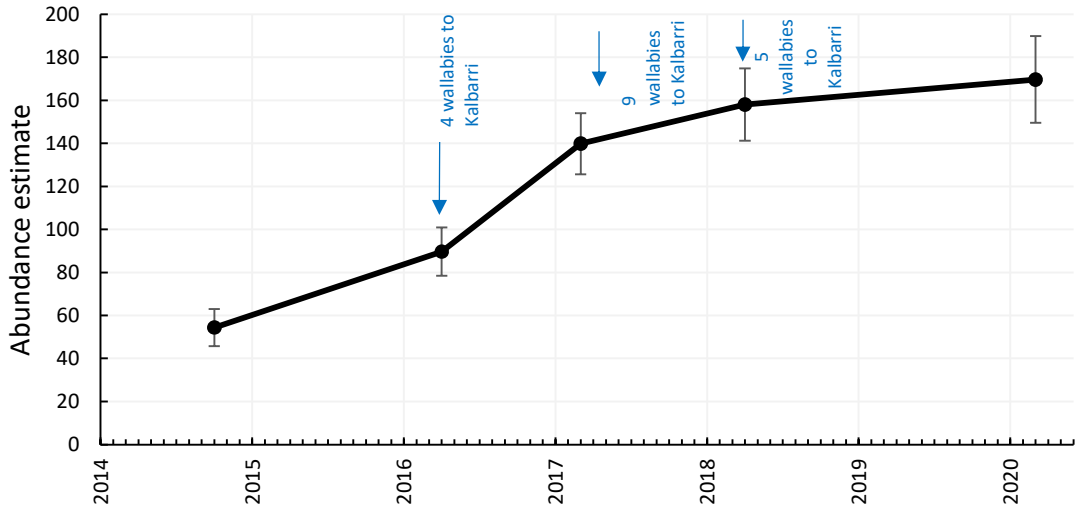

Figure 23: Abundance estimates of black-flanked rock-wallaby at Nangeen (central wheatbelt) using spatially explicit capture recapture (SECR) assuming an open population using package openCR in R (K. Nilsson).

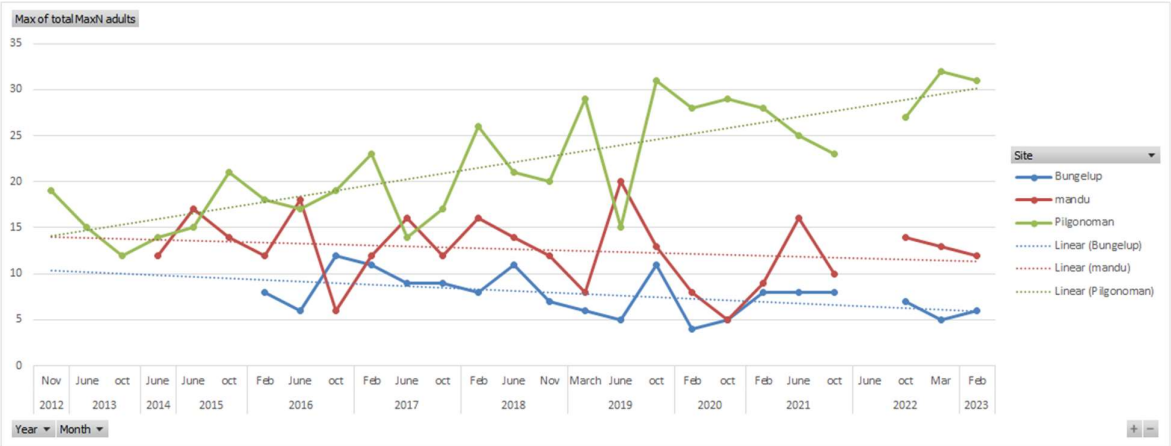

Figure 24. Population estimates of BFRW at Cape Range National Park.

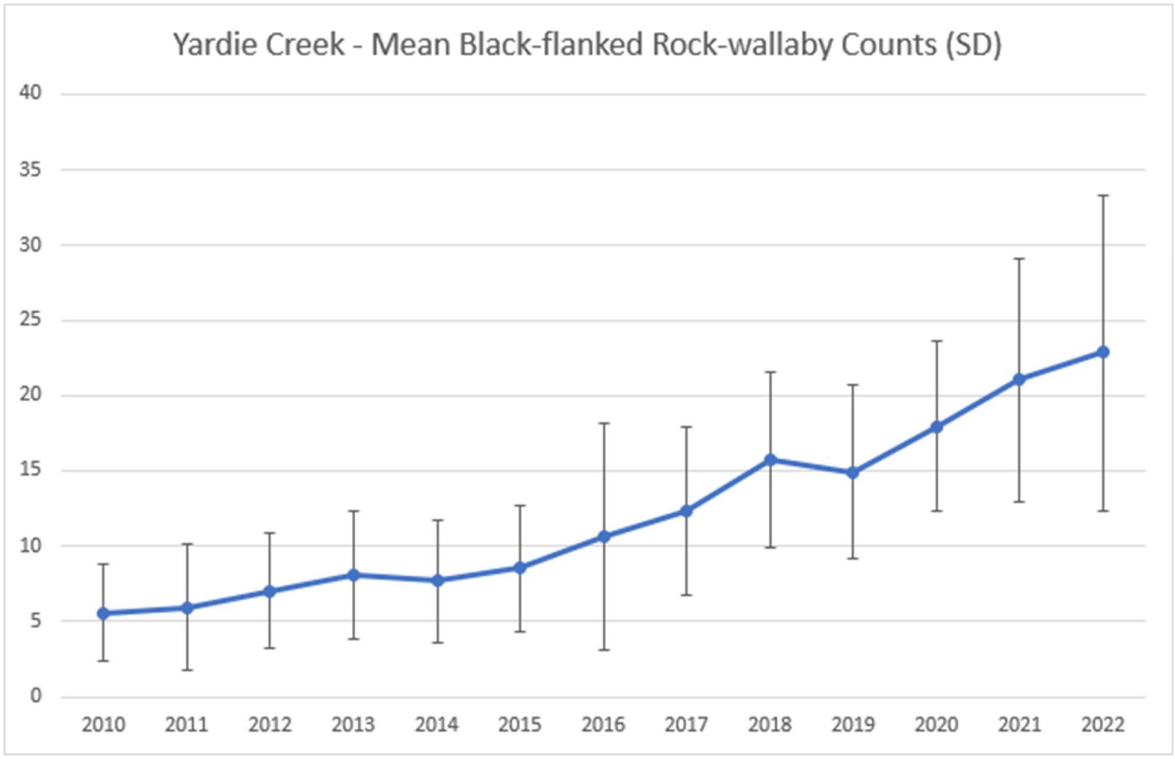

Figure 25: Mean (Error bars = ±standard deviation) of BFRW counts at Yardie Creek.

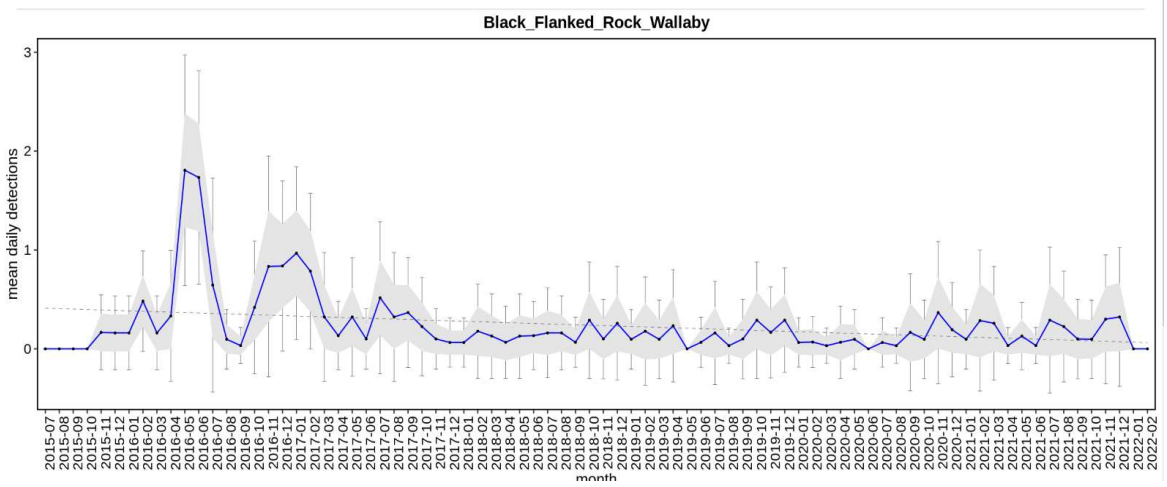

Figure 26: Mean daily detections of BFRW at Cape Le Grand National Park 2015 – 2022.

Foxes and feral cats

A summary of the aerial and ground baiting for each WS cell is provided in Appendix 2. Most WS cells received baits as per the program plan (Appendix 2, Table 6). Avon, Perth Hills, Lane Poole, and Wellington cells received additional aircraft deployments of Probait from 2021, bringing their annual delivery of aerial Probait to six events per annum. Funding received from the Alcoa Foundation has allowed for an increase in aircraft Probait events from four per annum to six per annum in these baiting cells, with some baiting cells to transition to five Probait events and one Eradicat event/annum as part of the 2023/2024 program.

Delivery of predator management at Calverts and Durba Hills recommenced in June 2022 after a temporary suspension in 2021 while awaiting approvals under joint management arrangements.

Predator monitoring

Predator monitoring uses automated wildlife cameras randomly deployed across areas a portion of a cell with a minimum distance of 1.5 km between cameras. Cameras are set according to the methods defined in the Western Shield Camera Trap Monitoring Protocols (Drew 2018).

Predator monitoring was conducted at 10 baited sites and five reference sites (i.e., areas with no predator management) in 2022 in the south-west of the state (see Appendix 1 for level of effort at each site in 2022). Table 3 provides a summary of the fox detections (i.e., number detections summed across each site per month (24 hour quiet period)/number trap nights each month and averaged across the sampling period) at baited and reference sites. The number of detections/trap nights is used as an indication of the level of fox or feral cat activity at the site.

Based on camera detections, fox activity is on average higher at sites with no fox management and on average higher at sandplain sites and woodland sites compared to that recorded in the jarrah forest sites over the same period (Table 3). This may be a result of reduced detectability of foxes in forest environments or that foxes are more prevalent in other habitats. A more detailed analysis will be completed shortly incorporating potential explanatory variables to improve our understanding of fox activity drivers and facilitate more targeted management.

Table 3: Number of fox detections/trap nights each month and averaged over the monitoring period (May/June and September/October each year). All fox detections are from camera monitoring unless otherwise stated.

Baited site (Probait: Eradicat prescription)	Monitoring Period	Average fox detections across the monitoring period ± std. dev.	Non-baited reference	Monitoring Period	Average fox detections across the monitoring period ± std. dev.
Swan coastal plain					
Nambung (2:1)	2014-2018	0.4 ± 0.35	Lesueur	2014-2018	2.31 ± 1.12
Moore River (GB 12:0)	2020-2021	0.48 ± 0.15	Nambung*	2019-2022	1.35 ± 0.73
Jarrah forest					
Batalling (4:0)	2014-2022	0.09 ± 0.04	Stene	2014-2022	0.20 ± 0.23
Julimar (4:0)	2019-2020; 2022	0.006 ± 0.002	Wandoo	2019-2022	0.03 ± 0.02
Shannon (3:0)	2020-2022	0.02 ± 0.02	Porongorups	2020-2022	0.44 ± 0.29
Sunklands (2:0)#	2018-2022	0.0 ± 0.0	Treeton	2018-2022	0.98 ± 0.56
Wheatbelt woodlands					
Dryandra (GB: 7:5)	2015 - 2022	0.19 ± 0.13			na
Boyagin (GB: 12:0)	2018 -2022	0.34 ± 0.18			na
Dragon Rocks	2021-2022	0.60 ± 0.40			na
South Coast					
Two Peoples Bay (3:1)	2014 -2022	0.06 ± 0.09			na
Cape Arid (3:1)	2020-2022	0.0 ± 0.0			
Cape Le Grand	2022	0.012 ± 0.011			
Pilbara					
Cape Range (0:1)	2017 – 2022 (track counts)	0.009 ± 0.02			

GB = ground baiting only. *Predator management discontinued in 2018. tbf = data to be finalised. # Only a single record of a fox in 2018, 2019 and 2021 and only two records in 2020. No records in 2022 for this site. Not all sites were monitored in all months. Therefore, averages for each site have been calculated using a 4 – 5 month period commencing in May/June and finishing in September/October for each year cameras were operating (naïve detections summed across each site per month (24 hour quiet period)/number trap nights each month and averaged across the sampling period)

On average, feral cats are detected less frequently than foxes in all habitat types (Table 3 and Table 4). It is unclear if this is a result of cryptic behaviour and/or the smaller size of cats resulting in lower detections compared to foxes, or because there are fewer feral cats than foxes in the monitored environments. Attempts to capture cats in leg hold traps in Batalling in autumn 2022 identified very few cats and in this instance the low feral cat detections on camera are likely representative of low density of feral cats in this forest area. Monitoring of feral cats using radio collars commenced in autumn 2022 in Avon Valley and Walyunga National Parks. Data from the collars is currently being analysed to assess the capacity of cameras to detect cats and to assess feral cat habitat use to assist with feral cat management in the northern jarrah forest.

Table 4: Number of feral cat detections/trap nights each month and averaged over the monitoring period (May/June and September/October each year).

Baited site (Probait: Eradicat prescription)	Monitoring Period	Feral cat detections/ year ± std. dev.	Non-baited reference	Monitoring Period	Feral cat detections/ year ± std. dev.
Swan coastal plain					
Nambung (2:1)	2014-2018	0.39 ± 0.17	Lesueur	2014 – 2018	0.27 ± 0.14
Moore River (GB 12:0^)	2020-2021	0.12 ± 0.12	Nambung*	2019 – 2022	0.33 ±0.11
Jarrah forest					
Batalling (4:0)	2014 – 2022	0.05 ± 0.06	Stene	2014 – 2022	0.07 ± 0.08
Julimar (4:0)	2019 – 2020; 2022	0.0005± 0.001	Wandoo	2019 – 2022	0.001 ± 0.002
Shannon (3:0)	2020 – 2022	0.01 ± 0.02	Porongorups	2020 – 2022	0.04 ± 0.05
Sunklands (2:0)	2018 – 2022	0.03 ± 0.03	Treeton	2018 – 2022	0.06 ± 0.05
Wheatbelt woodlands					
Dryandra (GB: 7:5)	2015 – 2022	0.05 ± 0.06			na
Boyagin (GB: 12:0)	2018 – 2022	0.04 ± 0.04			na
Dragon Rocks	2021 – 2022	0.13 ± 0.09			na
South Coast					
Two Peoples Bay (3:1)	2014 – 2022	0.09 ± 0.06			na
Cape Arid (3:1)		tbf			na
Cape le Grand	2022	0.02 ± 0.02			
Pilbara					
Cape Range (0:1)	2017 – 2022 (track counts)	0.23 ± 0.12			

GB = ground baiting only. ^ Ground bait transect is limited to a very small portion of the monitored area. *predator management discontinued in 2018. tbf + data to be finalised. Not all sites were monitored in all months. Therefore, averages for each site have been calculated using a 4 – 5 month period commencing in May/June and finishing in September/October for each year cameras were operating. Cat detections= naïve detections summed across each site per month and averaged across the year.

Swan Coastal Plain

Predator monitoring continued at Moore River and Nambung in 2022. However, data for Moore River is currently being classified and only Nambung data was available at the time of reporting (Figure 27). Of note is the continued increase in activity of foxes at Nambung after the cessation of predator management in 2018.

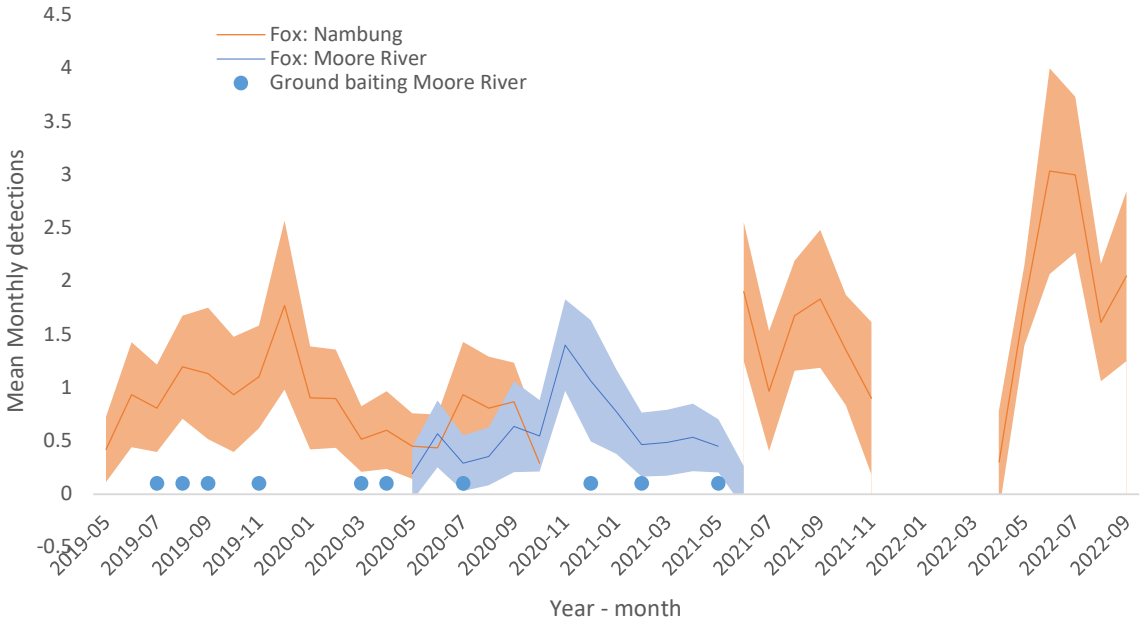

Figure 27: Fox detections at non-baited site (Nambung: orange line) and a ground baited site (Moore River: blue line). Blue dots indicate the month Probaits were delivered to Moore River (12 x ground Probait events/annum). Shading represents the 95% confidence interval.

Feral cat activity is higher on the Swan Coastal Plain compared to that recorded in the jarrah forest, woodland sites or on the south coast (Table 4). Sites with higher frequencies of feral cat management (i.e. > 1 x Eradicat/annum) have improved outcomes for native species (e.g. Dryandra, Figure 35). More analyses will be conducted to examine the impact of Eradicat deployment frequency on feral cat activity in 2023 with the aim of determining the most effective management regime for different environments.

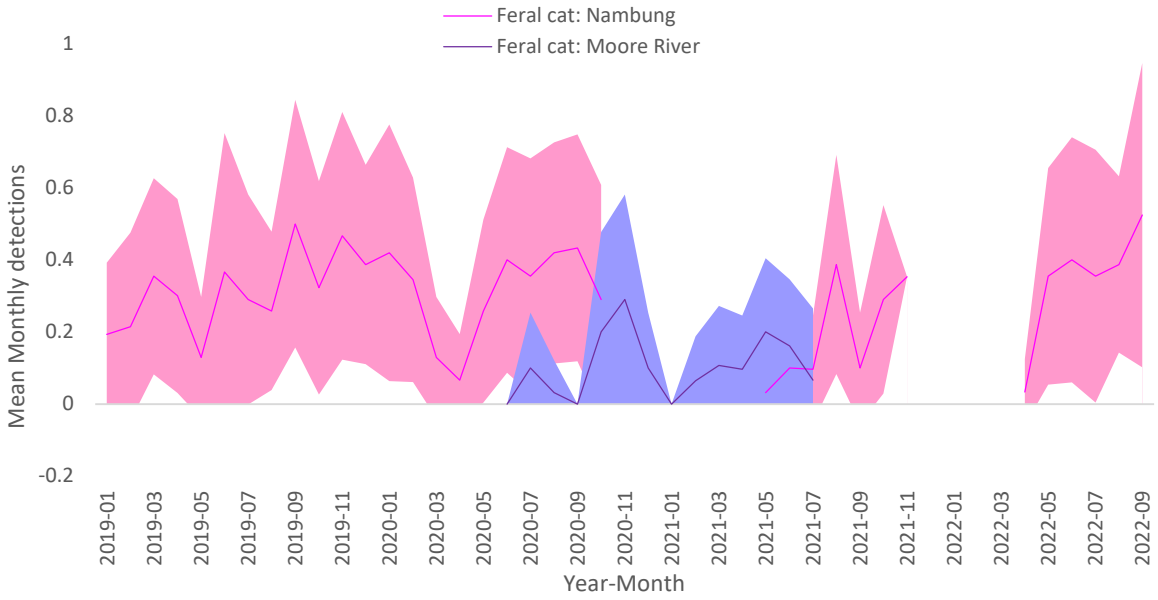

Figure 28: Feral cat detections at Nambung (no predator management since 2018) and at Moore River (12 x ground Probait events/annum). Shading represents the 95% confidence interval.

Jarrah Forest

Long-term predator monitoring at baited and non-baited areas in the jarrah forest shows fox activity is on average higher in the non-baited areas compared to areas with some fox management (Figure 29 and Figure 30). However, temporal fox activity is highly variable. Of note is the almost complete absence of foxes at St Johns (Sunklands cell), with only five independent detections of foxes in the period 2018 – 2022 (Figure 30). In comparison the detections in the control site (Treeton) were significantly higher with over 500 independent detections in the same period.

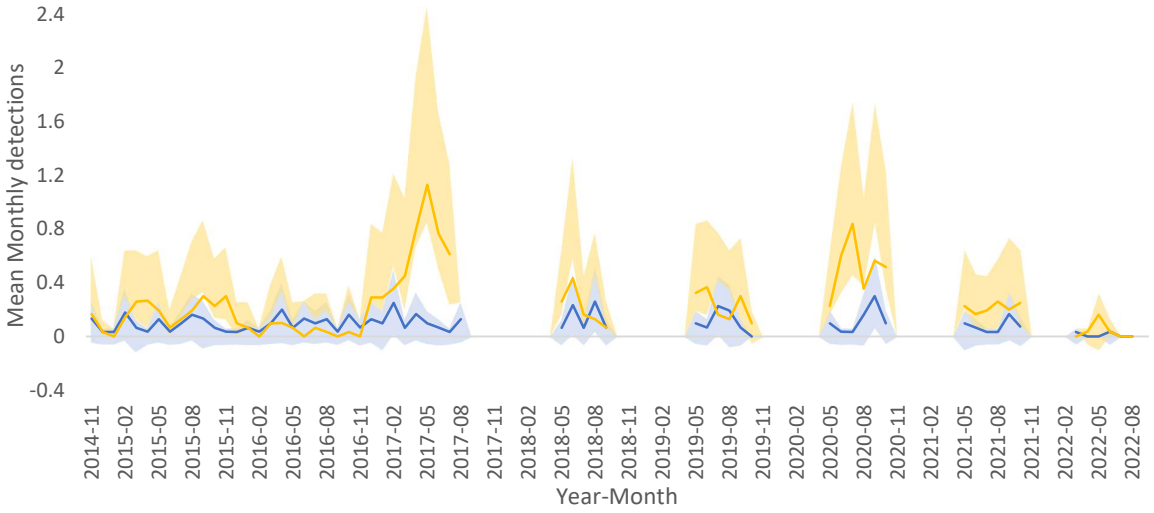

Figure 29: Fox detections on camera at a baited site (Batalling: blue line, 4 x aerial Probait events/annum 1996-2005; 2016-2021, 6 x aerial Probait events/annum 2006-2009; 2012-2015 and 2021 onwards) and non-baited reference site (Stene: yellow line) 2014 – 2022. Shading represents the 95% confidence interval. Note there was a bushfire in Stene in January 2016 which destroyed over 50% of the available cameras and affected detections in 2016.

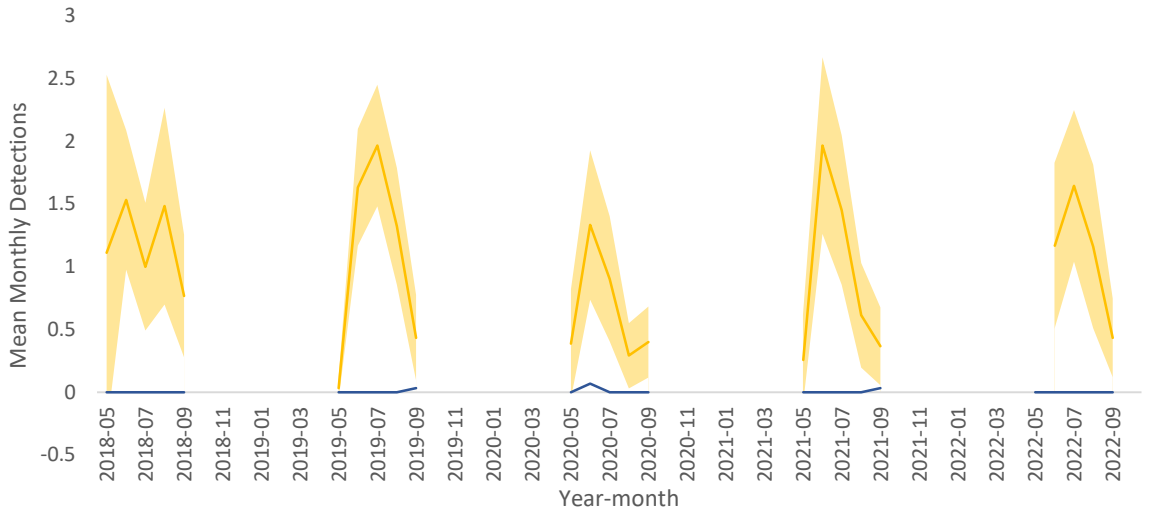

Figure 30: Fox detections on camera at a baited site (St Johns — Sunklands: blue line, 2 x aerial Probait events/annum) and non-baited reference site (Treeton: orange line) 2018 – 2022. Shading represents the 95% confidence interval.

Despite the absence of feral cat management in the northern jarrah forest, most monitored sites had low detections of feral cats (Figure 31 and Figure 32). Examination of images from the cameras suggests only two or three feral cats were detected in Batalling in the period 2019 – 2022. Sunklands and the paired non-baited control site also recorded low detections 2020-2022 (Figure 32). Vegetation structure may limit detections of feral cats in these forested habitats, compared to more open environments. However, feral cat trapping using leg hold traps in Batalling in 2022 indicates camera monitoring is likely a true reflection of overall feral cat activity at the site with only the three cats captured on camera captured in traps (Algar, pers. comm.).

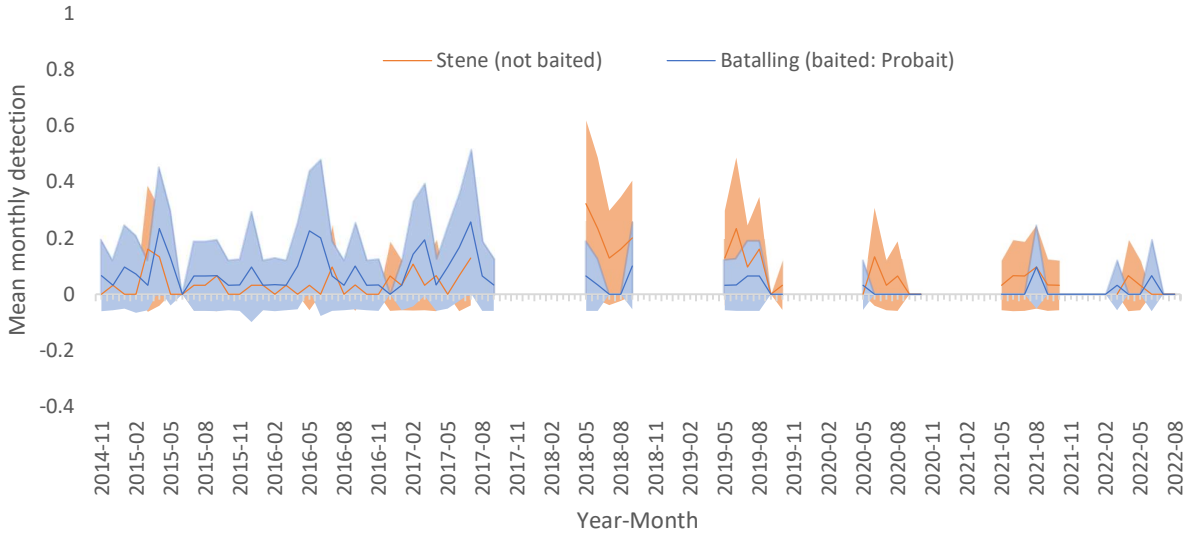

Figure 31: Feral cat detections at Stene (no predator management) and at Batalling (fox management: 4 x aerial Probait events/annum plus 12 x ground Probait events/annum to 2021, 6 x aerial Probait events/annum plus 12 x ground Probait events/annum 2021/2022). Shading represents the 95% confidence interval. Note from September 2017 cameras were only deployed between May and September/October each year.

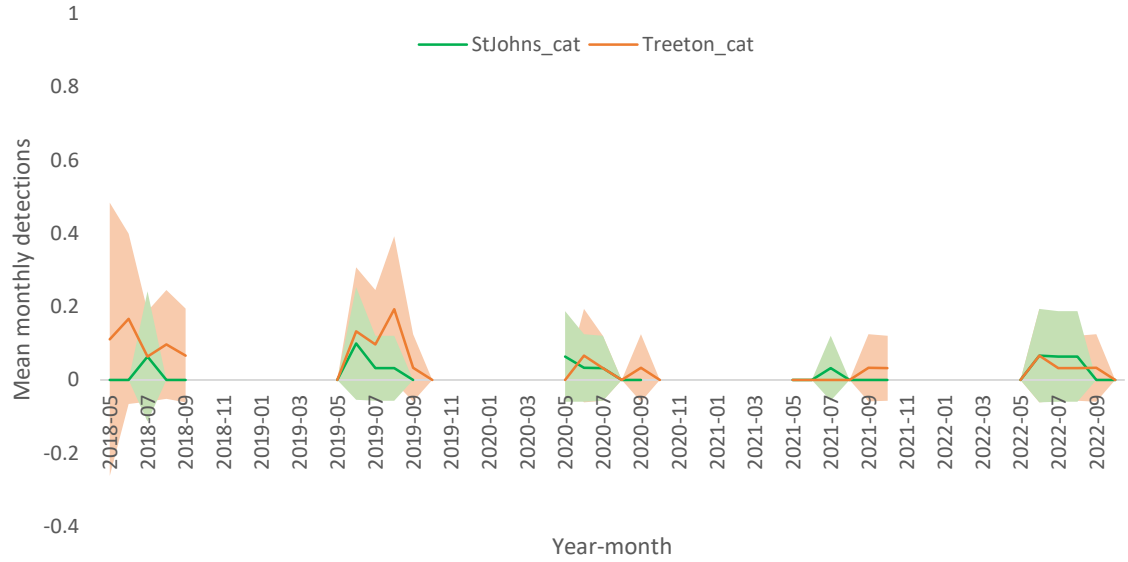

Figure 32: Feral cat detections at St Johns (Sunklands: 2 x aerial Probait events/annum) and at Treeton (no predator management). Shading represents the 95% confidence interval.

Wheatbelt woodlands

Wheatbelt predator monitoring was limited to baited only sites. Dryandra receives a combination of ground delivered Probait and Eradicat (ratio 7:5 events per annum respectively), Boyagin 12 x Probait ground delivered events per annum and Dragon Rocks 3 x aerial Probait events (increasing from 2 in 2021) and six ground Probait events in 2021 – 2022.

On average, fox detections at Boyagin are slightly elevated compared to Dryandra (Figure 33), however there is a high temporal variability in the detections. Notably, fox detections were also higher at Dragon Rocks compared to both Boyagin and Dryandra (Figure 34). This may reflect the lower frequency of bait deliveries at Dragon Rocks compared to both Boyagin and Dryandra. Dragon Rocks will receive Eradicat in 2023 as part of an externally funded project. On average, foxes are detected more frequently at wheatbelt sites compared to baited sites in the jarrah forest (Table 3).

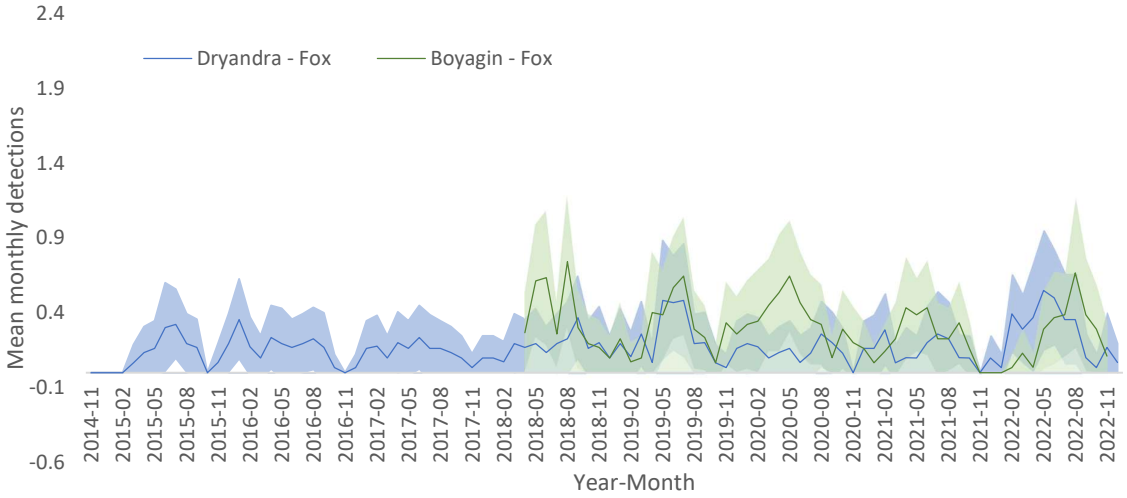

Figure 33: Fox detections at Dryandra (blue line: ground baited 7 x Probait events plus 5 x Eradicat events/annum) and Boyagin (green line: 12 x ground Probait events/annum). Shading represents the 95% confidence interval. Boyagin data courtesy of Project Numbat.

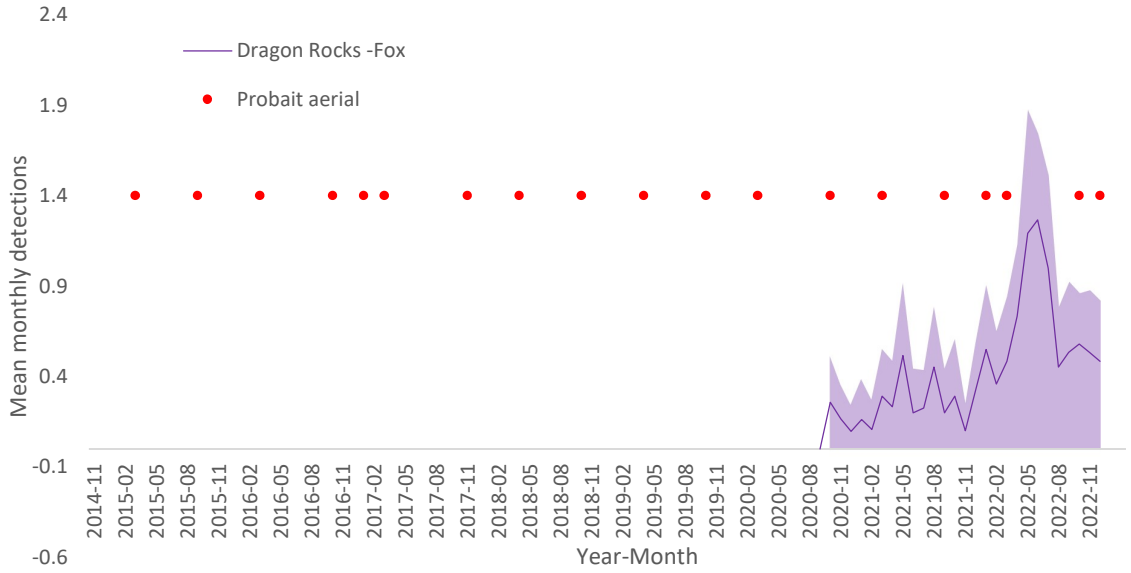

Figure 34: Fox detections at Dragon Rocks (aerial baited x 2 Probait events plus 6 x ground Probait events/annum, Aerial bait increased to 3 x Probait events/annum in 2021-2022). Shading represents the 95% confidence interval. Data courtesy of Mark Cowan.

Feral cats are rarely detected in Wheatbelt reserves (Table 4 and Figure 35). There is no current feral cat management at Boyagin, yet feral cat activity is similar to that recorded at Dryandra. This may relate to variations in detectability of feral cats in the two reserves or it may reflect true feral cat activity at the site. It is possible that localised suppression processes such as the high delivery rates of Probait (monthly), the natural level of natural 1080 in the environment from *Gastrolobium* spp., and/or neighbouring landholder behaviour are all contributing to the low feral cat activity at the site.

In comparison feral cat activity at Dragon Rocks (Figure 36) is elevated compared to the other two sites. This increase was particularly evident in autumn 2022, immediately after the increase in fox baiting. The site will receive Eradicat in 2023 as part of an externally funded project.

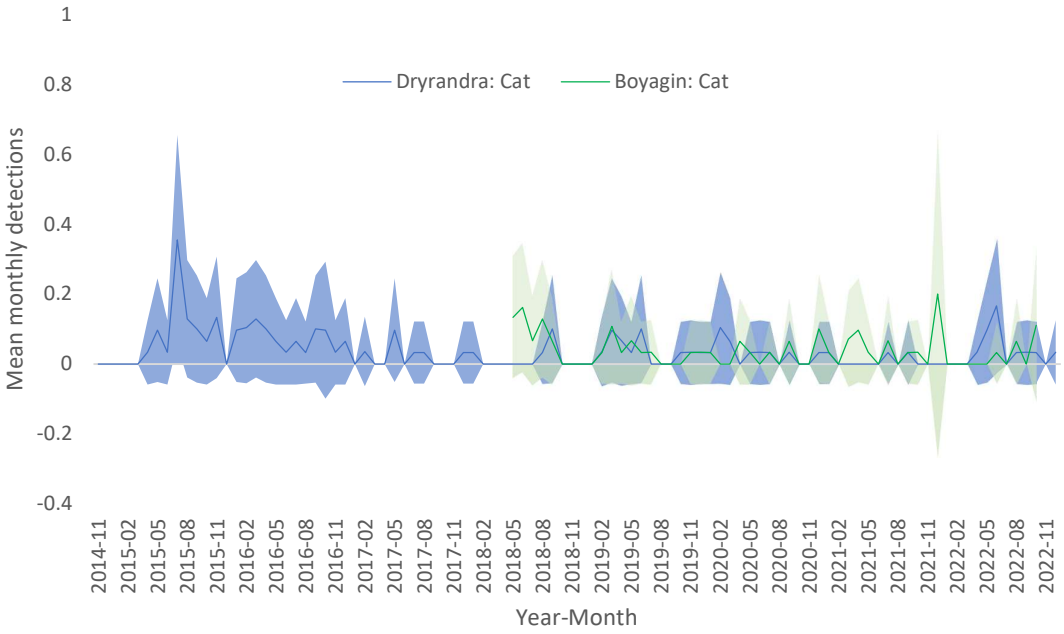

Figure 35: Feral cat detections at Dryandra (blue line: 7 x ground Probait events plus 5 ground Eradicat events/ annum) and Boyagin (green line: 12 x ground Probait events/annum). Feral cat management at Dryandra commenced in 2012. Shading represents the 95% confidence interval. Boyagin data courtesy of Project Numbat.

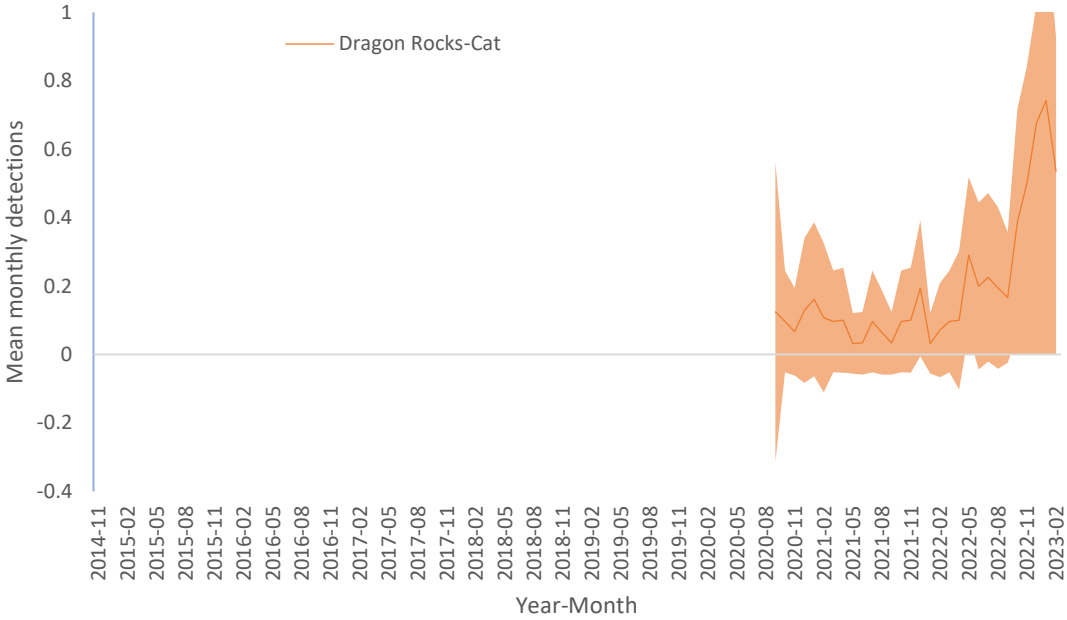

Figure 36: Feral cat detections at Dragon Rocks (Aerial baited x 2 Probait events plus 6 x ground Probait events/annum, Aerial bait increased to 3 x Probait events/annum in 2021-2022). Shading represents the 95% confidence interval. Data courtesy of Mark Cowan.

South Coast

Predator monitoring at Two Peoples Bay indicates very low fox activity compared to the jarrah forest, sandplains or wheatbelt woodlands (Figure 37 and Table 3). Eradicat has been integrated with Probait at this site since 2011. Predator monitoring using cameras commenced in 2014 (Figure 38). Monitoring suggests feral cat activity was low in 2015 and 2016, however there was a slight resurgence in activity in 2017 and 2018. It is possible this increase in activity is associated with a reduction in the frequency of Eradicat deployments from February 2017. Eradicat baiting was increased to two deployments in 2015 and 2016 to address the possible increase in predator activity driven by bushfires in October/November 2015. Notably, feral cat trapping has been conducted where possible at Two Peoples Bay with 10 feral cats removed between 2020 and 2022 (Table 5).

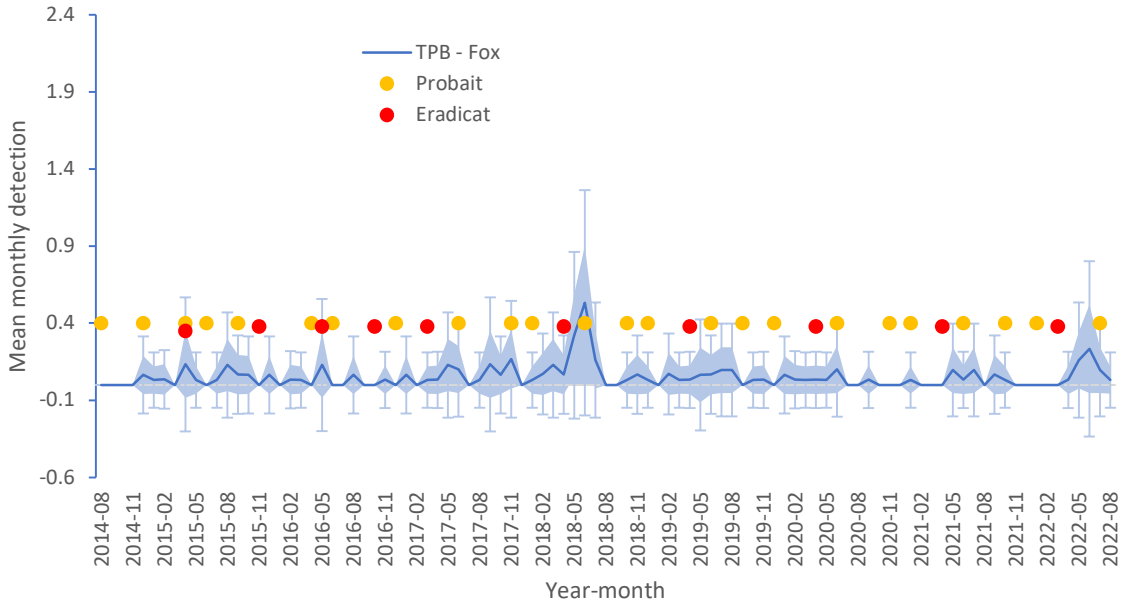

Figure 37: Fox detections at Two Peoples Bay (3 x Probait: 1 x Eradicat events/annum). Dots indicate the month Probait (yellow dots) or Eradicat (red dots) was aerially delivered to the site. Shading represents the 95% confidence interval.

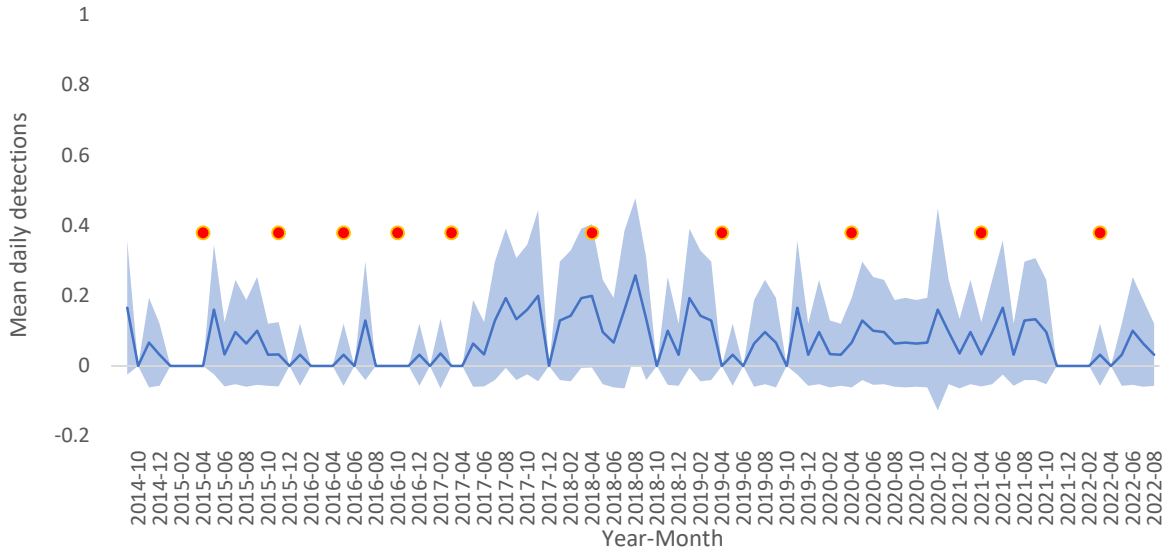

Figure 38: Feral cat detections at Two Peoples Bay relative to the aerial delivery of Eradicat (red dots) Shading represents the 95% confidence interval.

Feral cat trapping is also conducted by staff in the South Coast Region at selected reserves (Table 5). This provides additional ongoing protection to a range of threatened species.

Table 5: Summary of feral cat and fox removals from each location in the South Coast Region.

Location	Year	Number feral cats removed	Number foxes removed
Angove	2020	5	3
Peniup	2020	1	0
Two Peoples Bay	2020	7	0
Angove	2021	8	3
Peniup	2021	No trapping, too wet	No trapping, too wet
Two Peoples Bay	2021	2	0
Corackerup	2022	4	2
Peniup	2022	9	1
Two Peoples Bay	2022	1	0
Angove	2023	3	2

Pilbara

Monitoring at Cape Range National Park continues to indicate that there are very few foxes remaining in the landscape with only a single pre-bait incursion detected on the camera array in the last few years. Feral cats continue to be detected at the site (*Figure 39: Mean daily feral cat detections presented per 100 camera trap nights. Hatched columns represent surveyed areas that were not baited with Eradicat (i.e., control sites).*Figure 39), noting that there was a change in the lure in 2020. Between 2014 – 2019 the lure included a visual (tinsel and feathers) and an olfactory component (Catastrophic®), from 2020 onwards only the olfactory component was used. Captures of all introduced predators in the trapping program has a declined (DBCA 2021), however feral cat activity does appear to be on the increase with annual track counts suggesting a substantial increase in cat activity since 2021 (Figure 40). Examination of annual rainfall data would suggest that increased rainfall in the last few years may have increased the detections of both feral cats and dingoes at Cape Range (Figure 40).

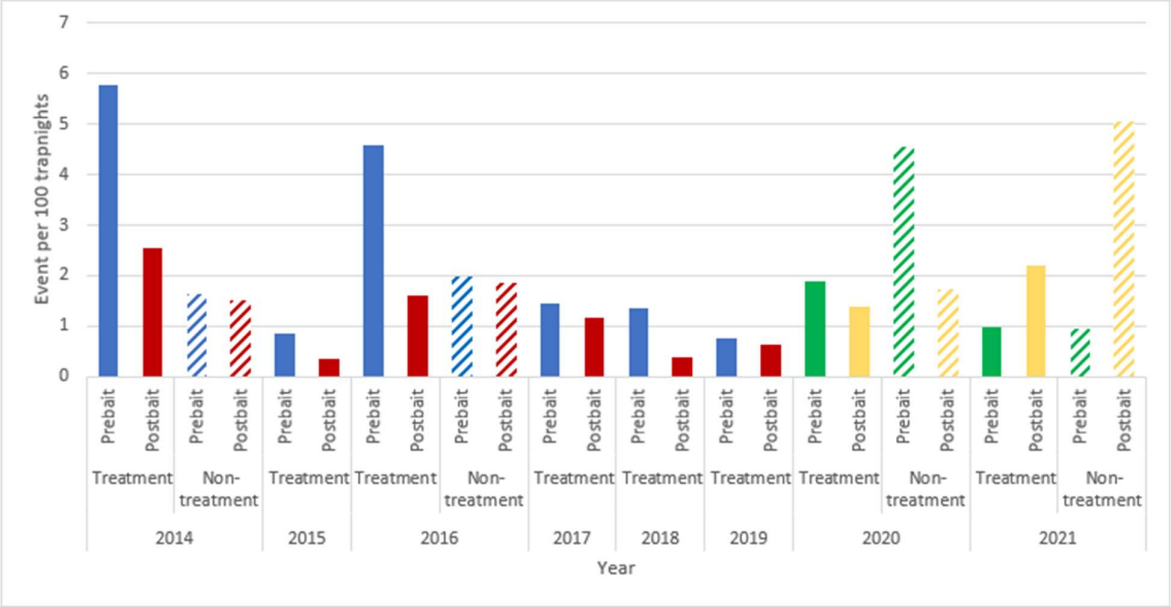

Figure 39: Mean daily feral cat detections presented per 100 camera trap nights. Hatched columns represent surveyed areas that were not baited with Eradicat (i.e., control sites). From 2020, only an olfactory lure was used.

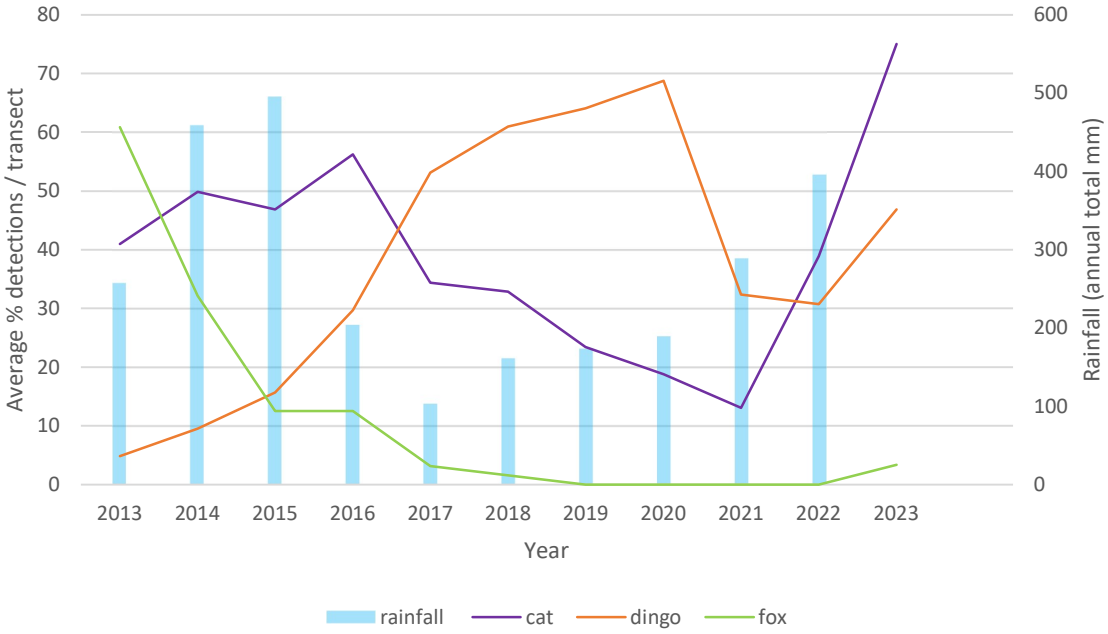

Figure 40: Average percentage activity of foxes, dingoes and feral cats using track counts relative to rainfall (BOM station: Learmonth) at Cape Range.

Future predator monitoring

Fox detections at sandplain sites is on average much higher compared to that recorded in the jarrah forest (Table 3). This may be a result of reduced detectability of foxes in forest environments or that foxes are more prevalent in the sandplain habitats. A more detailed analysis is planned to be completed as part of the three-yearly review of all monitoring data. Modelling will incorporate potential explanatory variables to improve our understanding of fox activity drivers. This will help facilitate targeted management. Modelling that incorporates the predictive impacts of varying baiting regimes is planned to be explored.

Ideally, predator monitoring and associated cage monitoring should be established at the remaining paired sites as defined in the *Western Shield Monitoring Plan 2021-2024* (Figure 41) and where possible at the suggested sites in northern regions. Information collected from all sites will provide essential data for modelling species response to different baiting prescriptions and is pivotal to understanding the dynamics of predator: prey relationships across all baiting prescriptions.

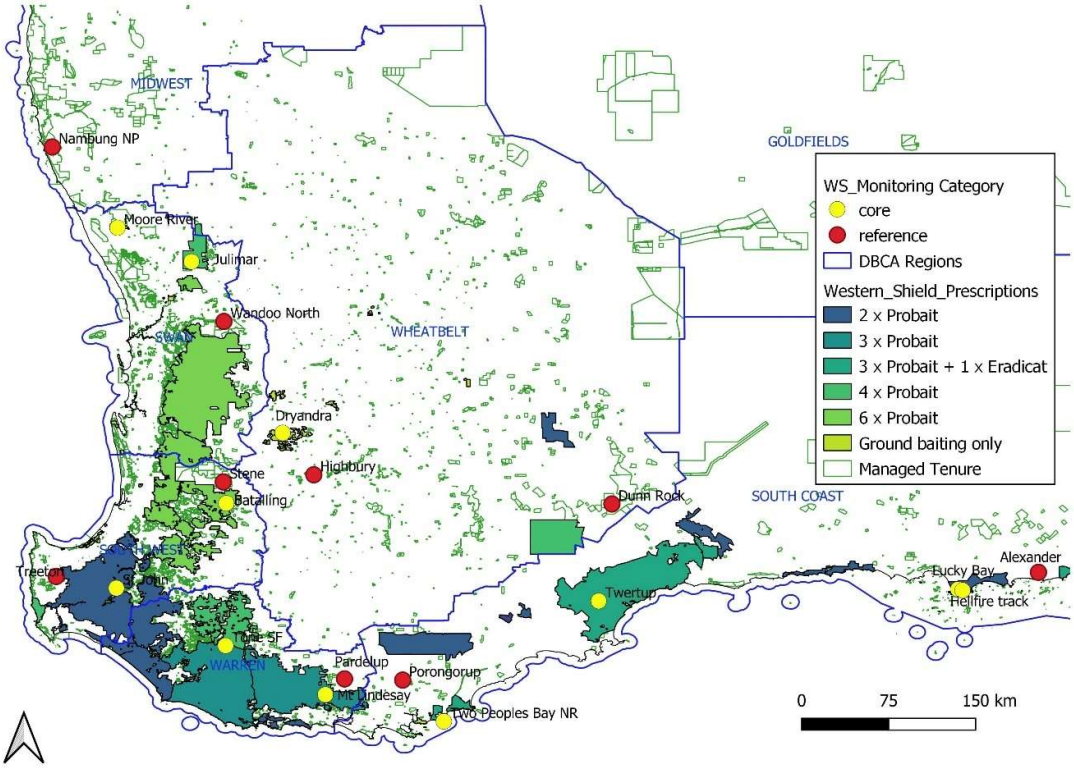

Figure 41: Monitoring sites defined as paired under the Western Shield Monitoring Plan 2021 – 2024 for the south-west of WA relative to current WS baiting prescriptions. Note that monitoring did not commence at Dunn Rock, Highbury or Pardelup in 2022. Pardelup (paired with Mt Lindesay) and Dunn Rock (paired with Fitzgerald River National Park — Twertup) are scheduled to commence in 2023.

Glossary

Activity: number of days where a species was detected on a camera in a month/number trap nights each month. The number of detections/trap nights is used as an indication of the level of activity of that species at the site.

Detection probability (p): derived from occupancy modelling and provides a metric of how likely you will detect a species if it is present at a site.

Occupancy (ψ): the probability of a species occurring within a site during the sampling session.

Occupancy Model: a model used to account for imperfect detection of a species in surveys and to predict the probability of the true presence or absence of a species at a site. This is done by quantifying the uncertainty in detection (detection probability) of a species at a site using the available data.

Appendix 1: Trap effort per site 2022

Cell/Area	Site_transect	Predator management Aerial fox: Aerial cat: Ground Fox: Ground Cat	# WS cages: trap nights	Elliotts: trap nights	Thomas traps: trap nights	# Predator cameras (trap nights)	Chuditch specific cages: #trap nights	Targeted camera monitoring (trap nights)	Comments
Alexander UCL	Alexander	not baited	0	0	0	0	0	0	proposed camera + cage
Perth Hills	Amphion	6:0:7:0	0	0	0	0	0	48	targeted quokka monitoring
Avon	Avon Valley	6:0:4:4	360	40	0	27 (5028)	0	0	district program
Manjimup	Balban	4:0:4 & 12*:0	0	0	0	0	250	0	
Lane Poole	Batalling	6:0:5:7	488	0	0	45 (9320)	500	0	
Julimar	Bindoon	4:0:8:0	400	0	0	28	0	0	cameras set on tethered baits stations
Sunklands	Blackwood River	2:0:12:0	0	0	0	0	0	0	
Boranup	Boranup	2:0:12:0	0	0	0	0	0	0	
Boyagin	Boyagin East	0:0:12:0	50	0	0	0	0	0	
Boyagin	BoyaginWest	0:0:12:0	200	0	0	30 (7830)	0	0	Cameras: Project Numbat
Manjimup	Boyicup	4:0:4/12:0	200	0	0	0	0	0	
Burrup	Burrup	0:1:0:2	0	0		57	0	0	
Calvert Range	Calvert Range	0:1:0:2	0	0		Track counts	0	0	
Cape le Grand	Cape le Grand	2:0:2/4:0	92	92	0	21 (4122)	0	0	
Cape Range	Cape Range	0:1:0:6	0	0		40 +track counts	0	0	BFRW:cameras and point counts
Wellington	Catterick	6:0:7:5	492	0	0	30 (4221)	500	0	
Wellington	Centaur	6:0:7:5	340	0	0	0	500	0	
Manjimup	Chariup	4:0:4/12:0	0	0	0	0	0	0	monitored every 3- 5 years
D'Entrecasteaux	Charley	2:0:0:0	0	0	0	0	0	10	linear cameras
Fitzgerald	Cocanarup	3:1:3:1	0	0	0	0	287	10 (51)	
Manjimup	Corbal	4:0:4/12:0	0	0	0	0	0	0	monitored every 3- 5 years
Dragon Rocks	Dragon Rocks NR	3:1:4:4	0	0	0	30	0	0	chuditch monitoring scheduled 2023
Dryandra	Dryandra	0:0:7:5	300	0	0	30	100	0	
Durba Hills	Durba Hills	0:1:0:0	0	0	?	26	0	0	

Cell/Area	Site_transect	Predator management Aerial fox: Aerial cat: Ground Fox: Ground Cat	# WS cages: trap nights	Elliotts: trap nights	Thomas traps: trap nights	# Predator cameras (trap nights)	Chuditch specific cages: #trap nights	Targeted camera monitoring (trap nights)	Comments
Manjimup	Dwalgan	4:0:4/12:0	0	0	0	0	0	0	monitored every 5 years
Lane Poole	George	6:0:5:7	0	0	0	0	0	0	reactivated under district program, monitored every 3 years
Wellington	Gervasse/Quokka swamp	6:0:7:5	160	0	100	0	0	0	
Shannon	Gobblecannup	3:0:4:0	200	0	0	0	0	50	
Gundaring/Sales	Gundaring	0:0:26:0	0	0	0	0	0	0	
Helena Aurora	Helena Aurora	not baited	0	0	0	0	400	12 (1428)	chuditch cameras (2 cameras per lure, 12 lures)
Cape Le Grand	Hellfire track	2:0:2/4:0	0	0	0	0	0	0	
Perth Hills	Hills Forest	6:0:7:0	0	0	0	0	0	0	annual?
Walpole	Hilltop	2:0:6:0	0	0	0	0	0	0	
Perth Hills	Hollyoak	6:0:7:0	0	0	0	0	0	7 (462)	quokka monitoring
Perth Hills	Jarrahdale	6:0:7:0	400	0	0	30	500	4 (220)	quokka monitoring, predator cameras BCS
Jaurdi	Jaurdi	not baited	0	0	0	0	500	9 (1091)	chuditch cameras (2 cameras per lure, 9 lures)
Julimar	Julimar	4:0:8:0	400	0	0	0	294	0	chuditch monitoring conducted by AWC
Kalbarri	Kalbarri NP	2:1:0:0	0	0	307	0	0	0	recommencing 2022?
Denbarker	Lake Muir (Myalgelup)	3:0:4:0	200	0	0	0	0	0	
Nambung	Lancelin DTA	0:0:0:0	0	0	0	0	0	0	
Cape Le Grand	Lucky Bay	2:0:2/4:0	0	0	0	0	0	0	no monitoring 2016_2019
Sunklands	Milyeannup	2:0:12:0	0	0	0	0	0	10 (700)	targeted quokka cameras
Fitzgerald	Moir Track	3:1:3:1	0	0	0	0	0	0	
Manjimup	Moopinup	4:0:4/ 12:0	200	0	0	15 (1239)	250	0	predator cameras
Moore River	Moore River NR	0:0:6/ 12:0	200	0	0	20	0	0	
Mt Caroline	Mt Caroline	0:0:26:0	0	0	0	0	0	0	
Denbarker	Mt Lindesay	3:0:4:0	200	0	0	0	0	10	
Mt Stirling	Mt Stirling	0:0:26:0	0	0	0	0	0	0	

Cell/Area	Site_transect	Predator management Aerial fox: Aerial cat: Ground Fox: Ground Cat	# WS cages: trap nights	Elliotts: trap nights	Thomas traps: trap nights	# Predator cameras (trap nights)	Chuditch specific cages: #trap nights	Targeted camera monitoring (trap nights)	Comments
Nambung	Nambung NP	0:0:0:0	200	0	0	30 (4067)	0	0	reference site
Nangeen	Nangeen	0:0:26:0	0	0	288		0	0	
Shannon	Nicol Rd	3:0:4:0	0	0	0	0	0	0	
Wellington	Noggerup	6:0:7:5	428	428	0	0	0	0	
Cape Arid	Paisley	3:1:2* & 4:3	0	0	0	0	0	0	
Denmark SF	Pardelup	not baited	0	0	0	0	0	0	reference site to commence 2023
Peak Charles	Peak Charles	not baited	0	0	0	0	400	20 (570)	chuditch monitoring,
Peniup	Peniup NR	1:1:7:5	0	0	0	0	0	0	
Cape Arid	Poison Creek	3:1:2 & 4:3	0	0	0	0	0	0	
Porongorup	Porongorup	not baited	200	0	0	20 (2074)	0	0	
Ravensthorpe	Ravensthorpe	2:0:4:0	0	0	0	0	269	10 (111)	chuditch cameras (2 cameras per lure, 10 lures)
Sunklands	St John	2:0:12:0	432	432	0	20 (2251)	0	0	
Gundaring/Sales	Sales	0:0:26:0	0	0	0	0	0	0	
Stene	Stene	not baited	400	0	0	45 (10004)	0	0	not baited
Stirling	Stirling Range	2:0:4:0	200	0	0	0	0	0	
Shannon	Tone SF	3:0:4:0	200	0	0	15 (1082)	0	0	
Treeton SF	Treeton	not baited	0	0	0	20 (1852)	0	0	reference site
Perth Hills	Tumlo	6:0:7:0	0	0	0	0	0	3 (369)	
Tutanning	Tutanning	0:0:10:2	200	0	0	0	0	0	
Fitzgerald	Twertup	3:1:3:1	0	0	0	0	0	0	
Two Peoples Bay	Two Peoples Bay NR	3:1:7:5	268	0	0	15	0	0	
Walpole	Valley of the Giants	2:0:6:0	200	0	0	0	0	10 (410)	linear cameras (not lured)
Manjimup	Warrup	4:0:4 & 12*:0	200	0	0	0	0	0	
Donnelly	Wheatley	2:0:0:0	0	0	0	0	0	50	
Perth Hills	Wandoo North	not baited	0	0	0	15 (1316)	0	0	
Shannon	Woolbales	3:0:4:0	0	0	0	0	0	0	

Cell/Area	Site_transect	Predator management Aerial fox: Aerial cat: Ground Fox: Ground Cat	# WS cages: trap nights	Elliotts: trap nights	Thomas traps: trap nights	# Predator cameras (trap nights)	Chuditch specific cages: #trap nights	Targeted camera monitoring (trap nights)	Comments
Yalgorup	Yalgorup	0:0:6:0	0	0	0	20	0	0	

Appendix 2: Fox and Feral cat management in each Western Shield cell or area.

Table 6: Square kilometres subject to aerial baiting December 2021 to November 2022 in each Western Shield cell. Standard delivery of aerial Probait is at a density of five probaits per square kilometre/event while Eradicat is delivered at 50 baits per square kilometre/event.

Region	Cell Name	Monitoring	Date aerial baiting commenced	Planned annual frequency	Bait type	2021-2022 Dec-Feb	2022 Mar-May	2022 Jun-Aug	2022 Sep-Nov	Total
South Coast	Angove	RFMS	Nov-96	4	Probait	29.7	29.78	29.78	29.78	119.04
Swan	Avon[2]	RFMS	Jun-99	6	Probait	102.47	204.94	102.47	204.94	614.82
South West	Boranup[3]	Boranup	Mar-05	4	Probait	64.81	64.81	64.81	64.81	259.24
Pilbara	Burrup	RFMS: Cameras	Jun-21	1	Eradicat			23.34		23.34
Pilbara	Burrup	RFMS: Cameras	Oct-97 (Ceased 2021)	0	Probait	Changed to Eradicat baiting only in 2022				0
Pilbara	Calvert Range	RFMS: cameras	Mar-03	1	Eradicat			198.03		198.03
South Coast	Cape Arid	Paisley, Poison Creek	Mar-11 (2016)	1	Eradicat		2021.69			2021.69
South Coast	Cape Arid	Paisley, Poison Creek	Dec-96	3	Probait	2021.69		2021.69	2021.69	6065.07
South Coast	Cape Le Grand	RFMS: Cameras	Dec-96	2	Probait		290.15		290.15	580.3
Pilbara	Cape Range	RFMS: cameras + BFRW	Aug-14	1	Eradicat			925.74		925.74
South Coast	Corackerup	not monitored	Apr-21	1	Eradicat		28.59			28.59
South Coast	Corackerup	not monitored	Sep-96	1	Probait				28.59	28.59
Warren	Denbarker	Lake Muir, Mt Frankland, Mt Lindsey	Nov-96	3	Probait	2095.41	2095.41		2095.41	6286.23
Warren	D'Entrecasteaux	Charley	Oct-97	2	Probait		738.92		738.92	1477.84
Warren	Donnelly	Wheatley, Gray	Oct-97	2	Probait		996.5		996.5	1993
Wheatbelt	Dragon Rocks	cameras (volunteer only)	May-96	3	Probait	238.45	238.45		238.45	715.35
Pilbara	Durba Hills	RFMS: Thomas/cameras	Jul-07	1	Eradicat			288.81		288.81
South Coast	Fitzgerald	Twertup, Drummond, Moir	Drummond 2010, Twertup	1	Eradicat		3597.01			3597.01

Region	Cell Name	Monitoring	Date aerial baiting commenced	Planned annual frequency	Bait type	2021-2022 Dec-Feb	2022 Mar-May	2022 Jun-Aug	2022 Sep-Nov	Total
			2013, Moir 2013 + 2016 only							
South Coast	Fitzgerald	Twertup, Drummond, Moir	Oct-96	3	Probait	3597.01		3597.01	3597.01	10791.03
Pilbara	Fortescue Marsh	RFMS	Aug-12	1	Eradicat			643		643
Warren	Irwin	not monitored	Dec-96	2	Probait		44.01		44.01	88.02
Swan	Julimar	Julimar	Jul-92	4	Probait	178.43	178.43	178.43	178.43	713.72
Midwest	Kalbarri	predator monitoring	Aug-16	1	Eradicat			1841.09		1841.09
Midwest	Kalbarri	predator monitoring	Nov-96	2	Probait		1662.44		3324.88	4987.32
Wheatbelt	Lake Magenta	Lake Magenta	May-96	4	Probait	946.5	946.5	946.5	946.5	3786
Swan + South West	Lane Poole ext[1,2]	Batalling, George	Jun-Apr-94	6	Probait	1535.24	3070.48	1535.24	3070.48	9211.44
Goldfields	Lorna Glen (Mutuwa)	Science	Jul-04	1	Eradicat			2226.69		2226.69
Warren	Manjimup	Balban, Boyicup, Camelar, Chariup, Moopinup, Warrup	Nov-96	4	Probait	817.3	817.3	817.3	817.3	3269.2
South Coast	Manypeaks	Waychinicup	Nov-96	3	Probait	107.05		107.05	107.05	321.15
South Coast	Manypeaks	Waychinicup	Feb-12	1	Eradicat		107.05			107.05
South Coast	Peniup	Peniup	Apr-21	1	Eradicat		36.3			36.3
South Coast	Peniup	Peniup	Sep-96	1	Probait				36.3	36.3
Midwest	Peron	not monitored	Mar-02	1	Eradicat		973.19			973.19
Swan	Perth Hills[2]	Hills Forest, Jarrahdale	Apr-94	6	Probait	3272.84	6493.92	3246.96	6493.92	19507.64
South Coast	Ravensthorpe Range	Chuditch	Sep-97(?)	2	Probait		265.39		265.39	530.78
South West	Scott	not monitored	Mar-98	2	Probait		8.37		8.37	16.74
South West	Shannon	KinKin, Nicol Rd, Tone, Woolbales	Nov-96	3	Probait	2717.52	2717.52		2717.52	8152.56
South Coast	Stirlings High	Stirlings	Nov-96	2	Probait		283.02		283.02	566.04
South Coast	Stirlings Low	Stirlings	Nov-96	2	Probait		675.13		675.13	1350.26
South Coast	Stokes	not monitored	Dec-96	2	Probait		189.7		189.7	379.4

Region	Cell Name	Monitoring	Date aerial baiting commenced	Planned annual frequency	Bait type	2021-2022 Dec-Feb	2022 Mar-May	2022 Jun-Aug	2022 Sep-Nov	Total
South West	Sunklands	Blackwood, Milyeannup, St Johns	Jul-97	2	Probait		2467.83		2467.83	4935.66
South Coast	Two Peoples Bay	RFMS	Feb-12	1	Eradicat		30.1			30.1
South Coast	Two Peoples Bay	RFMS	Nov-96	3	Probait	30.1		30.1	30.1	90.3
Warren	Walpole	Nornalup, Valley of the Giants	Dec-96	2	Probait		57.42		57.42	114.84
South West	Wellington[2]	Catterick, Centaur, Noggerup, Gervasse	Apr-94 to Oct 96	6	Probait	823.98	1647.96	823.98	1647.96	4943.88
					Total area baited /quarter	18617.06	33016.87	20486.33	33744.68	105864.94

1. Lane Poole ext. cell extends across Perth Hills and Wellington Districts. The area defined here includes the area subject to baiting in both districts. 2. Sites that received additional Probait delivery as part of Alcoa Foundation sponsorship. Additional baits are deployed in spring and autumn increasing the area baited in those two seasons. 3. Increase from two annual aerial Probait deliveries to four annual Probait deliveries in response to a significant bushfire at Boranup in the summer of 2021/2022.

Table 7: Number of baits deployed for ground baiting in each treatment area July 2020 to June 2021. Ground delivery of Probait is one bait every 200 m of track while Eradicat is delivered at one bait per 100 m of track.

WS cell/transect	Region/District	Bait type	Planned frequency	2021 Jul	2021 Aug	2021 Sep	2021 Oct	2021 Nov	2021 Dec	2022 Jan	2022 Feb	2022 Mar	2022 Apr	2022 May	2022 Jun	2021/2022 totals
Avon	Perth Hills	Probait	8													
Benger	Wellington	Probait	12	9	0	0	0	0	9	9	32	32	32	27	9	159
Bindoon	Perth Hills	Probait	8													
Boranup	Blackwood	Probait	12	220	199	220	201	220	18	212	223	223	245	207	243	2431
Boyagin	Wheatbelt	Probait	12	950	950	950	950	950	950	950	950	950	950	0	950	10450
Burrup	Karratha	Eradicat	2	0	22	0	0	0	0	0	0	0	0	0	0	22
Cape Arid	Esperance	Eradicat	3	0	0	0	0	0	994	0	1000	0	0	0	0	1994
Cape Arid	Esperance	Probait	2 & 4	0	0	0	0	0	0	455	0	600	0	0	0	1055
Cape Le Grand	Esperance	Probait	2 & 4	85	40	0	0	0	0	0	0	0	0	0	0	125

WS cell/transect	Region/District	Bait type	Planned frequency	2021 Jul	2021 Aug	2021 Sep	2021 Oct	2021 Nov	2021 Dec	2022 Jan	2022 Feb	2022 Mar	2022 Apr	2022 May	2022 Jun	2021/2022 totals
Cape Range + surrounds	Exmouth	Eradicat	6	0	0	0	400	0	0	0	0	0	0	0	200	600
Creery Wetlands /Channel Island Reserve	Swan	Probait	8													
Corackerup	Albany	Eradicat	5	0	0	0	0	0	0	0	0	500	0	0	0	500
Corackerup	Albany	Probait	7	0	246	0	241	252	275	248	275	0	0	250	0	1787
Denbarker	Donnelly	Probait	4	0	0	324	0	0	362	0	0	0	362	0	342	1390
Denbarker (Mt Lindsay)	Frankland	Probait	6	43	73	29	0	0	0	0	44	0	29	0	73	291
D'Entrecasteaux (Fire mitigation Nov 2021)	Donnelly	Probait	4	0	0	180	0	0	180	147	0	180	145	0	326	1158
Donnelly	Donnelly	Probait	?	0	0	756	0	0	627	54	0	707	0	0	742	2886
Dragon Rocks NR	Wheatbelt	Probait	8	700	573	0	700	700	0	0	0	0	700	700	0	4073
Dryandra	Wheatbelt	Eradicat	5	0	250	3075	1725	1020	0	250	0	3075	2900	2900	0	15195
Dryandra	Wheatbelt	Probait	7	3075	3075	0	0	708	1725	3075	2960	0	175	0	3075	17868
Ellen Brook	Swan	Probait	4													
Fitzgerald River	Albany	Eradicat	1													
Fitzgerald River	Albany	Probait	3	0	0	490	0	0	1087	0	0	0	0	0	0	1577
Gull Rock	Albany	Probait	4	0	0	0	86	0	0	0	0	0	105	0	105	296
Gundaring	Wheatbelt	Probait	26	80	80	85	40	45	40	85	85	130	85	85	85	925
Irwin	Frankland	Probait	6	26	0	26	0	0	0	26	0	0	26	26	0	130
Julimar	Perth Hills	Probait	8	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0
Kalbarri	Midwest	Eradicat	1	0	4750	0	0	4900	0	0	0	0	0	2000	0	11650
Kalbarri	Midwest	Probait	3	0	0	0	0	0	0	0	2405	0	0	1500	0	3905
Lake Magenta NR	Wheatbelt	Probait	4	0	0	600	0	1325	0	0	1325	0	0	0	0	3250
Lake Pleasant View	Albany	Probait		0	0	0	100	0	0	0	0	0	100	0	100	300
Lane Poole ext	Wellington	Probait	12	314	303	314	303	314	314	314	314	314	344	314	314	3776
Locke NR	Blackwood	Probait	12	9	8	8	8	8	2	28	30	30	30	30	17	208
Manjimup	Donnelly	Probait	4 & 12	619	600	2716	582	600	1855	1508	600	2817	600	600	2754	15851
Manypeaks	Albany	Eradicat	5													
Manypeaks	Albany	Probait	7	0	355	0	355	234	288	355	355	0	200	324	0	2466

WS cell/transect	Region/District	Bait type	Planned frequency	2021 Jul	2021 Aug	2021 Sep	2021 Oct	2021 Nov	2021 Dec	2022 Jan	2022 Feb	2022 Mar	2022 Apr	2022 May	2022 Jun	2021/2022 totals
Mehniup	Frankland	Probait	?	0	13	13	0	13	0	13	0	13	0	13	0	78
Mogumber Reserve	Swan	Probait	12													
Muddy Lakes	Wellington	Probait	6	9	0	9	0	0	0	0	0	0	0	0	0	18
Moore River NR	Swan	Probait	6 & 12													
Mt Stirling NR	Wheatbelt	Probait	26	150	150	150	75	75	75	150	150	225	150	150	150	1650
Mt Caroline NR	Wheatbelt	Probait	26	160	160	160	80	80	80	160	160	240	160	160	160	1760
Nangeen	Wheatbelt	Probait	26	0	0	0	0	0	0	0	0	20	0	0	0	20
Ningaloo Marine Park	Exmouth	Eradicat	3	0	350	0	0	89	21	81	29	0	81	0	0	651
Nuyts	Frankland	Probait	?	0	93	0	19	74	74	0	93	0	93	0	74	520
Peniup	Albany	Eradicat	5	0	0	0	0	0	0	0	0	500	0	0	0	500
Peniup	Albany	Probait	7	0	154	0	230	270	275	285	269	0	0	275	0	1758
Peron	Midwest	Eradicat	5													
Perth Hills	Perth Hills	Probait	12	1676	1647	587	605	686	654	747	756	708				8066
Ravensthorpe	Albany	Probait	4	0	0	659	0	0	1115	0	0	600	0	0	0	2374
Sales	Wheatbelt	Probait	26	70	70	70	35	35	35	70	70	105	70	70	70	770
Scott NP	Blackwood	Probait	12	37	36	36	37	35	93	109	115	114	106	114	37	869
Shannon	Donnelly	Probait	4	0	0	1141	248	0	847	192	0	1255	0	0	1430	5113
Shannon	Frankland	Probait		42	53	0	42	0	53	0	53	0	53	0	53	349
Stirling Range	Albany	Probait	4	0	0	0	254	0	0	2000	0	0	2000	0	0	4254
Stokes	Esperance	Probait	2 & 4	0	595	668	0	0	1523	0	0	0	0	508	0	3294
Sunklands	Blackwood	Probait	12	161	152	159	177	168	164	84	156	156	175	168	196	1916
Thomson's Lake	Swan	Probait	2													
Tuart Forest	Blackwood	Probait	12	156	147	179	175	153	182	120	63	186	184	184	181	1910
Tutanning	Wheatbelt	Eradicat	2	0	0	300	0	0	0	0	0	0	0	350	0	650
Tutanning	Wheatbelt	Probait	10	700	181	333	700	700	700	700	1006	700	700	350	700	7470
Twin Swamps NR	Swan	Probait	4													
Two Peoples Bay	Albany	Eradicat	5	0	0	0	0	0	0	0	0	370	370	0	0	740

WS cell/transect	Region/District	Bait type	Planned frequency	2021 Jul	2021 Aug	2021 Sep	2021 Oct	2021 Nov	2021 Dec	2022 Jan	2022 Feb	2022 Mar	2022 Apr	2022 May	2022 Jun	2021/2022 totals
Two Peoples Bay	Albany	Probait	7	0	167	167	166	177	0	185	185	0	0	0	185	1232
Walpole	Frankland	Probait	6	0	0	256	0	256	0	256	0	256	0	256	0	1280
Walyunga	Perth Hills	Probait	9 & 12													0
Water Corp Angove	Albany	Probait	4	0	0	0	0	0	0	0	0	0	128	0	0	128
Wellington	Wellington	Probait	12	200	200	200	200	227	227		227	235	235	200	200	2351
Yalgorup NP	Swan	Probait	6													

Appendix 3: Occupancy modelling

Methods

Occupancy modelling (i.e. presence/absence) using the unmarked program (Fiske and Chandler 2011) in R (R Core Team 2020) was used to model long term trends for the four primary Western Shield species across 43 of the most frequently monitored sites (cage monitoring only) in the period 1992 to 2022.

Noongar seasons were used to delineate the primary periods. However, surveys were not always conducted at consistent times during the year and as a result, there was considerable variability in whether a site was monitored in any one of the six Noongar seasons in any given calendar year. Based upon the monitoring regime, we were able to model two primary periods for each site within each calendar year. However, the season of monitoring varied from one site to another and from one calendar year to another. Each site was repeat (or secondary) surveyed over a maximum of four days (max n = 43, average n = 31.5); noting that we were comfortable assuming that the occupancy status did not change over the secondary survey period.

The unmarked single species multi-season modelling function (colext) was applied with the initial occupancy parameter modelled without a covariate. The colonisation and extinction parameters were allowed to vary as a function of primary period and the detection parameter was modelled as a function of the actual Noongar season (i.e., Birak, Bunuru, Djeran, Makuru, Djilba, Kambarang[6]). Our logic was that detection status was most likely to be driven by the actual season whereas occupancy was most likely to be driven by other factors (such as initial occupancy, management treatment, etc). We only used a small number of well justified biologically sensible covariates and as such, did not utilise any model comparison approaches (Royle et al. 2014).

The 'goodness-of-fit' of each model was assessed with the generic parametric bootstrapping function 'parboot' in unmarked as described by Fiske and Chandler (2011). Graphs were generated with ggplot2 (Wickham 2016).

Sites included in analyses

Avon Valley, Balban, Batalling, Bindoon, Blackwood River, Boranup, Boyagin EAST, Boyagin WEST, Boyicup, Camelar, Cape Arid, Cape Le Grand, Catterick, Centaur, Corackerup, Drummond Track, Dryandra, Dwalgan, George Block, Gervasse, Julimar, Lake Magenta, Lake Muir, Milyeannup, Moir Track, Moopinup, Mount Gairdner, Mt Lindsay, Nicol Rd, Noggerup, Peniup, Porongorup, St John, Stirling Range, Tone, Tutanning, Twertup, Valley of the Giants, Warrup, Waychinicup, Wellington National Park, Woolbales, Yalgorup

[6] Noongar seasons are defined by weather patterns and ecological changes and hence are not specifically defined by the Gregorian calendar, however for the purposes of detection modelling they were defined by: Birak = Dec-Jan; Bunuru = Feb-Mar; Djeran = Apr-May; Makuru =Jun-Jul; Djilba =Aug-Sep; Kambarang = Oct-Nov (https://www.noongarculture.org.au/food/).

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