Western Shield Monitoring Results: Mammals — trapping transects and camera monitoring to December 2021



June 2022

GOVERNMENT OF WESTERN AUSTRALIA
Department of **Biodiversity, Conservation and Attractions**
PARKS AND WILDLIFE SERVICE
western shield

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3.0	21/6/2022		Comments from WSAG added
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Acknowledgements

Thanks to all Department of Biodiversity, Conservation and Attractions (DBCA) staff who contributed their time both in the field and in collating the data for all monitoring programs reported within. To Project Numbat, Numbat Taskforce and other volunteer groups for allowing access to their camera monitoring data and to Mark Cowan for the use of his Shiny App (R Studio 2019) to produce detection maps and activity figures from camera data.

Summary

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. 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*), woylie (*Bettongia pencillata*), chuditch (*Dasyurus geoffroii*) and quenda (*Isoodon obesulus*), for the period 1996 to 2021. In addition, preliminary information on two additional species, quokka (*Setonix brachyurus*) and black-flanked rock-wallaby (*Petrogale lateralis lateralis*) and data from 13 sites monitored for predators.

A total of 24 sites were monitored for native fauna using WS cage trapping methods in 2021, 40% less than what was monitored in 2010. The number of sites monitored using these methods has declined since 2015. Reduced monitoring is likely to have significant impacts on WS's ability to effectively report on population trends for focal species and limit the capacity to implement adaptive management. It is important that at a minimum, monitoring data is collected from those sites recommended in the *Western Shield Monitoring Plan 2021 – 2024*.

The relative abundance of woylies continued to increase at five sites in 2021. At a metapopulation level there has been a decline in the number of sites where the species is detected in cage traps since the peak in the late 1990s. Camera monitoring has however been able to detect woylies at some sites where they have not been recorded in cages in recent years. This suggests that current cage trapping methods are only effective at monitoring this species once a threshold density is reached. Further management efforts are likely to be required to ameliorate threatening processes at some locations to facilitate improvements in the woylie population size.

Chuditch expanded their area of occupancy in the period 1996 – 2018 (based on cage monitoring). However, from 2019 the number of sites recording chuditch in cage monitoring has declined substantially. The implementation of chuditch specific monitoring at several sites suggests that WS monitoring methods do not adequately reflect the true population. Monitoring of additional sites using revised chuditch specific methods in 2022 will help further our understanding of the status of this species.

Koomal continue to be the most commonly recorded species in WS transects. However, the relative abundance of the species at key sites continue to demonstrate declines. At a state level, occupancy modelling using presence/absence suggests declining trends in the periods 2010 – 2013 and 2015 – 2017 for koomal. From 2018 occupancy has increased, with 73% (95% CI: 54%, 92%) of sites estimated to be occupied in 2021. This is similar to estimates recorded in 2001 when 74% (95% CI 60%, 89%) were occupied. The larger confidence intervals reflect reduced sampling in 2021.

There is a large temporal variability in quenda captures in cages, but from 1996 – 2020 the overall trend is a decline in the number of sites recording the species. Notably, in 2021 detections of quenda did improve to an estimated 58.5% sites (95% CI 0.9%, 100%), but with limited confidence, reflecting the reduced sampling in recent years. Extremely low captures of the species at most sites suggests that it will be important to consider alternative monitoring methods to determine trends at the population level.

Quokka monitoring under Western Shield was initiated in 2020 and the data is not fully collated, however evidence from a single site that has been monitored since 1996 suggests this population is increasing. Monitoring of black-flanked rock-wallabies indicates positive population trends across most sites with the exception of Cape Le Grand.

A total of 22 sites are now monitored for 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, however further examination of 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 strategy of WS fox and feral cat management 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 vulpecula*), 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 2021. 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 and 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

A total of 23 sites were monitored using cage traps in 2021 (Figure 1), four less than in 2020 and 40% less than in 2010 (Figure 2). Prioritisation of resources to bushfire response and other high priority activities, together with limitations on undertaking field work due to higher than expected rainfall, reduced monitoring capacity in 2021. However, since 2015 the number of sites monitored using cage trapping has declined. If this trend continues it is likely to have significant impacts on WS's ability to effectively interpret population trends for focal species.

Camera monitoring for predators continued at both baited and non-baited areas providing information on the effectiveness of different bait prescriptions, while targeted camera monitoring has been used at several sites to monitor for threatened species. Sites with active camera monitoring in 2021 are highlighted with light blue dots in Figure 1, noting that some sites are monitored through district or third-party programs (e.g., Project Numbat, Numbat taskforce, etc.).

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 2021). The sites included in the analyses and methods used are provided in Appendix A.

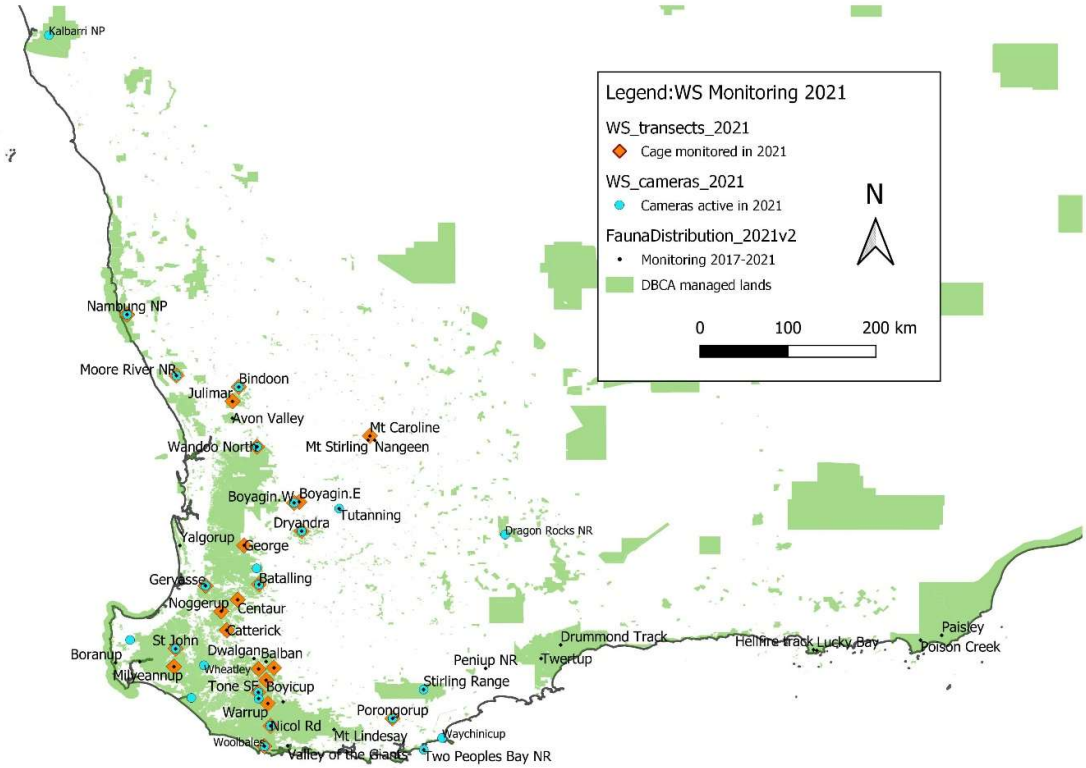

Figure 1: Map indicating the distribution of monitoring sites across the south of the state. Sites marked with an orange diamond were monitored with traps in 2021, black dots are sites that have been monitored at least once in the last five years and light blue dots indicate active camera monitoring in 2021. Note some of the sites indicated are not official WS sites but use the same or very similar methods. Monitoring at Mt Caroline, Mt Stirling and Nangeen uses Thomas traps.

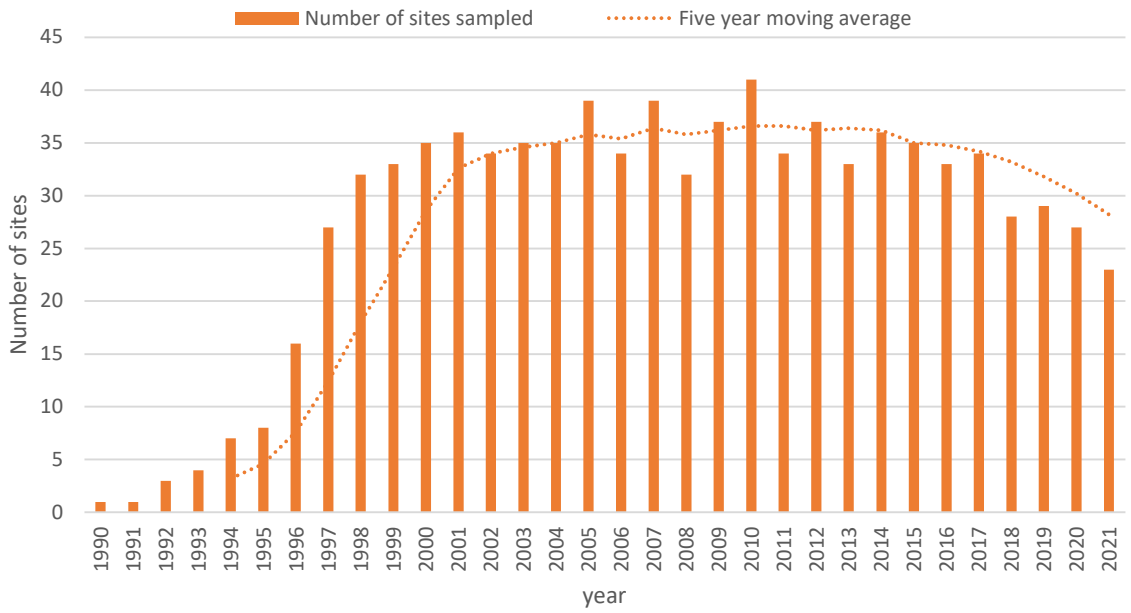

Figure 2: Number of sites monitored using WS standard cage monitoring methods each year. The dotted line represents the average number of sites monitored every five years.

Woylie

The number of sites where woylies were captured in WS or associated cage trapping has steadily declined since the early 2000s, with only 32% of sites monitored 2017 – 2021 (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[1] indicates that overall woylie distribution has declined over time (Figure 3).

[1] Occupancy modelling using unmarked with up to four visits per secondary survey and up to two per primary survey for each site each year.

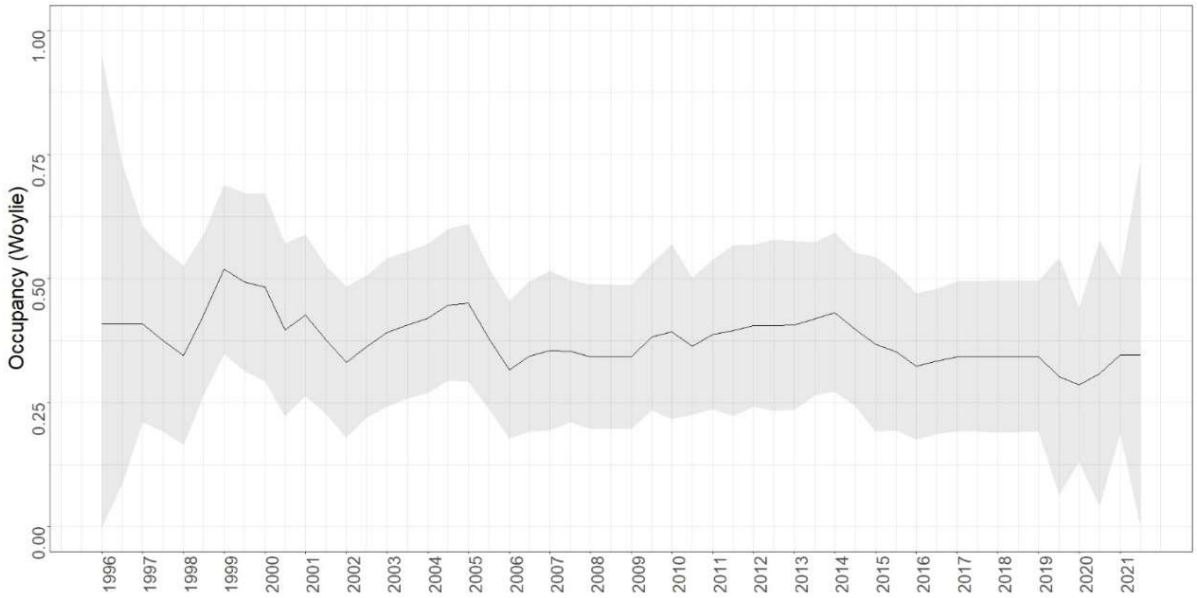

Figure 3: Modelled occupancy of woylies based on cage monitoring at WS monitoring sites (N = 43) 1996 – 2021 (x-axis = Year). Grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data. Larger confidence bounds usually reflect periods of lower trap effort.

Camera monitoring has identified that woylies continue to persist at Tutanning despite zero captures of this species in recent cage trapping. This brings the total of sites in which woylies have been detected (both cage and camera monitoring) to 14 in the period 2017 – 2021 (Figure 4), four less than that recorded in the 1997 – 2001 period.

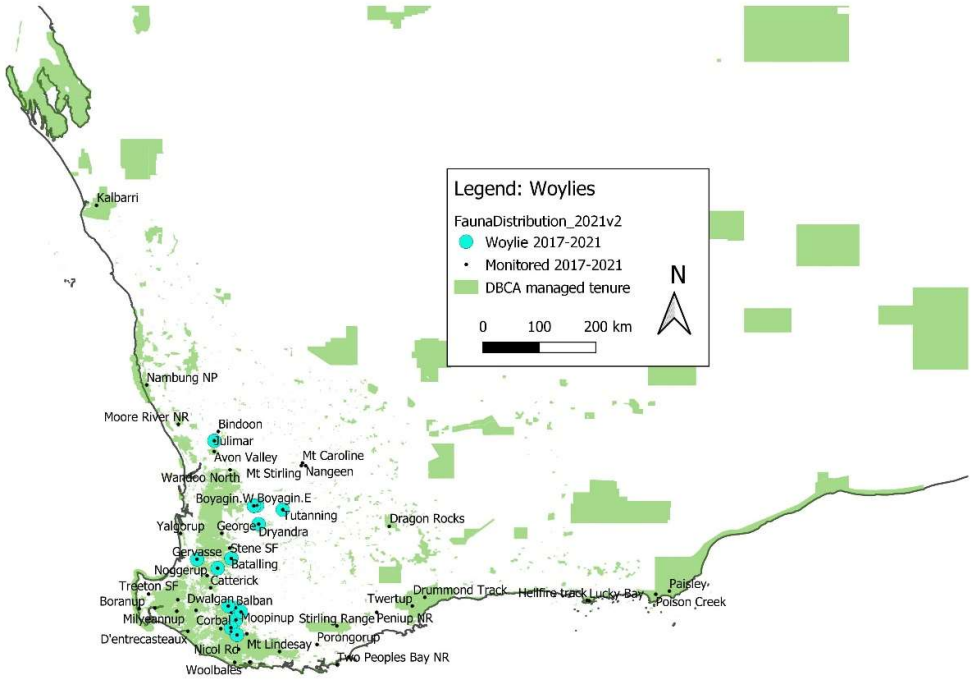

Figure 4: Sites where woylies were captured in cage trapping or noted on camera monitoring 2017 – 2021 (blue dots). Black dots indicate sites that were monitored at least once between 2017 and 2021 using either camera or cage.

Despite fewer sites recording woylies, relative abundance at high-performing sites (i.e., Boyagin West, Boyagin East, Boyicup, Dryandra, and Moopinup) indicates that most of these populations have increased or were stable in the period 2017 – 2021 (Figure 5). Except for Boyagin, in recent years all sites have had an increase in ground baiting (Moopinup and Boyicup, 2015) or introduction of feral cat management (Dryandra, 2016). In contrast, Batalling and Warrup continue to record very low number of woylies. Both sites have historically supported relatively high densities of woylies (Figure 5). It is likely that additional management will be required to ameliorate threats at these and other sites with low-density populations to facilitate improvements in the local woylie population.

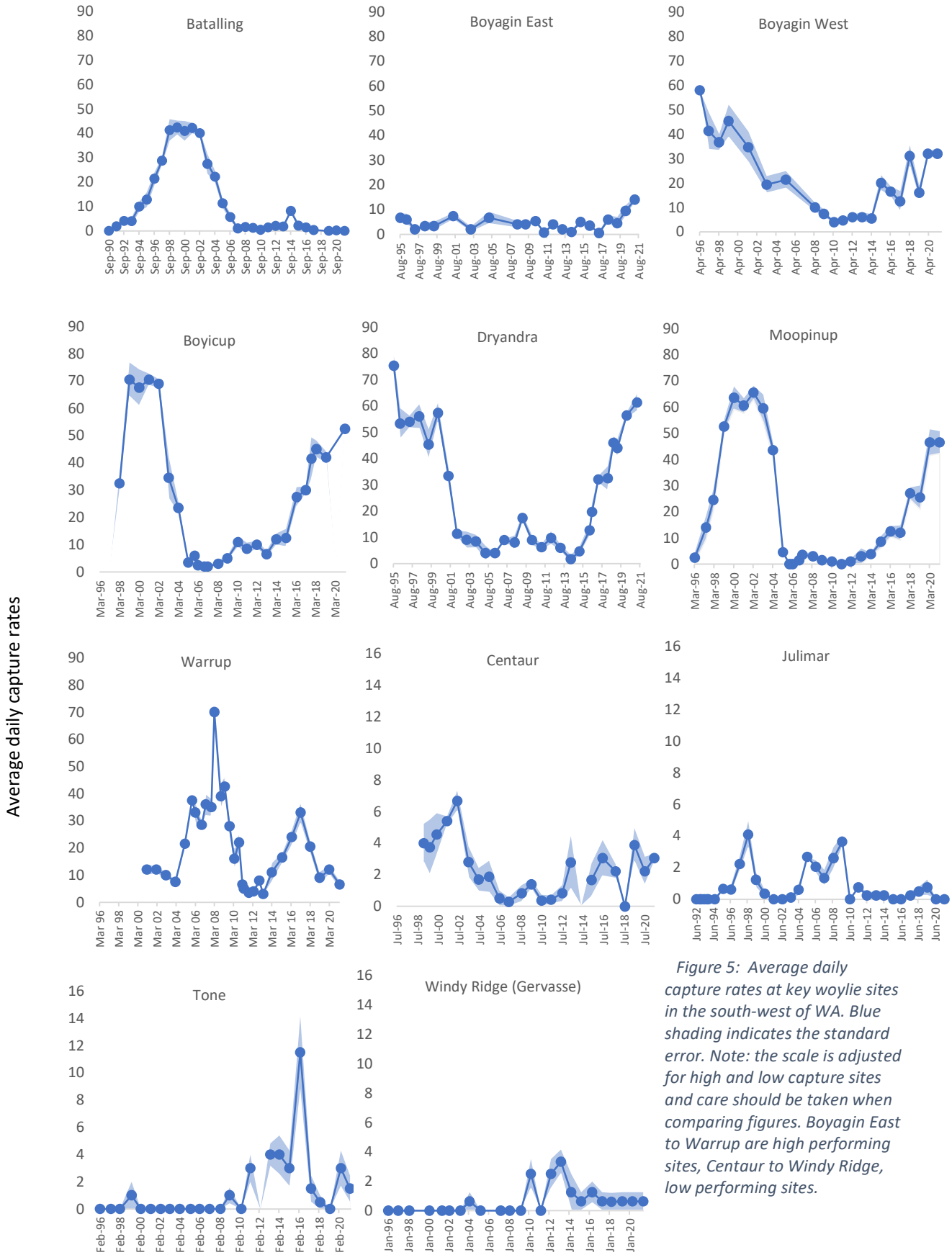

Figure 5: Average daily capture rates at key woylie sites in the south-west of WA. Blue shading indicates the standard error. Note: the scale is adjusted for high and low capture sites and care should be taken when comparing figures. Boyagin East to Warrup are high performing sites, Centaur to Windy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

Chuditch

Overall, there has been an increasing trend in the number of sites where chuditch has been detected in cages (1996 – 2019). However, from 2020 onwards there has been a concerning decline in the number of sites recording this species (Figure 6).

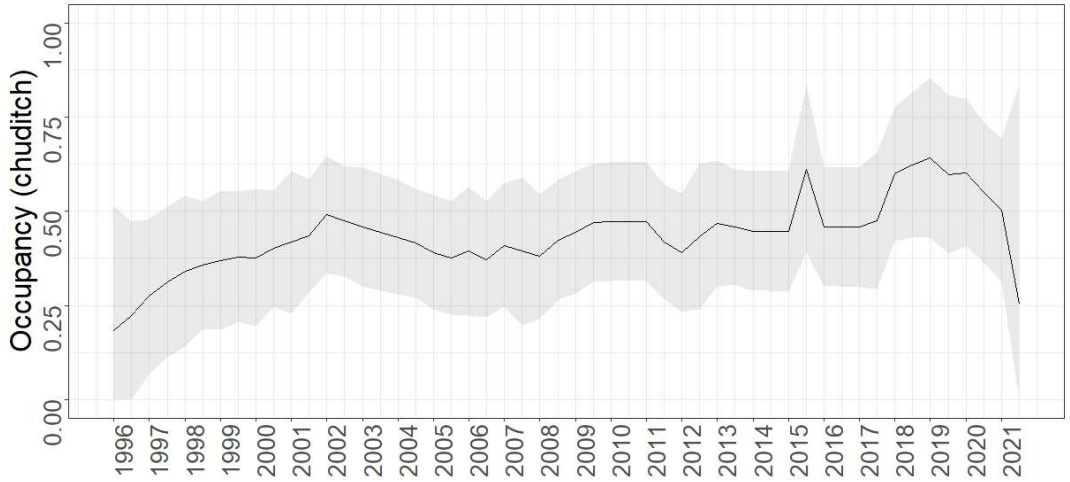

Figure 6: Modelled occupancy of chuditch based on cage monitoring at WS monitoring sites (N=43) 1996 – 2021 (x-axis=Year). The grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data — this usually reflects periods of lower trap effort.

Chuditch continue to be recorded on automated wildlife cameras at Kalbarri National Park, St Johns (Blackwood District) and in Stene state forest (non-baited control site), increasing the number of sites recording the species in 2021 to 15. In the period 2017 – 2021 chuditch have been recorded either on camera or in cage monitoring at 25 monitored locations (Figure 7). At a site level the relative abundance of chuditch has also declined, with only Batalling and Warrup recording a slight increase in captures since 2017 (Figure 8).

Notably, results from chuditch specific monitoring have indicated that at some sites chuditch are more common than WS monitoring would suggest (see section below “Chuditch specific monitoring”). It is unclear why monitoring methods that had previously been effective at catching chuditch have had a reduced efficacy over time. It is hoped that targeted chuditch monitoring will improve the capacity to monitor population trends of this species more effectively, informing improved identification of potential threats to the species persistence and mitigation options.

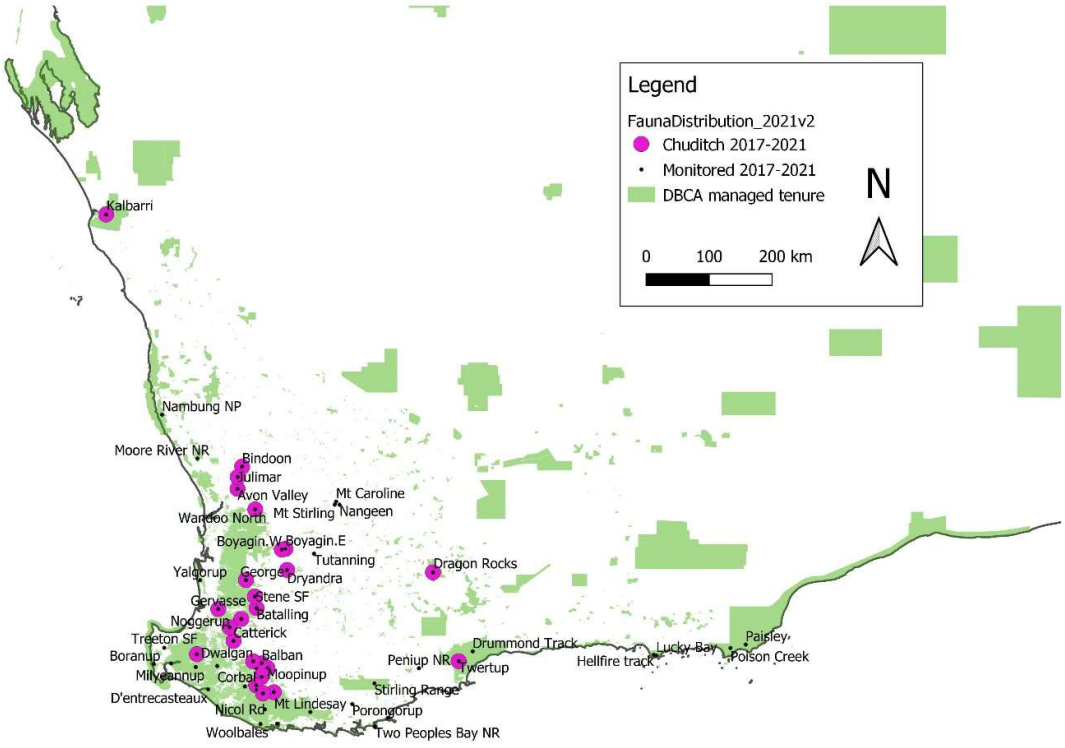

Figure 7: Sites where chuditch were captured in cage trapping or noted on camera monitoring 2017 – 2021 (pink dots). Black dots indicate sites that were monitored at least once between 2017 and 2021 using either camera or cage.

Chuditch specific monitoring

As part of a collaborative project between Biodiversity and Conservation Science, Conservation and Ecosystem Management and Regional and Fire Management Services divisions and funded through Regional Priorities Funding (2020 – 2021), chuditch specific monitoring was expanded to include five forest sites in 2021. Cage traps were lured with chicken and cages were set every 500 m along unpaved tracks near or along WS transects. Trapping was conducted in autumn and early winter (Noongar season, Makuru: Figure 9) to target periods when male chuditch are most likely to be actively seeking females for breeding and hence more likely to intercept traps.

Capture of chuditch was significantly higher using the chuditch specific methods compared to captures of chuditch at similar locations using traditional WS methods (Figure 10). Information collected from this project will enable more robust estimates of chuditch population sizes and the population trajectory across the state.

Additional funding was granted through Regional Priorities Funding in 2021 – 2022 to expand this method to two sites on the South Coast and two in the Goldfields. Four of the forest sites (i.e., Batalling, Jarrahdale, Catterick and Centaur) will also be monitored using this method in 2022 through funding received from the Alcoa Foundation.

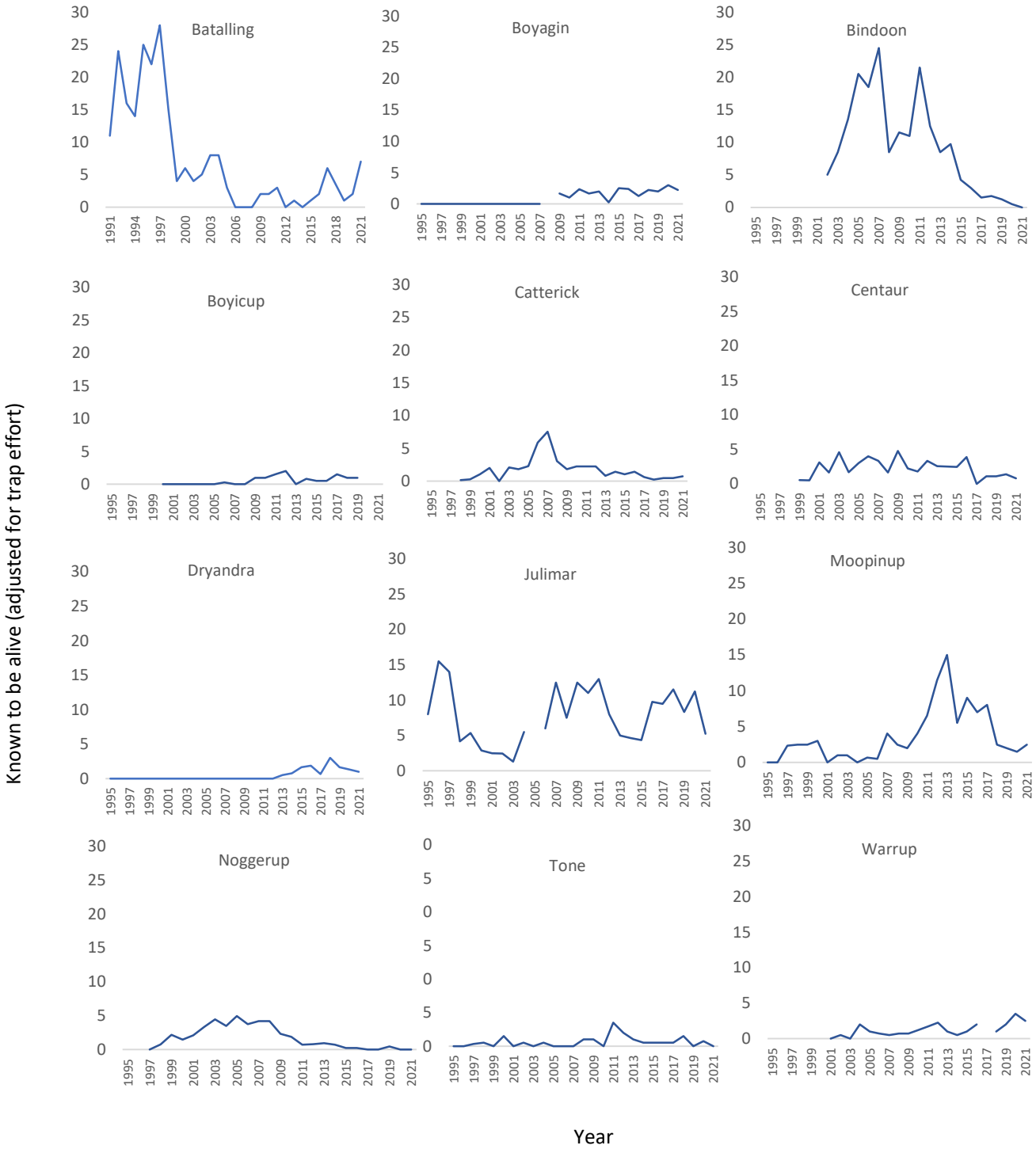

Figure 8: Known to be alive (KTBA) adjusted for trap effort (y-axis) of chuditch across WS and district monitoring sites, where chuditch are regularly captured. X-axis = year.

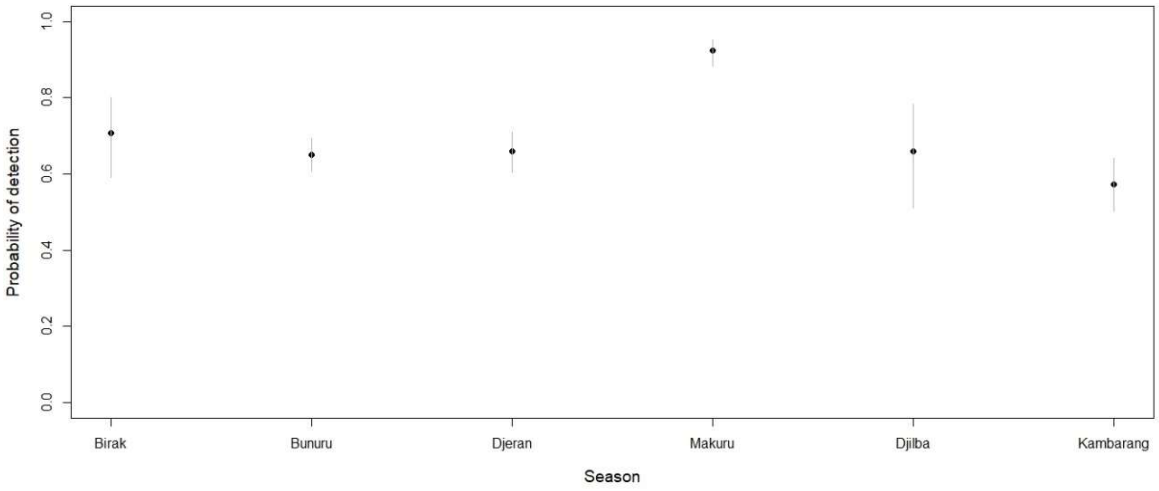

Figure 9: Probability of detection of chuditch in each of the six Noongar seasons[2]

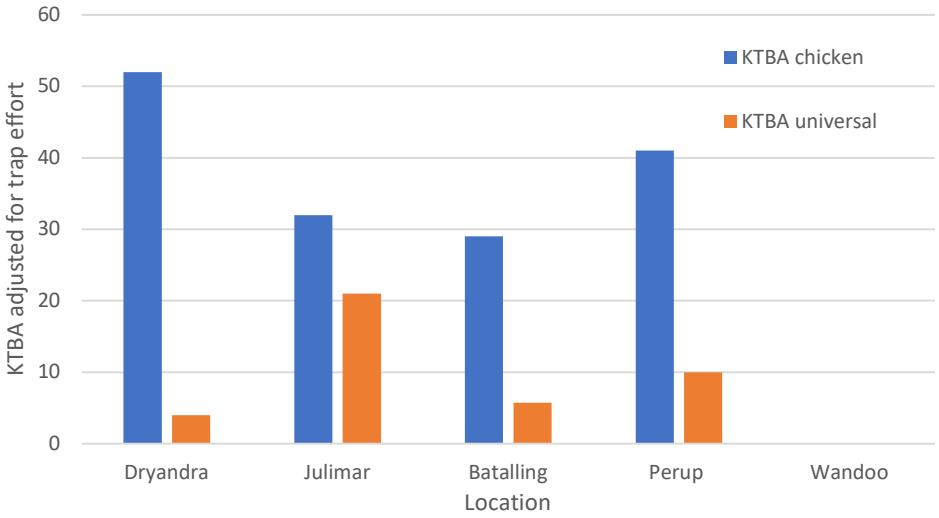

Figure 10: Number of individual chuditch captured (adjusted for trap effort) using two different capture methods in 2021. Blue = cage traps set every 500 m, lured with chicken. Orange = cage traps set every 200 m, lured with universal bait. No chuditch were captured in 2021 in Wandoo (this is an unbaited section in the northern portion of Wandoo National Park).

[2] 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/).

Koomal

Koomal are the most frequently captured medium-sized marsupial in cage traps in WS 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 steadily declined. In recent years there has been some recovery, with occupancy in 2021 recorded at over 70% of sites.

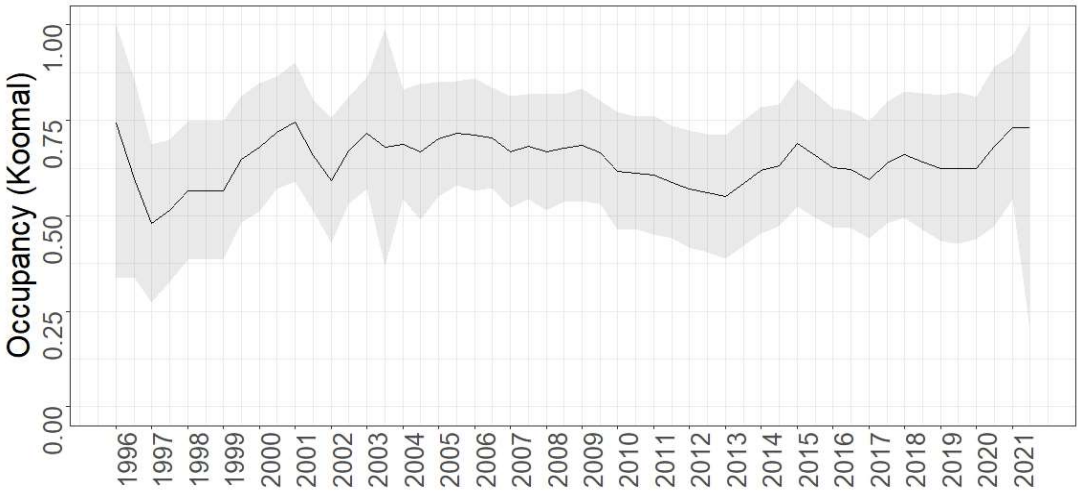

Figure 11: Modelled occupancy of koomal based on cage monitoring at WS monitoring sites (N = 43) 1996 – 2021 (x-axis = Year). Grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data — this usually reflects periods of lower trap effort.

Several sites that had not recorded koomal in cages did record the species on camera — Bindoon, Avon Valley, and Kalbarri, suggesting 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).

Koomal relative abundance

Koomal relative abundance has declined at most monitored sites, except for Batalling, Boyagin East, and Boyagin West (Figure 13). It is probable that observed declines in the relative abundance at Boyicup, Dryandra, and Moopinup may be a result of fewer traps being available to capture a koomal as in recent years most traps are occupied with woylies, however camera monitoring at Dryandra has suggested a slight decline in koomal detections at this site since 2015 (Figure 14). Observed declines in captures of koomal at sites which have low captures of other species (e.g., Stirling Range, St Johns, Tone) are likely representative of a true decline and are of concern.

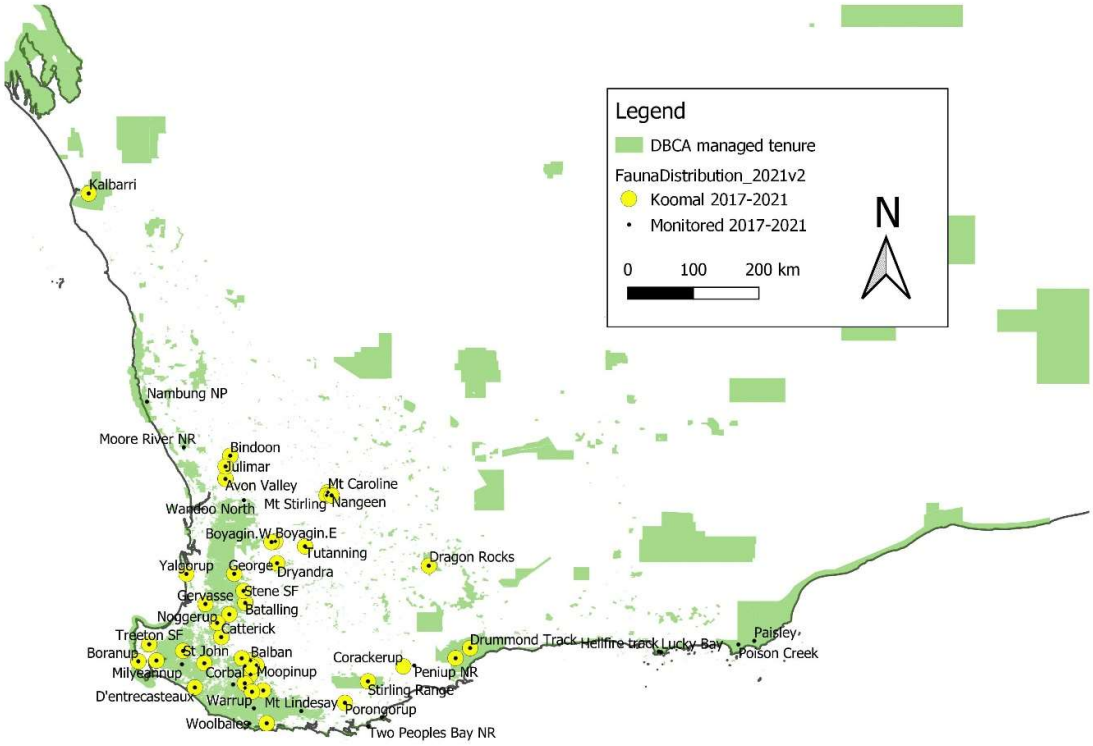

Figure 12: Sites where koomal were captured in cage trapping or noted on camera monitoring 2017 – 2021 (yellow dots). Black dots indicate sites that were monitored at least once between 2017 and 2021 using either camera or cage.

Figure 13: KTBA (adjusted for trap effort; y-axis) for koomal at selected WS sites (x-axis = year). There was no monitoring at Stirling Range, Tutanning in 2021. Note only 12 sites with highest captures included here. Refer to regional summaries for other sites.

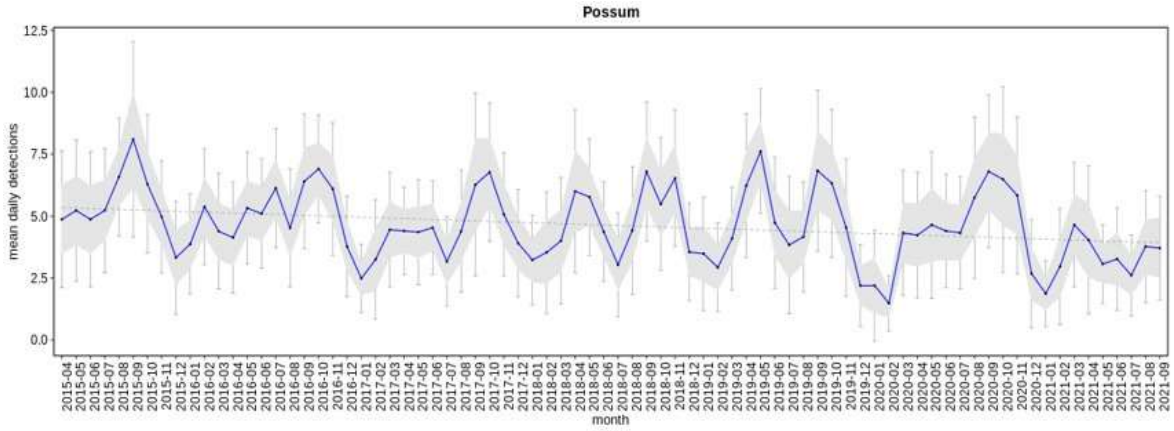

Figure 14: Koomal activity at Dryandra 2014 – 2021. Note data for 2021 is not complete and the mean daily detections for 2021 may be slightly higher than indicated above.

Quenda

The records of quenda in cage traps indicate that the detectability of this species fluctuates substantially from year to year. However, since 1996 the general trend has been a decline in the number of sites in which the species was detected (Figure 15), with occupancy of the species at monitored sites at its lowest in 2013. The underlying processes driving these changes are unknown. Detection estimates suggests the species is more likely to be detected in the Noongar season of Birak (December to January: Figure 16) but most monitoring occurs in autumn or spring potentially limiting the capacity to detect the species. However, it is probable that multiple processes such as rainfall, fire, habitat change, and predation influence the detection/presence of this species.

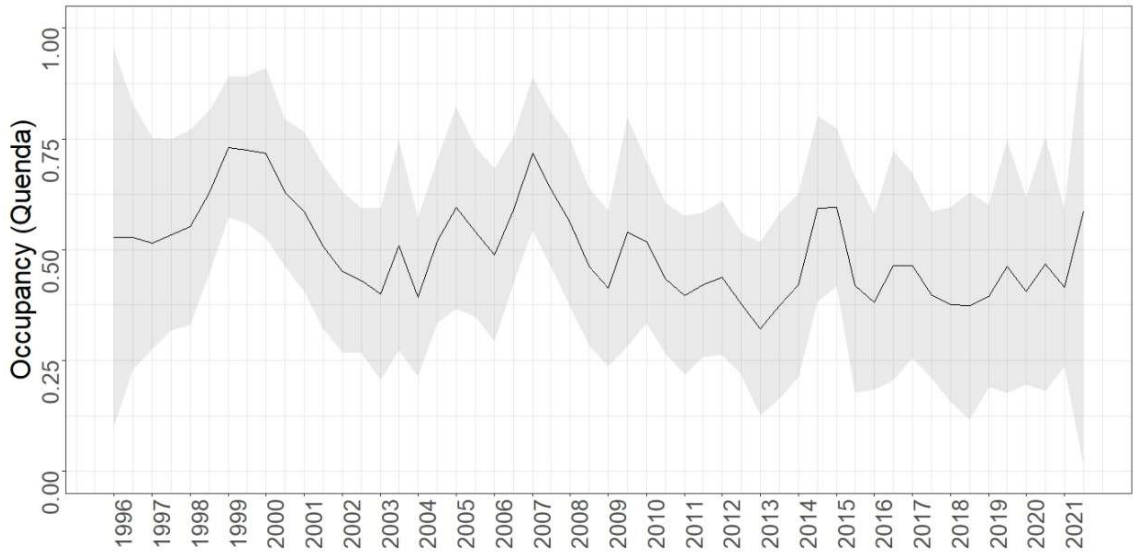

Figure 15: Modelled occupancy of quenda based on cage monitoring at WS monitoring sites over time (N=43). Grey area is the 95% confidence bound, the larger the bounds the lower the confidence in the data — this usually reflects periods of lower trap effort. Note that in 1996 only a single site was monitored.

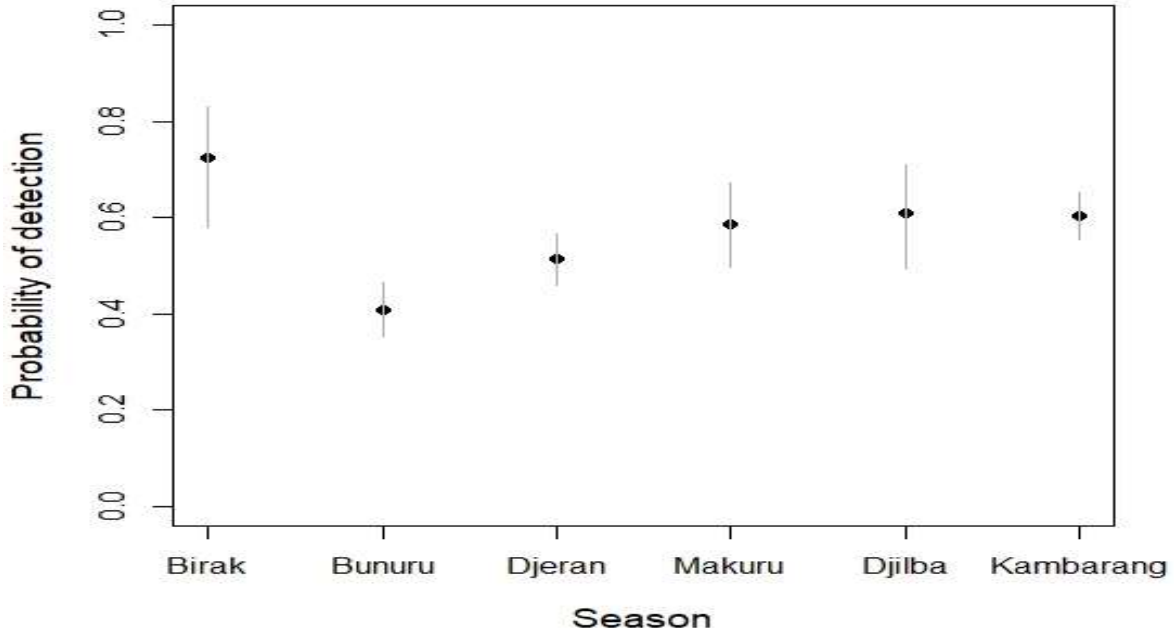

Figure 16: Probability of detection of quenda in each of the six Noongar seasons[3]

Although cage trapping did not detect quenda in 2021, camera monitoring identified the species at Avon Valley, St Johns, and Bindoon. Two non-baited control sites, Stene (monitored: 2015 – 2021) and Porongorups (monitored: 2020 – 2021) also recorded quenda activity, bringing the total number of sites with the species present in 2021 to nine of the 29 sites sampled (cages and cameras) and 30 of the 52 sites sampled in the last five years (Figure 17). No quenda were detected on cameras at Nambung (monitored: 2015 – 2021) or Treeton (monitored: 2018 – 2021).

The relative abundance of quenda has declined since the early 2000s at most sites (Figure 18). Boyicup, Gervasse, and Moopinup did however see some increases in 2021. 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.

[3] 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/).

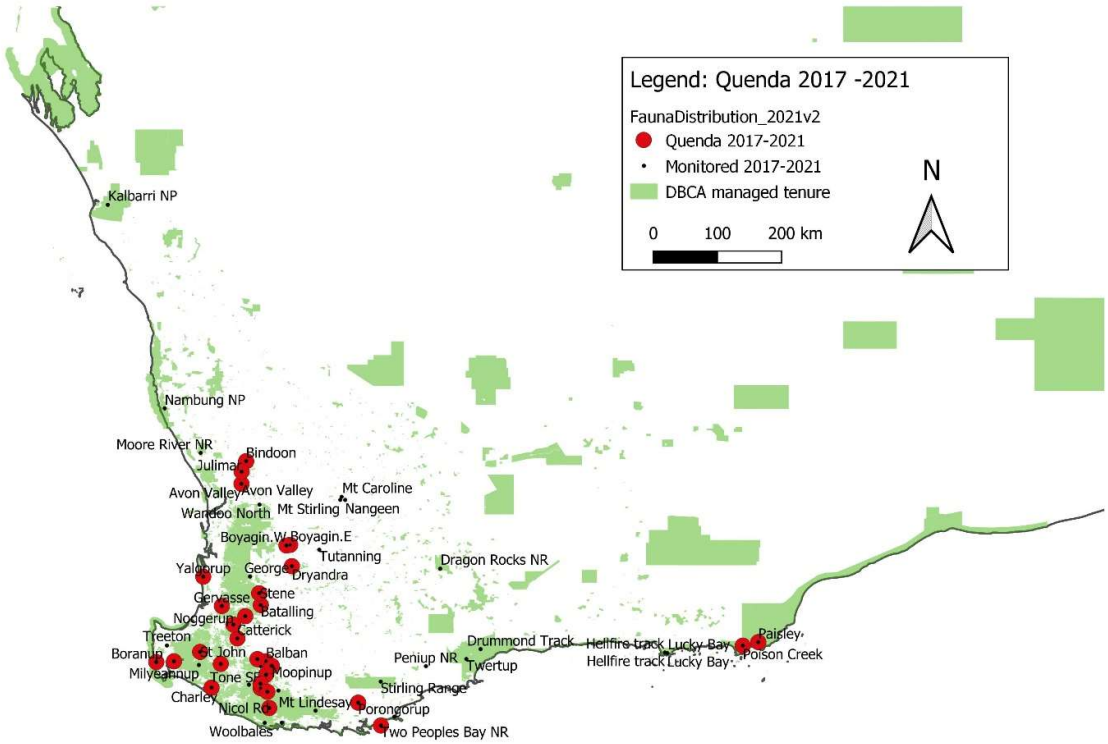

Figure 17: Sites where quenda were recorded by cage trapping or camera monitoring 2017 – 2021 (red dots). Black dots indicate sites that were monitored at least once between 2017 and 2021 using either camera or cage.

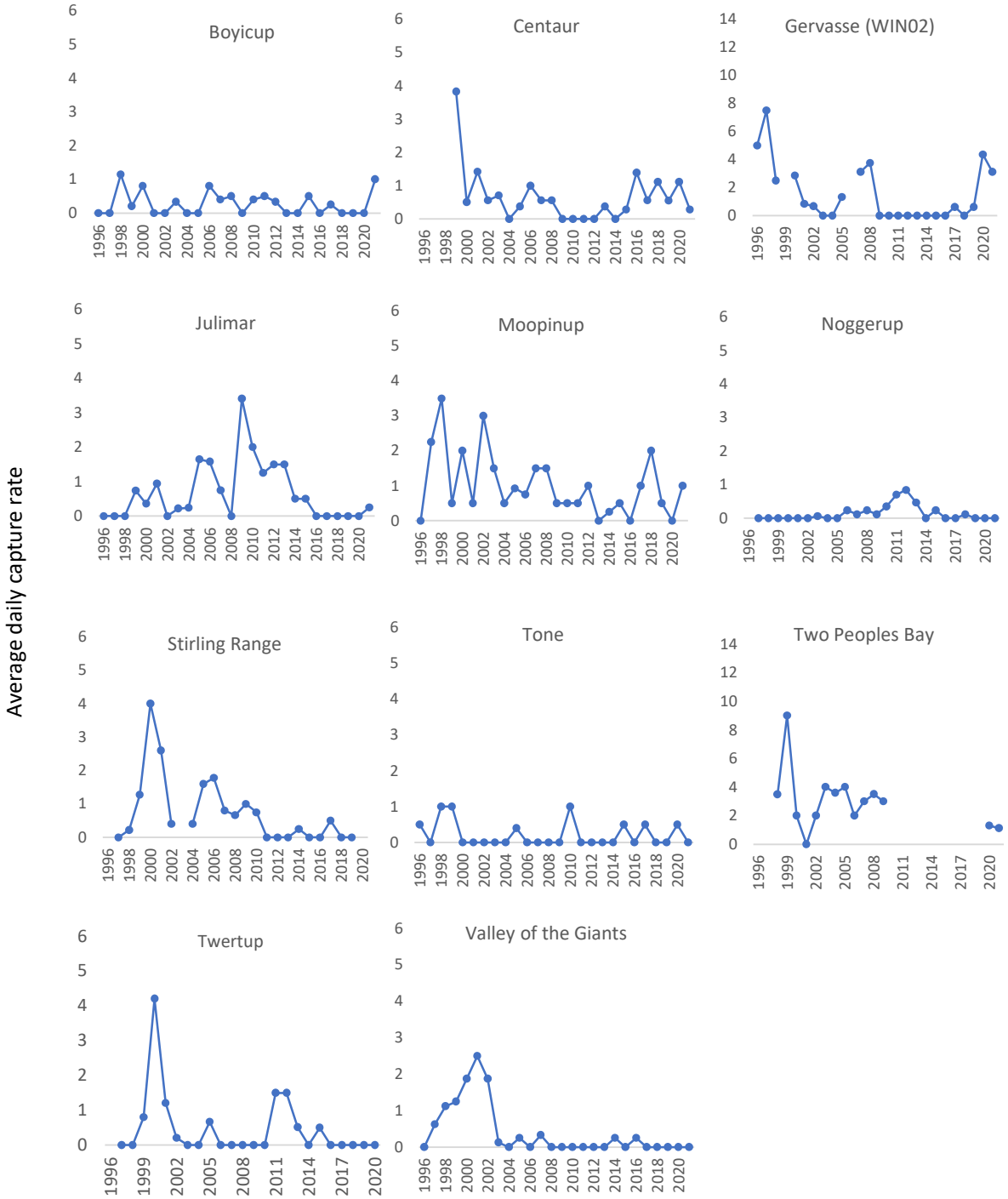

Figure 18:Average daily capture rates at selected sites with frequent captures of quenda across the south-west of Western Australia. Note that the scale is adjusted for high and low capture sites and care should be taken when comparing figures. Gervasse and Two Peoples Bay are high performing sites while the remainder are low performing sites. No monitoring was conducted at Stirling Ranges, Twertup and Boyicup in 2020.

Quokka

Quokkas are known to occur in several WS cells on the mainland and data on this species will be included in future reporting as an indicator species at sites where the target WS species captures are low. Camera monitoring for the species was initiated at several sites in 2020 and 2021. Gervasse has been monitored using targeted cage or soft traps since 1992. Seven monitored sites recorded quokka in 2021 (including both cages and camera monitoring) with a total of 15 sites recording the species between 2017 and 2021 (Figure 19).

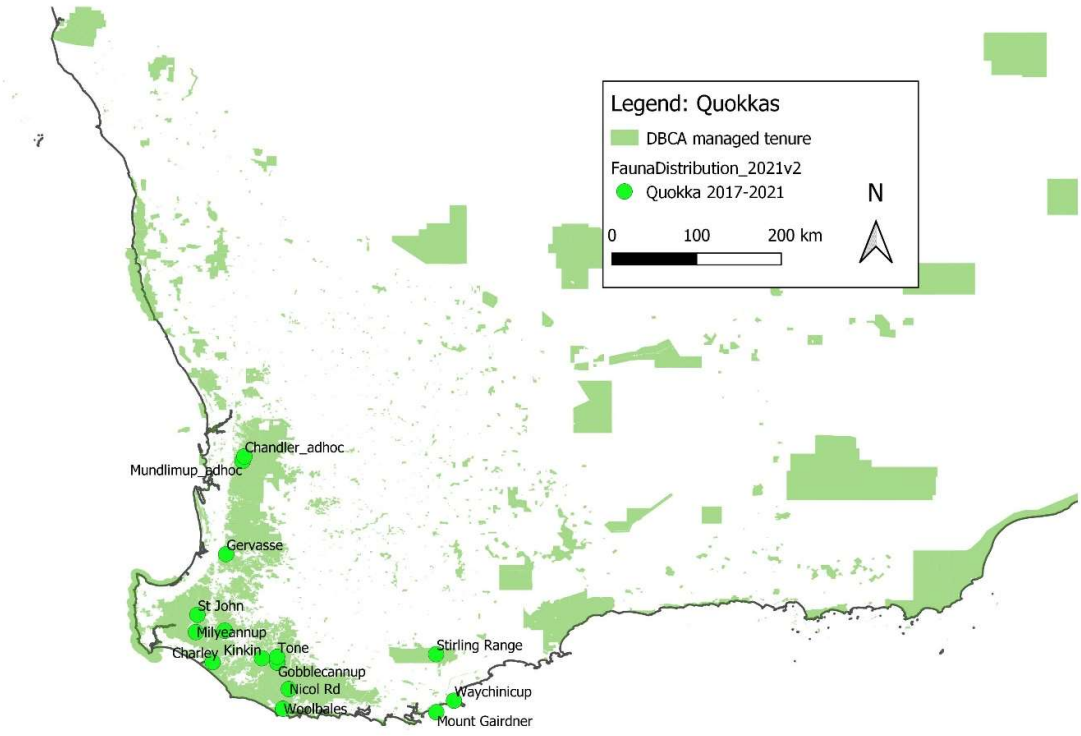

Figure 19: Sites where quokka were captured in Thomas traps or on camera 2017 – 2021 (green dots). Monitoring for quokka is limited and generally targeted to likely habitats. Ad hoc monitoring is associated with known disturbance events, such as prescribed burns (e.g., Mundlimup ad hoc and Chandler ad hoc).

Camera monitoring data is still to be collated from most sites and more detail will be reported in 2022 (e.g., Figure 20). Results from targeted 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 has started to increase (Figure 21).

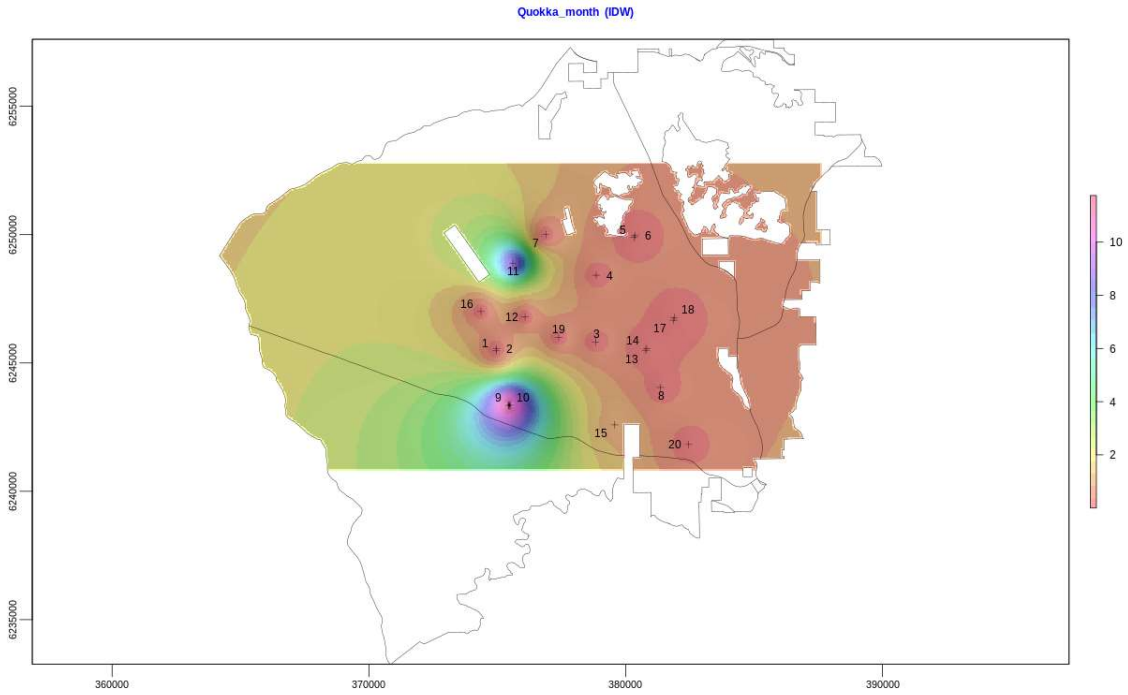

Figure 20: Quokka activity at St Johns. Numbers represent camera locations, colour scale indicates areas of most frequent detection of quokkas each month.

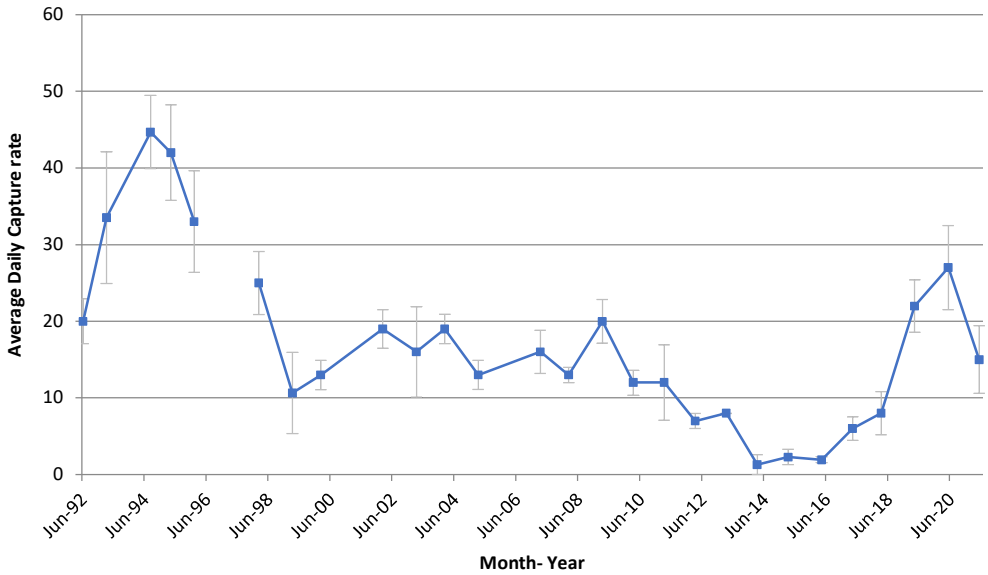

Figure 21: Relative abundance of quokkas at Gervasse, Wellington National Park over time. Error bars = standard error.

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

Populations of black-flanked rock-wallaby are currently monitored under various district programs across Western Australia (Figure 22). Monitoring at the Cape Range cell (Pilbara), Central Wheatbelt sites, Avon Valley National Park and Kalbarri gorges (Midwest) is conducted using both cameras and Thomas traps (Table 1). Camera monitoring has also been established at Durba Hills and the Calverts in the Pilbara, at Cape Le Grand and Salisbury Island (south coast). Monitoring data indicates that most populations are increasing or stable (Figure 23 and Figure 24). However, monitoring at Avon Valley National Park has only recorded a single animal 2017 – 2021, while camera monitoring at Cape Le Grand has indicated a reduction in activity recorded from 2017 (Figure 25).

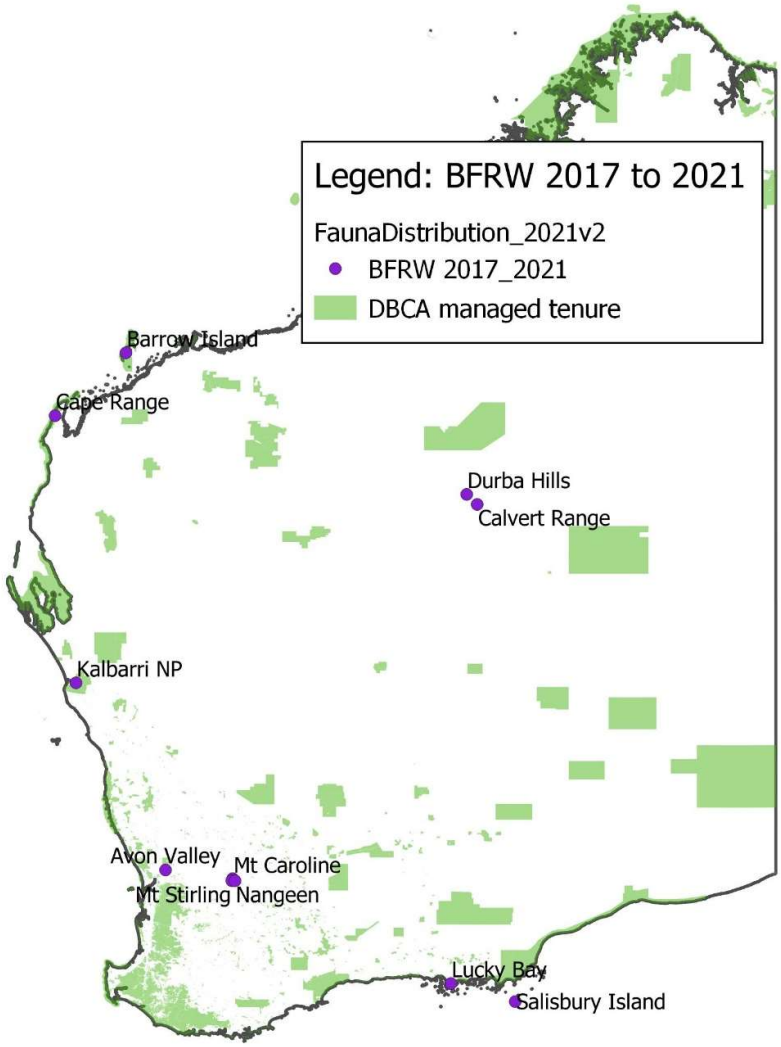

Figure 22: Sites where black-flanked rock-wallabies were captured in Thomas traps or on camera 2017 – 2021 (purple dots). Note that monitoring for black-flanked rock-wallabies is targeted to known habitats.

Table 1: Summary of recent BFRW monitoring at sites with active predator management

Location	*Monitoring type*	*Years*	*Summary*
Avon Valley	Camera and Thomas	2019	One individual recorded.
Mt Caroline	Thomas	2021	See Figure 23, % trap success rates indicate the population is increasing.
Mt Stirling	Thomas	2018	9 individuals KTBA, population increasing.
Nangeen	Thomas	2020	See Figure 24, population stabilising, but likely close to carry capacity.
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 and planned to be checked in May 2022. 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.
Kalbarri	Cameras and Thomas	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.
Cape Le Grand	Cameras	2021	Figure 24; Camera monitoring indicates decline in activity since 2015.

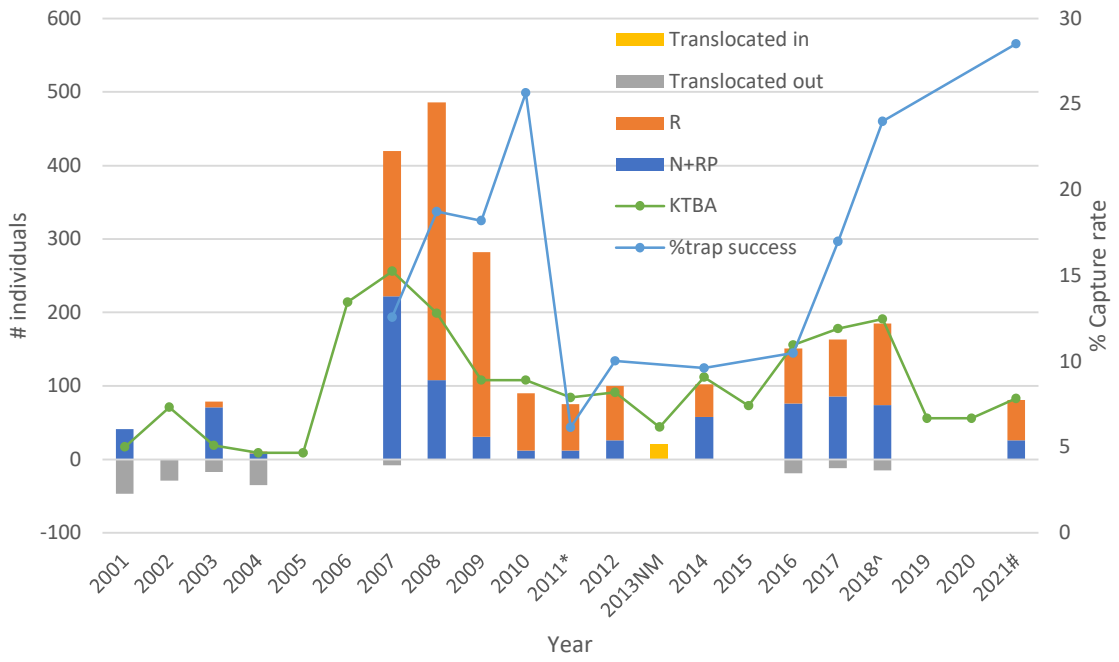

Figure 23: Relative abundance of black-flanked rock-wallabies at Mount Caroline (central wheatbelt), noting the reduced effort over time (in 2018 trap effort was half of 2016, while trap effort in 2021 was similar to effort in 2010, no monitoring was conducted in 2019 and 2020).N = new animal, R = recaptured animal, RP = marked but no prior record.

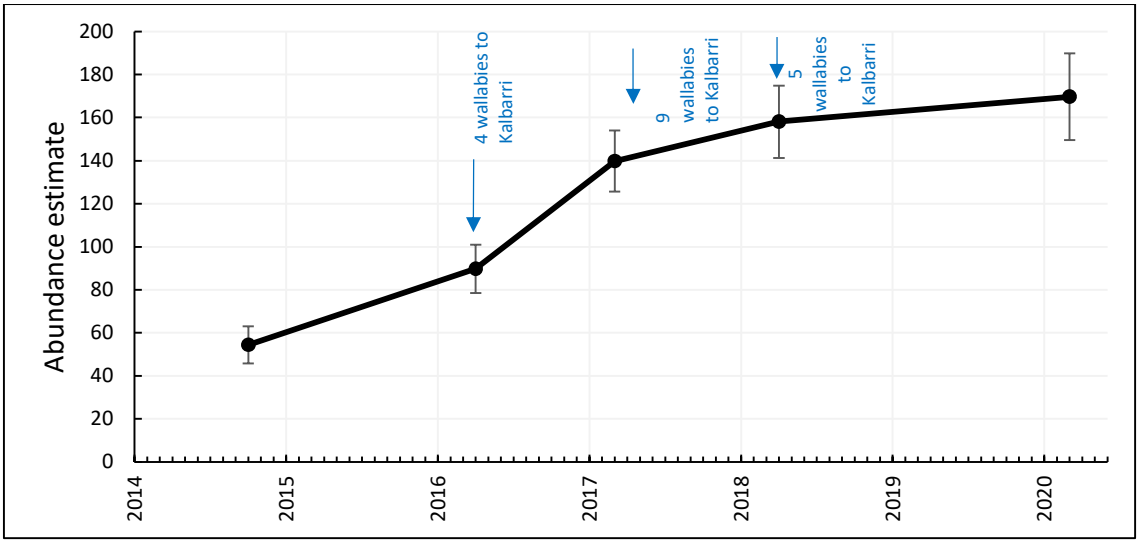

Figure 24: Abundance estimates of black-flanked rock-wallaby at Nangeen (central wheatbelt) using spatially explicit capture recapture (SECR) assuming an open population using package openCR in R (K. Nilsson).

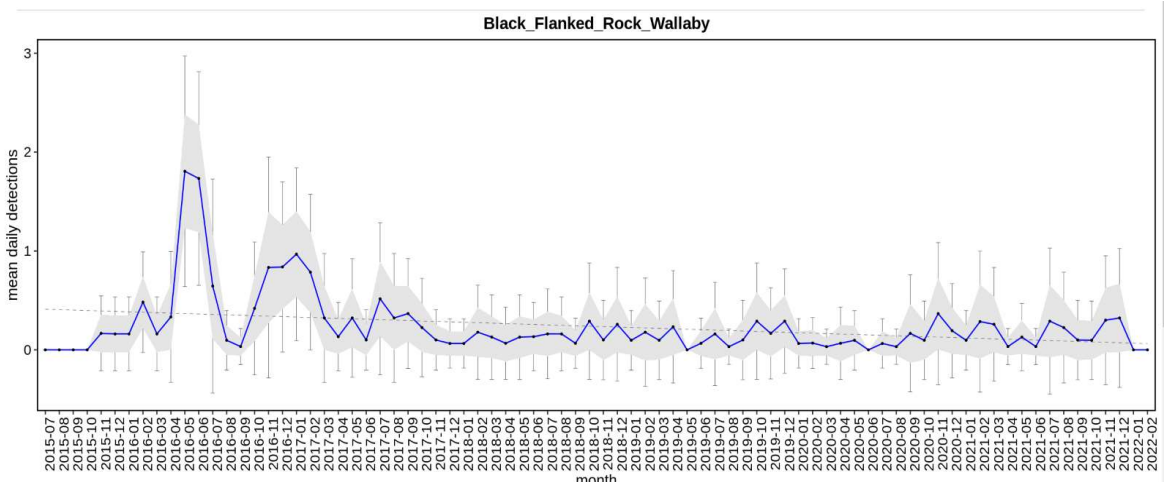

Figure 25: Mean daily detections of BFRW at Cape Le Grand National Park 2015 – 2022.

Foxes and feral cats

A summary of the aerial and ground baiting for each WS cell is provided in Appendix A. Most WS areas received baits as planned (Appendix A, Table 4). Exceptions include Avon, Perth Hills, Lane Poole, and Wellington cells which received an additional deployment of Probait in 2021, bringing their annual delivery of Probait to five per annum in 2020 – 2021 financial year. Funding received from the Alcoa Foundation will increase fox baiting from four per annum to six per annum in these cells for the next three years.

Delivery of predator management at Calvert's and Durba Hills was suspended in 2021 as the approvals required under joint management arrangements were not received from traditional owners.

Predator monitoring

Predator monitoring was conducted at six baited sites and five reference sites (i.e., areas with no predator management) in 2021 in the south-west of the state. Table 2 provides a summary of the fox activity at baited and reference sites. Fox activity is on average higher at sites with no fox management.

Examining average fox activity across different habitats indicates that fox activity at the sandplain sites is much higher compared to that recorded in the jarrah forest sites over the same period (Table 2). 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 will be completed once three years of predator monitoring data are collected for multiple paired sites (i.e., baited and non-baited sites). Modelling will incorporate potential explanatory variables to improve our understanding of fox activity drivers. This will help facilitate more targeted management.

Table 2: Average detections of foxes on camera in baited and non-baited sites in different habitat areas between June and October each year.

Baited site (fox: feral cat prescription)	Monitoring Period	Fox detections/ month ± std. dev.	Non-baited reference	Monitoring Period	Fox detections/ month ± 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*	2019-2020	1.10 ± 0.52
Jarrah forest					
Batalling (4:0)	2014-2021	0.1 ± 0.02	Stene	2014-2021	0.23 ± 0.22
Julimar (4:0)	2019-2020	0.07 ± 0.03	Wandoo	2019-2021	0.43 ± 0.25
Shannon (3:0)	2020-2021	tbf	Porongorups	2020-2021	0.66 ± 0.21
Sunklands (2:0)#	2019-2021	0.0 ± 0.0	Treeton	2019-2021	1.06 ± 0.58
Wheatbelt woodlands					
Dryandra (GB: 7:5)	2015 - 2021	0.19 ± 0.1			na
Boyagin (GB: 12:0)	2018 -2021	0.34 ± 0.18			na
South Coast					
Two Peoples Bay (3:1)	2014 -2020	0.05 ± 0.1			na
Cape Arid (3:1)		tbf			

GB = ground baiting only. *predator management discontinued in 2018. Tbf = data to be finalised. # there was only a single record of a fox in each year in 2018, 2019 and 2021 and only two records in 2020. 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.

On average the activity of feral cats is lower than that recorded for foxes for all habitat types (Table 2 and Table 3). 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. A feral cat specific monitoring project will commence in 2022 with the aim of determining how best to manage feral cats in the northern jarrah forest.

Table 3: Average detections of feral cats in on camera in different habitat areas between June and October each year.

Baited site (fox: feral cat prescription)	Monitoring Period	Feral cat detections/ month ± std. dev.	Non-baited reference	Monitoring Period	Feral cat detections/ month ± 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*	2019-2020	0.31 ±0.14
Jarrah forest					
Batalling (4:0)	2014-2021	0.05 ± 0.06	Stene	2014-2021	0.07 ± 0.08
Julimar (4:0)	2019-2020	0.02 ± 0.02	Wandoo	2019-2021	0.03 ± 0.04
Shannon (3:0)	2020-2021	tbf	Porongorups	2020-2021	0.05 ± 0.06
Sunklands (2:0)	2019-2021	0.02 ± 0.03	Treeton	2019-2021	0.09 ± 0.08
Wheatbelt woodlands					
Dryandra (GB: 7:5)	2015 - 2021	0.05 ± 0.06			na
Boyagin (GB: 12:0)	2018 -2021	0.03 ± 0.04			na
South Coast					
Two Peoples Bay (3:1)	2014 -2020	0.08 ± 0.07			na
Cape Arid (3:1)		tbf			

GB = ground baiting only. *predator management discontinued in 2018. 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.

Swan Coastal Plain

Research examining the integration of feral cat and fox management at Nambung National Park concluded in 2020. The study identified significant differences in fox activity between baited and non-baited areas and a significant decline in fox activity after the integration of an Eradicat baiting deployment compared to the existing two fox bait deployments (Probait) per annum (Drew 2021). Although fox activity was suppressed compared to the non-baited area, fox activity within the baited area returned to pre baiting levels relatively rapidly after each baiting period. This suggests that at a local scale there is rapid reinvasion of areas by foxes. This highlights the need for higher frequency of baiting at sites supporting sensitive species to keep fox activity low (Gwinn and Drew, 2022, unpublished data). There was only a minor reduction in feral cat activity after the integration of Eradicat (Figure 26). It is possible that any impacts of the baiting to feral cats were masked by changes in feral cat behaviour associated with significantly reduced fox activity at the commencement of Eradicat baiting.

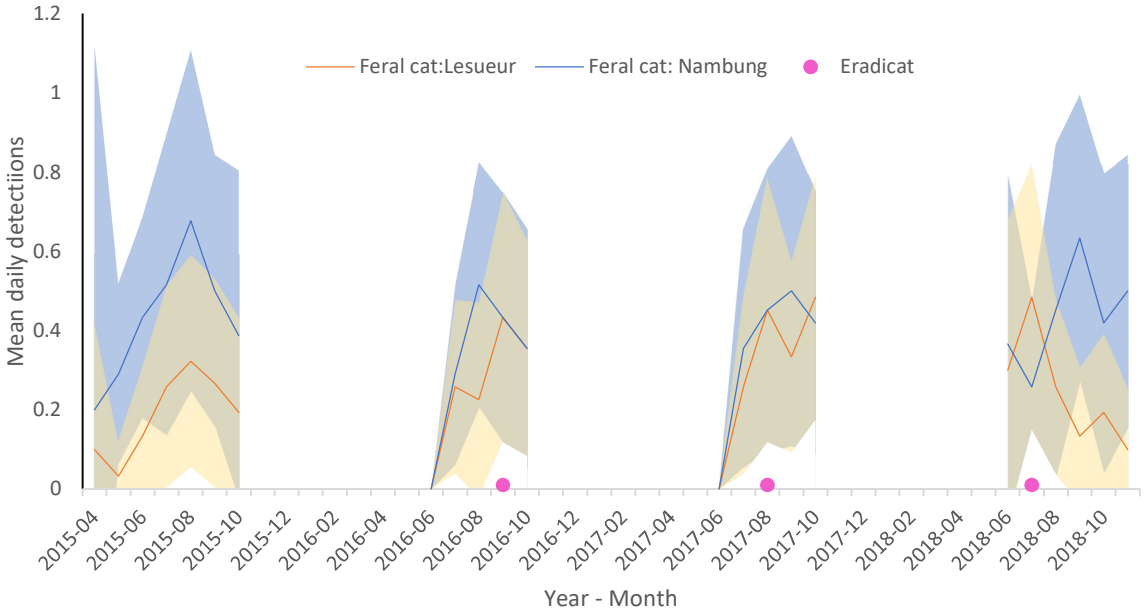

Figure 26: Feral cat activity at Nambung (1 feral cat + 2 fox bait events) and at Lesueur (no predator management). Pink dots represent delivery of Eradicat. Shading represents the 95% confidence intervals.

Predator monitoring at Moore River indicates that fox activity is similar at this site to that observed at its paired non-baited site, Nambung (Figure 27). Of note is the relatively rapid increase in activity of foxes in a period when baiting activity was briefly suspended (August 2020 – October 2020) at Moore River. Moore River in 2020 – 2021 was only ground baited for foxes along a 6.7 km transect surrounding highly sensitive habitat, this was increased to an 11 km transect in 2022. The longer transect is more accessible and will provide protection for a broader area of the nature reserve.

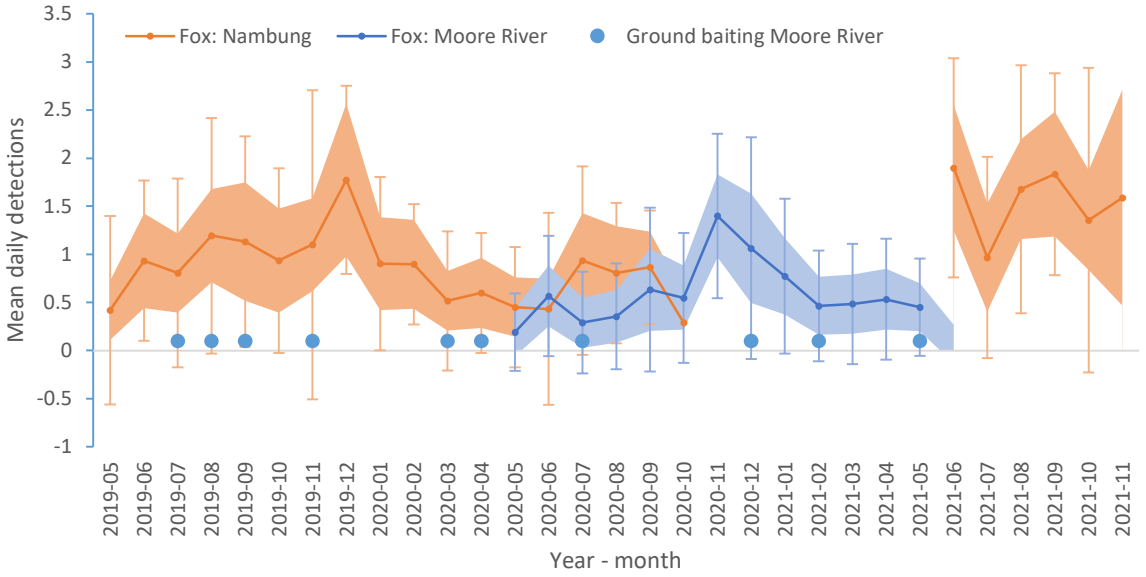

Figure 27: Fox activity at non-baited site (Nambung – orange line) and a ground baited site (Moore River – blue line). Blue dots indicate the month Probaits were delivered to Moore River.

As with foxes, 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 3). Nambung, Two Peoples Bay (TPB) and Dryandra (Table 3) were all actively managed for feral cats in the period 2015 – 2018, yet there was only minimal evidence of feral cat suppression post feral cat baiting in Nambung in this time frame. Notably Dryandra (Figure 34) and TPB (Figure 36) were able to implement more frequent feral cat baiting than Nambung and both integrated additional feral cat management to supplement the baiting in this period. More analyses will be conducted to examine the impact of feral cat baiting frequency on feral cat activity in 2022 with the aim or determining the most effective management regime for different environments.

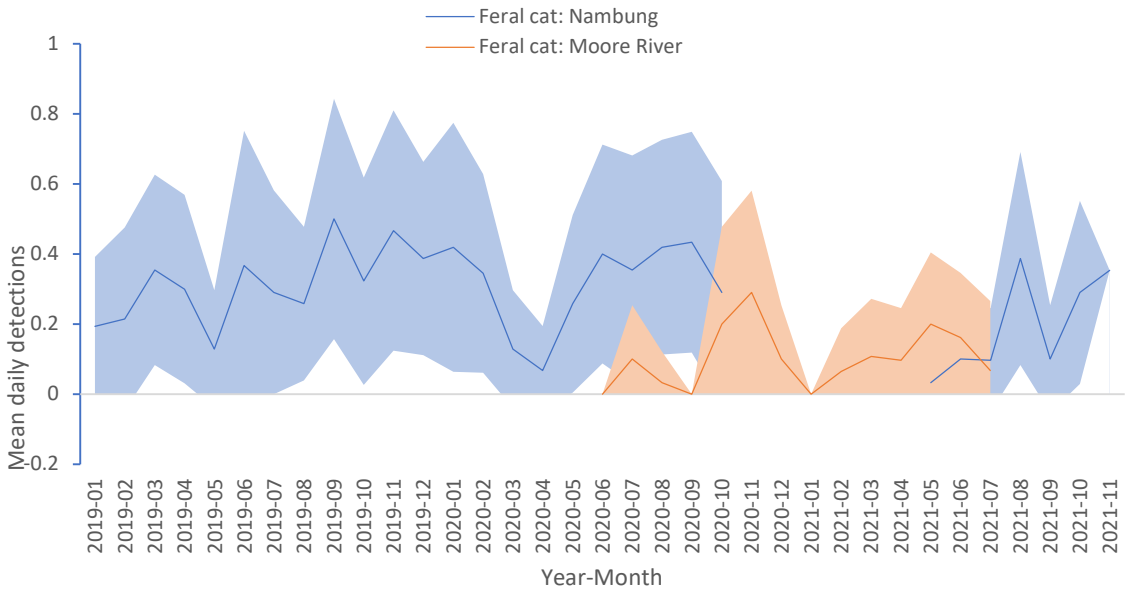

Figure 28: Feral cat activity at Nambung (no predator management) and at Moore River (fox baited, ground 12/annum). Shading represents the 95% confidence interval

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, and it appears to be only significantly different between the baited and non-baited sites in some years for some sites (e.g., 2017 and 2020 Figure 29 and 2020 Figure 30). Of note is the almost complete absence of foxes in the Sunklands cell, with only five records of foxes in the period 2018 – 2021. In comparison the detections in the control site (Treeton) were significantly higher with over 500 independent detections in the same period.

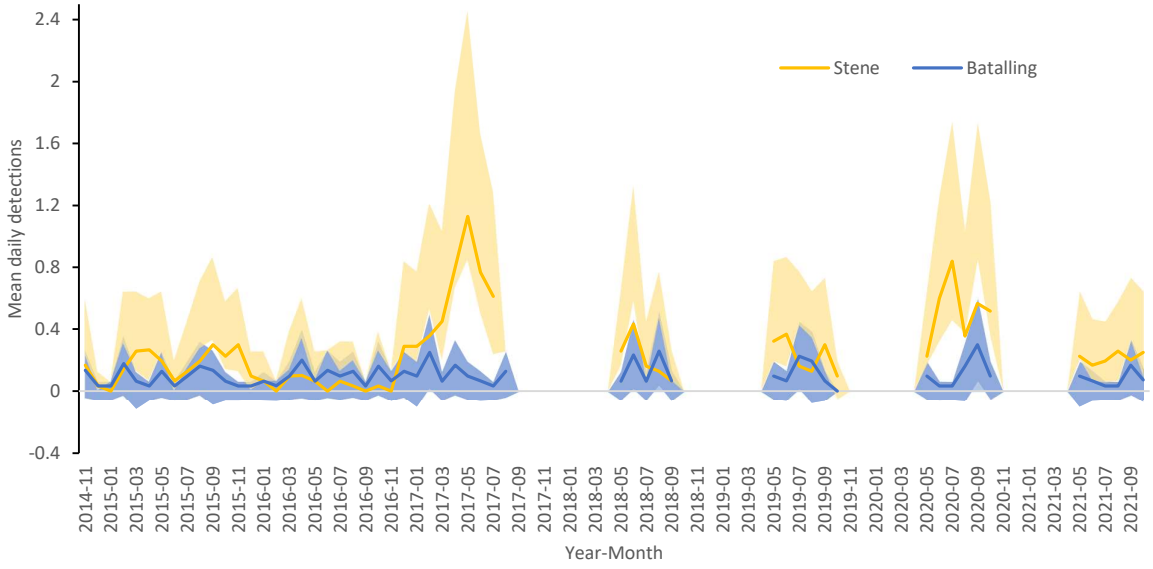

Figure 29: Fox detections on camera at a baited site (Batalling — blue line, 4 x fox baits/annum) and non-baited reference site (Stene — yellow line) 2014 – 2021. Shading represents the 95% confidence interval. Note there was a bushfire in Stene in January 2016 which destroyed over 50% of the available cameras.

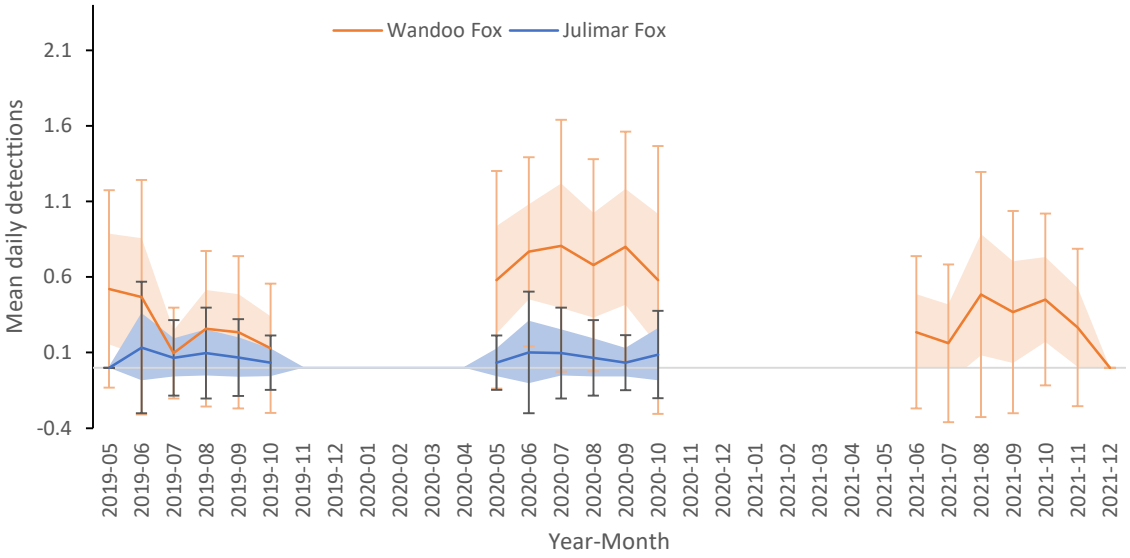

Figure 30: Fox detections on camera at a baited site (Julimar – blue line, 4 x fox baits /annum) and non-baited reference site (Wandoo – orange line) 2019 – 2021. Shading represents the 95% confidence interval. Cameras were not deployed in Julimar in 2021.

Despite the absence of any feral cat management in the northern jarrah forest, most monitored sites recorded relatively low activity of feral cats (Figure 31 and Figure 32). Examination of images suggests only two or three animals are being captured on cameras in Batalling in the period 2019 – 2021. Julimar recorded no feral cats in 2019 and very low detections in 2020. Vegetation struture may limit detections of feral cats in these forested habitats, compared to more open environments. However, recent trapping

in Batalling indicates camera monitoring is likely a true reflection of overall feral cat activity at the site (Algar, pers. com.)

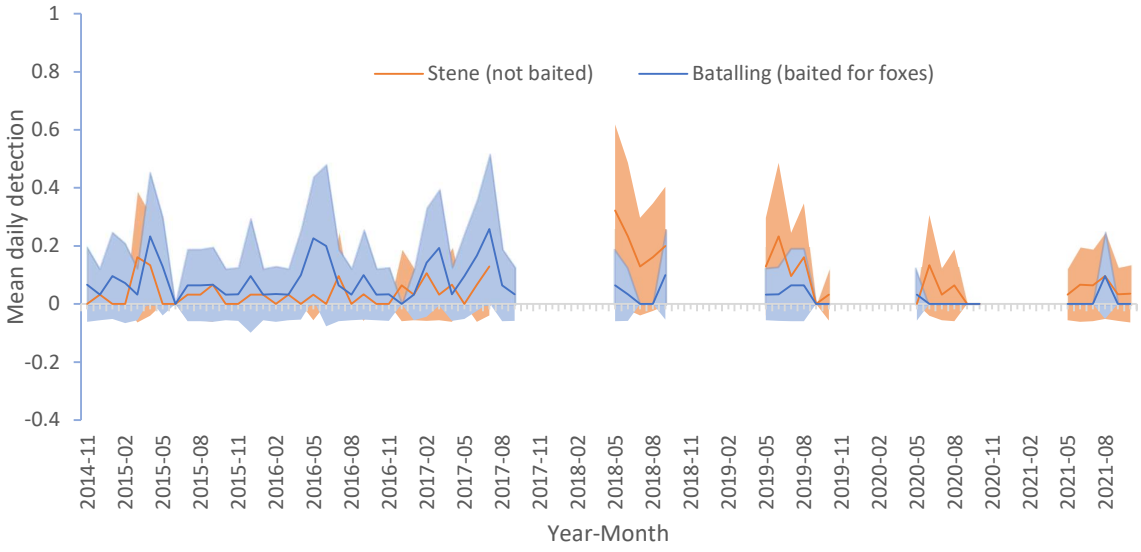

Figure 31: Feral cat activity at Stene (no predator management) and at Batalling (fox baited at 4 x aerial + 12 x ground events/annum). Shading represents the 95% confidence interval. Note from September 2017 cameras were only deployed between May and September/October each year.

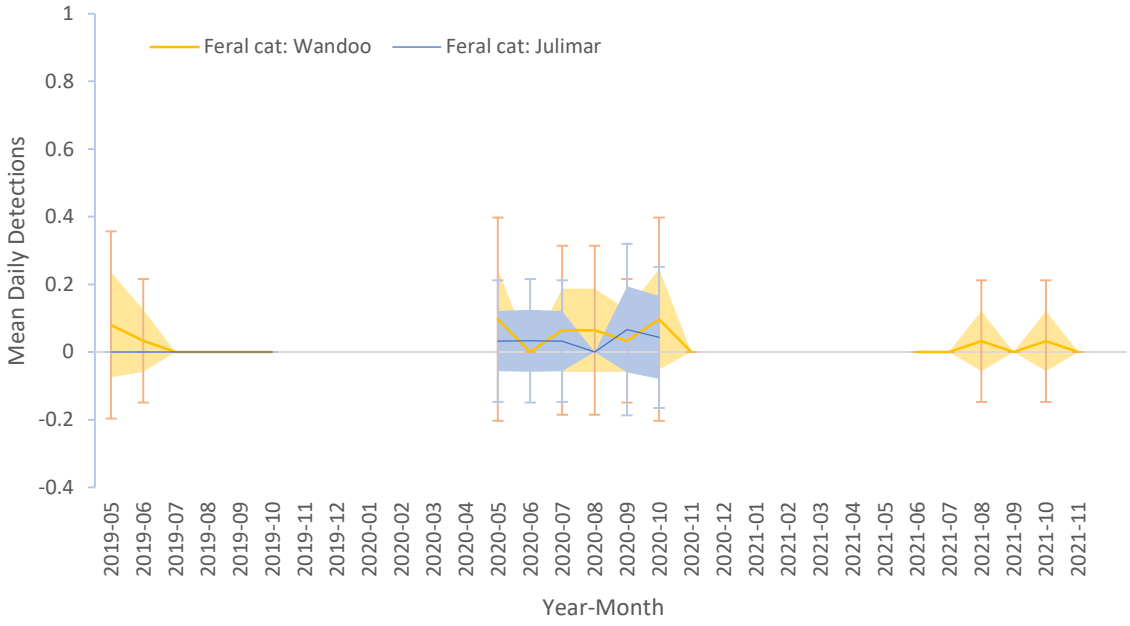

Figure 32: Feral cat activity at Wandoo (no predator management) and at Julimar (fox baited 4 x aerial + 12 x ground events/annum). Shading represents the 95% confidence interval. Cameras only deployed autumn to spring each year. No predator monitoring was conducted at Julimar in 2021.

Wheatbelt woodlands

Wheatbelt predator monitoring was limited to baited only sites. Dryandra receives a combination of fox and feral cat baiting events (ratio 7:5 per annum respectively), while Boyagin only receives 12 fox bait events per annum. Fox activity at Boyagin was slightly elevated in some periods compared to Dryandra, however as with other habitats there is a high variability in fox activity over time (Figure 30). Notably, fox activity appears to peak around May/June each year, this is particularly evident at Boyagin. On average fox activity is higher at wheatbelt sites compared to baited sites in the jarrah forest (Table 2).

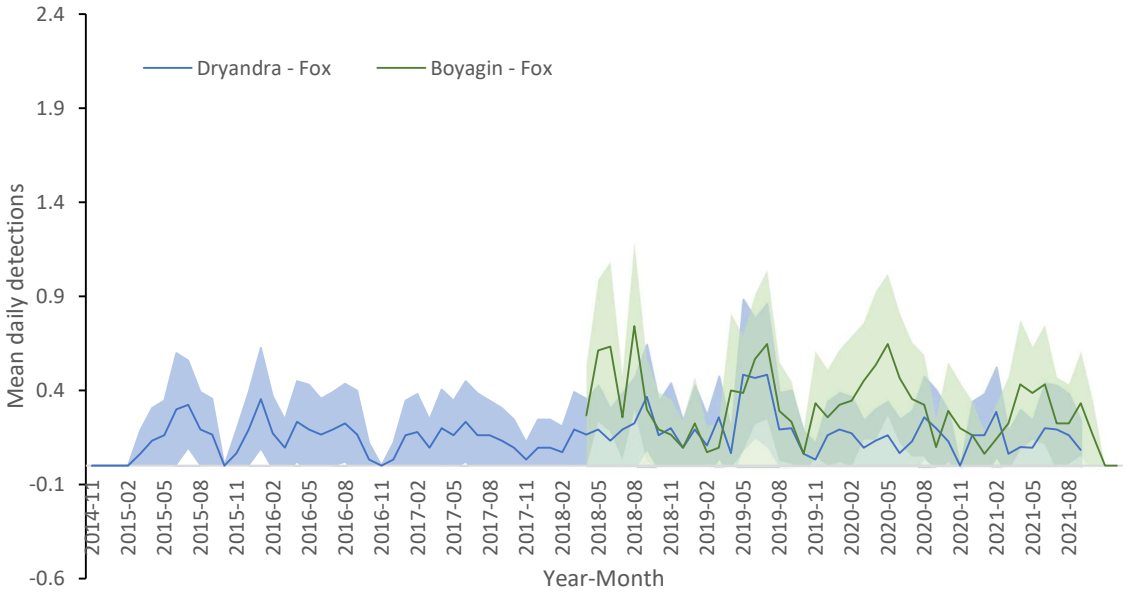

Figure 33: Fox activity at Dryandra (blue line: ground baited 7 x fox: 5 x feral cat baits/ annum) and Boyagin (green line: fox baited 12 x ground bait events/annum). Shading represents the 95% confidence interval. Boyagin data courtesy of Project Numbat.

Feral cat activity in Wheatbelt reserves is relatively low (Table 3: Average detections of feral cats in on camera in different habitat areas between June and October each year. Despite no current feral cat management at Boyagin, feral cat activity is very similar between this site and at Dryandra. This may relate to variations in detectability of feral cats in the two reserves or localised suppression processes (e.g., the level of natural 1080 in the environment from *Gastrolobium* spp., neighbouring landholder behaviour or management, etc.). Understanding the level of feral cat activity in other nearby reserves with different management regimes may assist in understanding the dynamics of these ecosystems.

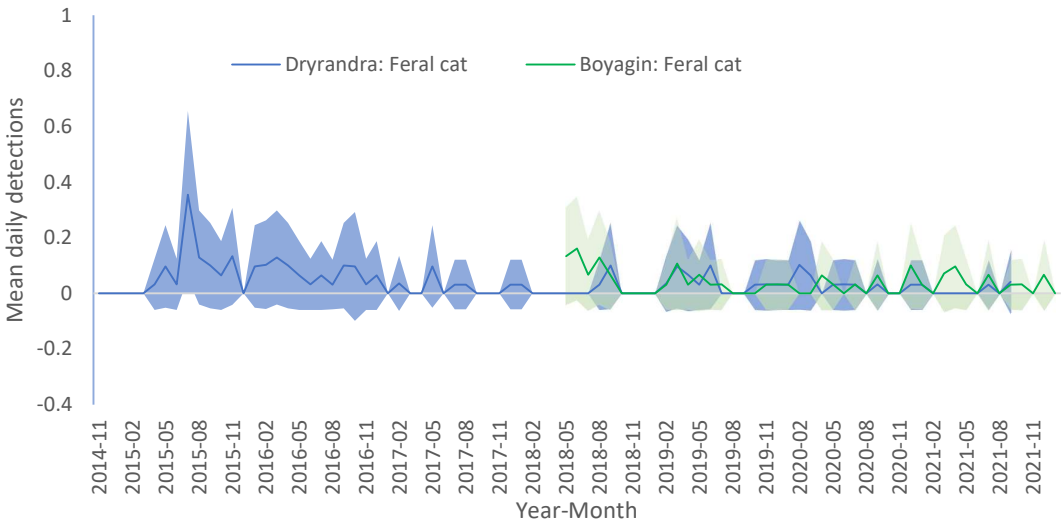

Figure 34: Feral cat activity at Dryandra (blue line: ground baited 7 fox: 5 feral cat bait events/ annum) and Boyagin (green line: 12 fox bait events/annum). Feral cat management at Dryandra commenced in 2012. Shading represents the 95% confidence interval. Boyagin data courtesy of Project Numbat.

South Coast Predator Monitoring

Monitoring on the south coast at Two Peoples Bay indicates very low fox activity compared to other monitored habitats (Figure 35 and Table 2). Feral cat baiting has been integrated with fox baiting at this site since 2011, however monitoring using cameras only commenced in 2014 (Figure 36). Camera monitoring suggests feral cats have been managed to very low levels in 2015 and 2016, however there was a resurgence in activity from 2017. It is possible this increase in activity is associated with a reduction in the frequency of feral cat baiting from February 2017. Feral cat baiting had been increased at the site in 2015 to address the possible increase in predator activity driven by bushfires in October/November 2015.

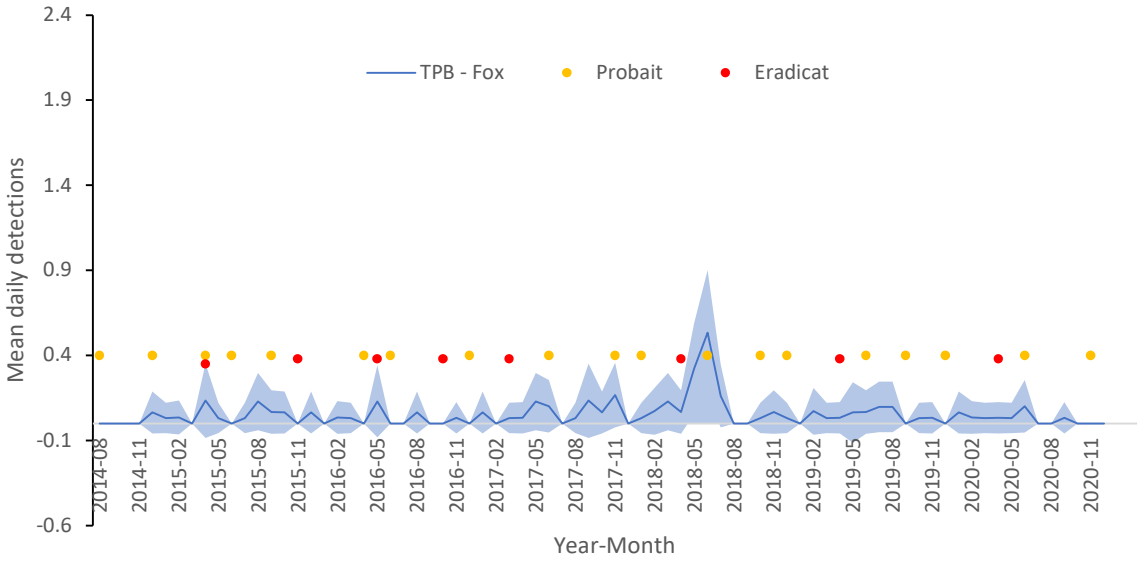

Figure 35: Mean daily detections of foxes at Two Peoples Bay (3 fox bait and 1 feral cat bait events /annum). Dots indicate the month Probait (yellow dots) or Eradicat (red dots) was aerially delivered to the site. Shading represents the 95% confidence interval.

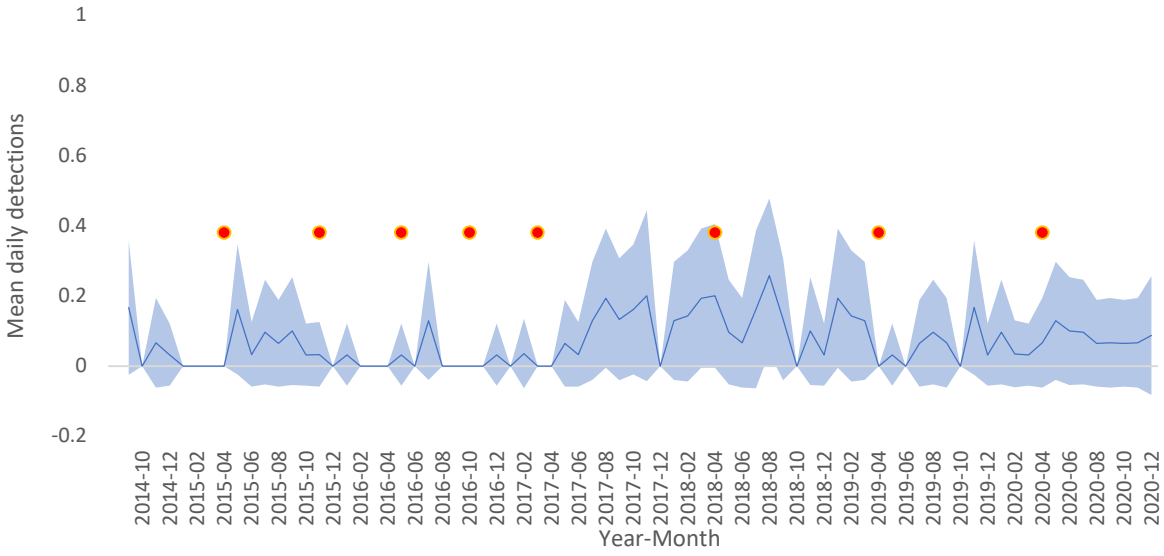

Figure 36: Feral cat activity at Two Peoples Bay relative to the aerial delivery of Eradicat (red dots) Shading represents the 95% confidence interval.

Pilbara Predator Monitoring

There has been active camera monitoring on the Burrup Peninsula (57 cameras) and Dolphin Island (20 cameras) for several years. Predator monitoring using track transects has been conducted over several years at both the Calvert's and Durba Hills. Information from these sites will be available in the 2022 report.

At the WS Cape Range cell, foxes have largely been eradicated on Northwest Cape with only a single pre bait incursion detected on the camera array in the last three years. Feral cat activity has declined substantially since the integration of Eradicat baiting at this site (*Figure 37: Mean daily feral cat detections presented per 100 camera trap nights in context of the past six years of Cape Range camera data. Hatched columns represent surveyed areas that were not exposed to Eradicat baits (i.e., control sites).*Figure 37). Captures of all introduced predators in the trapping program has also declined (DBCA 2021).

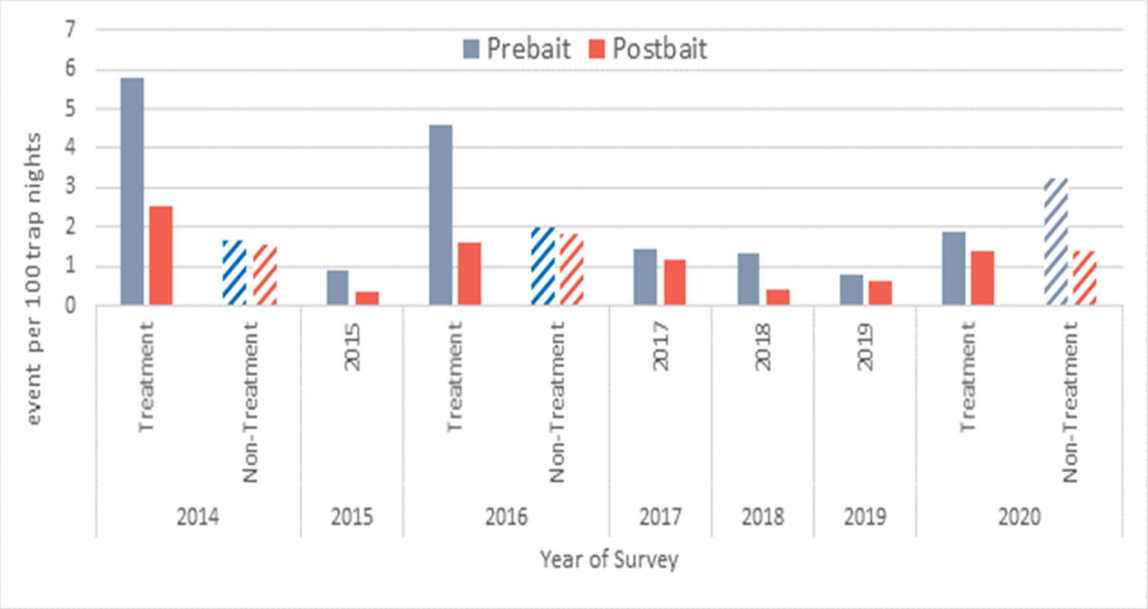

Figure 37: Mean daily feral cat detections presented per 100 camera trap nights in context of the past six years of Cape Range camera data. Hatched columns represent surveyed areas that were not exposed to Eradicat baits (i.e., control sites).

Future predator monitoring

Examining average fox activity across different habitats shows that fox activity at the sandplain sites is much higher compared to that recorded in the jarrah forest sites over the same period (Table 2). 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 will be completed once three years of predator monitoring data are collected for multiple paired sites (i.e., baited and non-baited sites). 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 will be explored if sufficient funding can be sourced.

If funding is sourced, 2022 predator monitoring will be established at the remaining paired sites as defined in the *Western Shield Monitoring Plan 2021-2024* (Figure 38). 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.

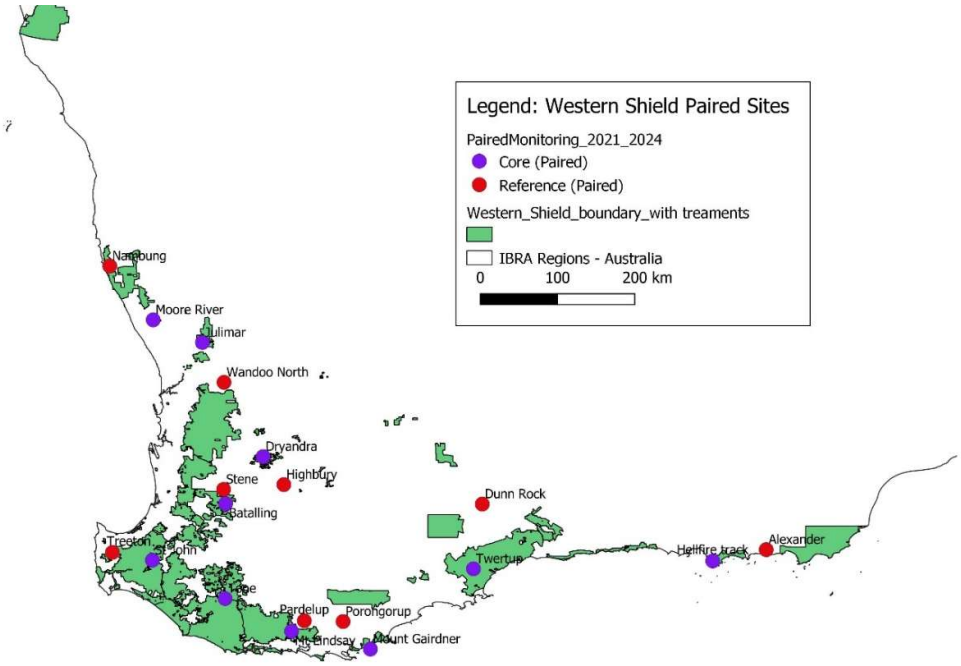

Figure 38: Monitoring sites defined as paired under the Western Shield Monitoring Plan 2021 – 2024.

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Appendix 1: Fox and Feral cat management in each Western Shield cell or area.

Table 4: Square kilometres subject to aerial baiting December 2020 to November 2021 in each Western Shield cell.

Region	Cell name	WS transect	Date aerial baiting commenced	Planned Frequency 2020-2021	Bait type	2020-2021 Dec-Feb	2021 Mar-May	2021 Jun-Aug	2021 Sept-Nov	Grand Total
South Coast	Angove	RFMS	Nov-96	4	Probait	29.7	29.78	29.78	29.7	118.96
Swan	Avon[3]	RFMS	Jun-99	4	Probait	102.47	102.47	102.47	204.94	512.35
South West	Boranup	Boranup	Mar-05	2	Probait		64.81		64.81	129.62
Pilbara	Burrup		Jun-21	1	Eradicat			23.34		23.34
Pilbara	Burrup		Oct-97	1	Probait				38.16	38.16
Pilbara	Calvert Range[4]	Cameras	Mar-03	1	Eradicat					0
South Coast	Cape Arid		Mar-11	1	Eradicat		2021.69			2021.69
South Coast	Cape Arid		Dec-96	3	Probait	2021.69		2021.69	2021.69	6065.07
South Coast	Cape Le Grand		Dec-96	2	Probait		290.15		290.15	580.3
Pilbara	Cape Range	Cameras	Aug-14	1	Eradicat			925.74		925.74
South Coast	Corackerup		Apr-21	1*	Eradicat		28.59			28.59
South Coast	Corackerup		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	not monitored	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	2	Probait		238.45		238.45	476.9
Pilbara	Durba Hills[4]	Thomas/cameras	Jul-07	1	Eradicat					0
South Coast	Fitzgerald	Twertup, Drummond, Moir	Drummond 2010, Twertup 2013, Moir 2013 + 2016 only	1	Eradicat		997.58			997.58
South Coast	Fitzgerald	Twertup, Drummond, Moir	Oct-96	4	Probait	3597.01	2593.89	3597.01	3597.01	13384.92
Pilbara	Fortescue Marsh	Cameras	Aug-12	1	Eradicat					0
Warren	Irwin	not monitored		2	Probait		44.01		44.01	88.02

Region	Cell name	WS transect	Date aerial baiting commenced	Planned Frequency 2020-2021	Bait type	2020-2021 Dec-Feb	2021 Mar-May	2021 Jun-Aug	2021 Sept-Nov	Grand Total
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			1718.95		1718.95
Midwest	Kalbarri	predator monitoring	Nov-96	2	Probait		1590.81		1590.81	3181.62
Wheatbelt	Lake Magenta	Lake Magenta	May-96	4	Probait	946.5	946.5	946.5	946.5	3786
Swan + South West	Lane Poole ext[1,3]	Batalling, Amphion, George, O'Neill	Jun to Apr-1994	4	Probait	1561.516	1561.52	1561.52	3070.48	7755.036
Goldfields	Lorna Glen (Mutuwa)	Science		1*	Eradicat			2226.69		2226.69
Warren	Manjimup	Balban, Boyicup, Camelar, Chariup, Moopinup, Warrup	Nov-96	4	Probait	817.31	817.31	817.31	817.3	3269.23
South Coast	Manypeaks	Waychinicup	Nov-96	1	Eradicat		107.05			107.05
South Coast	Manypeaks	Waychinicup	Feb-12	3	Probait	107.06		107.06	107.05	321.17
South Coast	Peniup	Peniup	Apr-21	1	Eradicat		36.3			36.3
South Coast	Peniup	Peniup	Sep-96	2	Probait				36.3	36.3
Midwest	Peron	not monitored	Mar-02	1	Eradicat		985.28			985.28
Swan	Perth Hills[3]	Hills Forest, Jarrahdale	Apr-94	4	Probait	3272.84	3246.96	3246.96	6545.68	16312.44
South Coast	Ravensthorpe Range	not monitored	Sep-97(?)	2	Probait		272.25		272.25	544.5
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
South West	Sunklands	Blackwood, Milyeannup, St Johns[2]	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

Region	Cell name	WS transect	Date aerial baiting commenced	Planned Frequency 2020-2021	Bait type	2020-2021 Dec-Feb	2021 Mar-May	2021 Jun-Aug	2021 Sept-Nov	Grand Total
South West	Wellington[2]	Catterick, Centaur, Noggerup, Gervasse	Apr-94 to Oct-96	4	Probait	826	823.98	823.98	1647.96	4121.92

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.Ground baiting (4 events per annum) initiated for a two-year period in an area adjoining St Johns commencing Autumn 2020 to maximise fox management post burning. 3. Sites that received additional fox baiting in spring as part of Alcoa Foundation sponsorship. 4. Feral cat management at Calvert Ranges and Durba Hills was suspended in 2021 as approvals required under joint management arrangements were not achieved with traditional owners.

Table 5: Number of baits deployed for ground baiting in each treatment area July 2020 to June 2021.

Region	GB transect /Cell name	bait type	Planned frequency 2020-2021	2020 July	2020 Aug	2020 Sep	2020 Oct	2020 Nov	2020 Dec	2021 Jan	2021 Feb	2021 Mar	2021 Apr	2021 May	2021 Jun	total FY
South Coast	Angove	Probait	12	0	0	0	200	0	0	200	0	0	200	0	0	**600**
Swan	Avon	Probait	8	210	0	214	0	0	197	216	0	214	197	0	208	**1456**
South West	Benger Swamp Nature Reserve	Probait	2	9	0	0	0	0	9	32	32	32	32	32	0	**178**
Swan	Bindoon	Probait	8	170	0	0	0	94	339	155	0	185	209	206	0	**1358**
South West	Boranup	Probait	12	0	257	333	215	284	0	0	273	238	186	243	253	**2282**
Wheatbelt	Boyagin	Probait	12	950	867	950	950	950	950	950	0	950	950	950	950	**10367**
South Coast	Cape Arid	Probait	2 & 4	367	0	0	0	0	0	401	0	0	596	0	0	**1364**
South Coast	Cape Arid	Eradicat	2 & 4	0	0	0	1600	0	1650	0	0	0	0	0	0	**3250**
South Coast	Cape Le Grand	Probait	2 & 4	466	0	0	0	0	0	465	51	465	19	55	20	**1541**
South Coast	Corackerup	Eradicat	5	0	0	0	0	0	0	0	0	0	540	540	0	**1080**
South Coast	Corackerup	Probait	7	250	250	259	237	252	252	245	249	250	0	0	0	**2244**
Swan	Creery	Probait	8	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Warren	Denbarker	Probait	4	0	0	0	0	338	0	362	0	0	362	0	323	**1385**
Warren	Denbarker	Probait	4	0	0	0	0	44	0	73	0	44	0	0	29	**190**
Wheatbelt	Dryandra	Eradicat	5	0	0	1285	3078	0	0	0	0	3075	3075	3075	0	**13588**
Wheatbelt	Dryandra	Probait	7	3090	3090	1805	0	3110	3011	2951	3075	0	0	0	3075	**23207**
Swan	Ellen Brook	Probait	4	0	0	0	0	12	0	0	0	0	0	12	0	**24**
South Coast	Fitzgerald River	Probait	3	0	0	982	0	0	921	0	0	989	0	0	0	**2892**

Region	GB transect /Cell name	bait type	Planned frequency 2020-2021	2020 July	2020 Aug	2020 Sep	2020 Oct	2020 Nov	2020 Dec	2021 Jan	2021 Feb	2021 Mar	2021 Apr	2021 May	2021 Jun	total FY
South Coast	Gull Rock	Probait	4	0	0	0	105	0	0	105	0	0	87	0	0	**297**
Warren	Irwin	Probait	0	0	0	0	0	0	0	26	0	26	0	26	0	**78**
Swan	Julimar	Probait	8	268	0	279	0	0	267	0	235	268	264	0	258	**1839**
Midwest	Kalbarri	Eradicat	3	50	0	0	0	0	0	4680	20	0	0	5150	0	**9900**
Midwest	Kalbarri	Probait	1	0	0	0	2487	0	0	0	0	0	0	0	0	**2487**
South Coast	Lake Pleasant View	Probait	4	100	0	0	100	0	0	100	0	0	100	0	0	**400**
South West	Lane Poole ext	Probait	12	264	0	0	266	266	266	266	235	292	304	307	10	**2476**
South West	Locke NR	Probait	12	13	0	0	0	0	19	0	22	24	0	22	21	**121**
Warren	Manjimup	Probait	4 & 12	475	475	2447	475	475	2355	475	475	2495	475	475	2495	**13592**
South Coast	Manypeaks	Probait	4	0	0	0	370	0	0	335	0	355	0	269	0	**1329**
South Coast	Manypeaks	Eradicat	0	0	0	0	0	0	0	0	0	0	921	0	0	**921**
Swan	Mogumber NR / Lake Wannamal NR	Probait	12	90	0	0	0	0	90	0	90	0	0	90	0	**360**
Swan	Moore River Nature Reserve	Probait	6 & 12	46	0	0	0	0	70	0	70	0	0	46	0	**232**
South West	Muddy Lakes	Probait	6	0	0	8	0	8	0	8	0	8	0	8	0	**40**
South Coast	Peniup	Eradicat	0	0	0	0	0	0	0	0	0	0	540	510	0	**1050**
South Coast	Peniup	Probait	12	313	350	258	275	255	264	283	275	261	0	0	0	**2534**
Swan	Perth Hills	Probait	12	1559	0	1678	1661	1080	2047	900	730	1613	1627	1616	1659	**16170**
South Coast	Ravensthorpe Range	Probait	4	780	0	1156	0	0	1292	0	0	1195	0	0	0	**4423**
South West	Scott	Probait	12	37	0	0	0	73	98	0	105	0	227	114	53	**707**
Warren	Shannon	Probait	4	0	0	0	74	0	146	0	72	0	0	61	93	**446**
South Coast	Stirling Range	Probait	4	1930	0	0	2133	0	0	1961	0	0	2000	0	0	**8024**
South Coast	Stokes	Probait	2 & 4	0	0	0	722	0	0	0	0	770	0	0	0	**1492**

Region	GB transect /Cell name	bait type	Planned frequency 2020-2021	2020 July	2020 Aug	2020 Sep	2020 Oct	2020 Nov	2020 Dec	2021 Jan	2021 Feb	2021 Mar	2021 Apr	2021 May	2021 Jun	total FY
South West	Sunklands	Probait	12	241	190	185	168	184	0	174	179	0	373	181	178	**2053**
Swan	Thomson's Lake	Probait	2	0	0	0	0	50	0	0	0	0	0	0	0	**50**
South West	Tuart Forest	Probait	12	121	0	0	0	0	152	0	84	177	141	33	179	**887**
Wheatbelt	Tutanning Nature Reserve	Probait	7	700	661	700	700	700	700	700	700	700	700	340	700	**8001**
Wheatbelt	Tutanning NR	Eradicat	2	0	0	0	0	0	0	0	0	0	0	325	0	**325**
Swan	Twin Swamps Nature Reserve	Probait	4	0	0	0	0	20	0	0	0	0	0	20	0	**40**
South Coast	Two People's Bay	Eradicat	4	0	0	0	0	370	0	0	0	0	399	370	0	**1139**
South Coast	Two People's Bay	Probait	8	210	0	188	185	0	185	185	0	185	0	0	166	**1304**
Warren	Walpole	Probait	6	256	0	121	0	256	0	135	121	135	121	135	121	**1401**
Swan	Walyunga	Probait	9 (south) & 12 (north)	0	0	144	0	139	0	0	0	110	125	0	119	**637**
South West	Wellington	Probait	12	137	0	0	0	173	183	172	170	236	235	235	0	**1541**
Swan	Yalgorup	Probait	6	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Appendix 2: 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 2021.

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). 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

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