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Mammals of the southern jarrah forest: Results from a camera trapping study

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Mammals of the southern jarrah forest

Results from a camera trapping study

Adrian Wayne, Marika Maxwell, Colin Ward, Jodie Quinn, Mark Virgo, Mark Cowan

South West Threatened Fauna Recovery Project: Southern Jarrah Forest

March 2019

Department of **Biodiversity, Conservation and Attractions**

GOVERNMENT OF WESTERN AUSTRALIA

Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000
Fax: (08) 9334 0498

www.dbca.wa.gov.au

This report/document/publication was prepared by Adrian Wayne

Questions regarding the use of this material should be directed to:
Position: Research Scientist, Forest fauna Ecology
Program: Animal Science
Department of Biodiversity, Conservation and Attractions
Locked Bag 2
Manjimup WA 6258
Phone: 08 97717992
Email: adrian.wayne@dbca.wa.gov.au

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This document is available in alternative formats on request.

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Acknowledgements

We acknowledge the Noongar Traditional Owners of country throughout the southern jarrah forest including the Kaniyang, Minang and Bibbulman groups and recognise their continuing connection to land, plants, animals, waters and culture. We pay our respects to their Elders past, present and emerging. While there are many variants, the indigenous names for the animals used in this report are generally based on those recommended by Abbott (2001). We would like to thank Donnelly, Frankland and Blackwood DBCA Districts for their support and assistance with this project, including the provision of fauna records, planning, logistical and administrative support and assistance in the field. We are also very grateful to the large number of volunteers that assisted with the field work and image processing. Thank you also to Matthew Williams who provided statistical advice and support. The work was conducted as part of the South West Threatened Fauna Recovery Project with funding from the Australian Government's National Landcare Program and DBCA BCS Terrestrial Biodiversity Conservation Research Fund. The work was conducted under the approval of the DBCA Animal Ethics Committee (#2016/04).

Summary

Wildlife detections on remote sensor cameras (RSC) deployed as part of Eradicat® bait trials in the southern jarrah forests (SJF) of Western Australia were opportunistically used here for a regional mammal survey. The source of the data used here came from two bait uptake trials. The first was conducted at 40 sites over a 65-week period (September 2016 – November 2017) to identify how, when and where the most efficient use of Eradicat® baits is to target feral cats and to assess the risks to potentially vulnerable non-target native species. The second trials were at an additional seven sites conducted over seven weeks (May – July 2018) to investigate whether Eradicat® baiting efficiency could be improved immediately after autumn prescribed burning. The aim of this study was therefore, to use the RSC data to quantify the distribution, occupancy and activity of introduced and native mammal species across the southern jarrah forest. While not specifically designed for this purpose, this study represents the most extensive and comprehensive systematic mammal survey ever undertaken in the region. The SJF is particularly important for the conservation of several native mammals including the *Critically Endangered Bettongia penicillata* (woylie), *Pseudocheirus occidentalis* (ngwayir or western ringtail possum), the *Endangered Myrmecobius fasciatus* (numbat), *Vulnerable Dasyurus geoffroii* (chuditch), *Setonix brachyurus* (quokka), *Conservation dependent Phascogale tapoatafa wambenger* (wambenger), and *Priority 4* species including *Isoodon fusciventer* (quenda), *Notamacropus eugenii derbianus* (tammar wallaby) and *Notamacropus irma* (western brush wallaby). Several of these species and others, such as *Sminthopsis spp.*(dunnarts) and *Rattus fuscipes* (mootit or bush rat) have undergone significant and sustained declines since the 1990s, while others have increased (Wayne et al. 2015, 2017).

The study was conducted within the 456,029 ha of land managed by the Department of Biodiversity, Conservation and Attractions (DBCA) with southern jarrah forest types. Generally, 50 Reconyx HC600 or PC900 RSC were deployed for 19 – 49 days per site for the purposes of recording animal interactions for Eradicat® baits deployed to simulate operational conditions. As a result, a total of 1,613,886 images of fauna were collected from 47 study sites across the SJF involving 2,330 camera trap points and 69,393 camera trap nights between September 2016 and July 2018. At least 25 non-human mammalian taxa were identified in the images as well as 28 bird taxa, four reptiles, some frogs and invertebrates.

There was a strong spatial match between RSC records from this study and other fauna records available from local districts within the Department of Biodiversity, Conservation and Attractions collected over decades and reposited in the *Fauna File* database. This indicated that the RSC had performed well in detecting terrestrial mammal species across the region. Furthermore, they revealed extensions to the previously recorded ranges of several species (e.g. *Setonix brachyurus*) and/or confirmed contemporary persistence where they had not otherwise been recorded for some time (e.g. *Rattus fuscipes*). The RSC data also substantially increased the number of records within the southern jarrah forest for several species (e.g. *Cercatetus concinnus, Tachyglossus aculeatus, Tarsipes rostratus*).

Occupancy models for the 20 most abundant mammal taxa provided estimates of occupancy and detection probability, the latter of which was used to formulate a standardised metric of species activity. Simple spatial interpolation models of species activity and species richness were derived using inverse distance weighting (IDW) methods. These models identify areas of importance for individual and groups of species. For instance, the Upper Warren Region (UWR) is shown to be especially important for most native mammals and threatened species in particular. The spatial models for introduced mammals (*Capra hircus* (goat), *Felis catus* (cat), *Mus musculus* (house mouse), *Rattus rattus* (black rat), *Sus scrofa* (pig) and *Vulpes vulpes* (red fox)), are also useful for informing management and conservation activities. Temporal (diel) activity patterns of mammal species were also described and compared between seasons, between species and between areas immediately after autumn prescribed burns with unburnt areas.

The management implications of having a better understanding of the distribution, occupancy, species richness and spatial and temporal activity patterns of mammalian wildlife are briefly discussed. As well as identifying areas of priority for management and conservation this study provides ecological and behavioural insights of the species and ecosystems in which they live. This study also demonstrates the value of RSC in the survey and monitoring of a broad suite of species, many of which are otherwise difficult to adequately detect by other methods (e.g. *F. catus, Ce. concinnus, Tac. aculeatus, Tar. rostratus* and *V. vulpes*). Future opportunities for the use of the data and findings from this study are discussed. They include relating the distribution and activity of fauna to management (e.g. burning, predator control, timber harvesting) and environmental factors, using the data to review and improve management tools such as the department’s Fauna Distribution Information System (FDIS), and improving the monitoring of priority species and introduced predators. This study provides an indication of the substantial benefits of having a regional-scale survey and monitoring program that is appropriately designed to demonstrate fauna responses to management and conservation activities and spatio-temporal, environmental and population changes.

1 Introduction

While not specifically designed as a regional mammal survey, remote sensor cameras (RSC) deployed across the southern jarrah forest as part of the South West Threatened Fauna Recovery Project (SWTFRP) represents the most extensive and comprehensive systematic mammal survey ever undertaken in the area.

The primary goal of the SWTFRP was to contribute to the recovery of key threatened mammal and bird species at four sites in south-western Western Australia (Kalbarri, Dryandra, South Coast and Southern Jarrah Forest), through integrating feral cat (*Felis catus*) baiting with existing introduced predator control programs. As part of the Southern Jarrah Forest (SJF) component, Eradicat® bait uptake trials were conducted at 40 sites over a 65-week period (September 2016 – November 2017) to identify how, when and where the most efficient use of Eradicat® baits is to target feral cats and to assess the risks to potentially vulnerable non-target native species. Trials at an additional seven sites over seven weeks (May – July 2018) investigated whether Eradicat® baiting efficiency could be improved immediately after autumn prescribed burning. The 50 RSC used at each site (with the exception of one of the Autumn burn sites that had 30 RSC) resulted in the collection of over 1.6 million images of wildlife confidently identified to species.

The aim of this study was therefore, to use the RSC data to quantify the distribution, occupancy and activity of introduced and native mammal species across the southern jarrah forest. This information is intended to increase our understanding of these species and to inform land management and species conservation activities in the area.

This work directly contributes to several strategic goals in the DBCA Science Strategic Plan (2018-21) including;

- Biodiversity knowledge: adequate knowledge of biodiversity available to support the department’s conservation and management of terrestrial ecosystems
- Conservation of threatened species: provision of scientific knowledge that can assist in the assessment of the conservation status of species and provide a scientific basis for monitoring.
- Management of invasive species: improve the effectiveness or monitoring and management of invasive species.
- Availability of scientific information for evidence-based decision making: address gaps in biodiversity knowledge.
- Effective data management: data is effectively captured, curated and accessible to support conservation, management and decision-making.

2 Methods

2.1 Study area

The SJF is located between Nannup and Denmark in the southwest of Western Australia, in the Southern Jarrah Forest IBRA subregion (JAF02) and the adjacent northern margins of the Warren IBRA region (WAR01; Environment Australia, 2000). It is dominated by forest ecosystems predominantly classified as 'Jarrah– South,' but also some adjacent 'Jarrah– Unicup', 'Jarrah woodland' and Jarrah/Yellow Tingle (Department of Parks and Wildlife 2016). Much of the remnant SJF is managed by the Department of Biodiversity, Conservation and Attractions (DBCA) (Figure 1). A total of 456,029 ha of DBCA-managed land was included in this study.

The western node of the study area is predominantly State Forest located between Nannup and Manjimup in the Blackwood and Donnelly River catchments, on the Darling Range and bound on the west by the western edge of the Darling Scarp. The northern half of the node is surrounded by agricultural and plantation freehold land, while the southern half is generally surrounded by National Park.

The central area, east of the Southwest Highway between Bridgetown and Manjimup, is known as the Upper Warren region (UWR). While sometimes considered to be the area north of the Muir Highway, the actual upper catchment boundary of the Warren River is further south. Furthermore, the results from this study demonstrate a clear ecological distinction that coincides with this catchment boundary. Therefore, the UWR regarded here includes the southern boundary of catchment area and is considered to be north of a line running ESE from the Quininup townsite to the mid-point of Lake Muir (i.e. north of Sutton Rd, Beard Rd, Arthur Rd and Gobblecannup Rd) and includes several forest blocks south of Muir Highway (Dordagup, Quininup, Dingup, Quilben, Kin Kin, northern half of Murtin, Tone and Stoate). More than half of the DBCA-managed land in the UWR is State Forest and the remainder is Nature Reserve or National Park. The UWR is also more fragmented by free-hold agricultural and plantation land than other parts of the study area.

The southern third of the study area, between Quininup townsite and the Kent River and mostly east of the South Western Highway, is predominantly National Park and includes part of the Walpole Wilderness area. Being part of a large contiguous area of DBCA-managed native vegetation, very little freehold land exists within or adjacent to this node (except along the northern boundary between Lake Muir and Kent River. The area includes parts of the river catchments of the Warren, Shannon, Deep, Frankland and Kent Rivers.

The SJF is particularly important for the conservation of several native mammals including the *Critically Endangered Bettongia penicillata* (woylie), *Pseudocheirus occidentalis* (ngwayir or western ringtail possum), the *Endangered Myrmecobius fasciatus* (numbat), *Vulnerable Dasyurus geoffroii* (chuditch), *Setonix brachyurus* (quokka), *Conservation dependent Phascogale tapoatafa wambenger* (wambenger), and *Priority 4* species including *Isoodon fusciventer* (quenda), *Notamacropus eugenii* *derbianus* (tammar wallaby) and *Notamacropus irma* (kwara or western brush wallaby). Several of these species and others, such as *Sminthopsis spp.*(dunnarts) and *Rattus fuscipes* (mootit or bush rat) have undergone significant and sustained declines since the 1990s, while others have increased (Wayne et al. 2015, 2017). *Vulpes vulpes* (red fox) and *Felis catus* (cat) are a significant threat to many native mammals. Other introduced species in the SJF that are of management interest and conservation concern include *Sus scrofa* (pig), *Capra hircus* (goat) and *Cervus elaphus* (red deer).

Fox baiting for conservation purposes began in some areas in 1977 (Burrows and Christensen 2002). It became broadscale to cover most of the study area in 1996 as part of the *Western Shield* program (Wyre 2004; Wayne et al. 2017). Other major management activities in the region include prescribed burning (McCaw et al. 2005), timber harvesting (Wayne et al. 2006, 2016 and references therein) and dieback hygiene (i.e. reducing the spread of the plant pathogen *Phytophthora cinnamomi*).

2.2 Study design and site selection

Details of the study design and site selection are provided by Wayne et al. (in prep). Briefly, for the first Eradicat® bait uptake trials sites were selected from generally alternate 5 km x 5 km cells with >75% of the area managed by DBCA in the SJF (Figure 2). The trials were conducted over 15 months using RSCs to observe animals interacting with the baits. The key principles applied during these trials were that they should resemble operational conditions as closely as possible and to minimise observer effects as much as practically possible. A stratified-random cell selection process was used to allocate sites to (i) one of two baiting deployment methods; 5 km transects along forest tracks with 100 m intervals and 200 m x 40 m plots >50 m from trafficable forest tracks to resemble the spread of a single aerial drop of 50 baits from a baiting aircraft) and (ii) one of 10 successive rounds between September 2016 and November 2017 (i.e. four sites conducted simultaneously in each of 10 rounds, with each of two replicates of each of two deployment methods per round) (Figure 3).

The second Eradicat® bait uptake trials (May – July 2018) were designed to assess whether baiting immediately after Autumn prescribed burns would increase the detection, opportunity and consumption of baits by *F. catus* and *V. vulpes*. The trials used seven transects in a replicated treatment versus control/reference study design (4 burn treatments and 3 unburnt reference sites; Figure 4). The RSCs were deployed along with Eradicat® baits as soon as possible after the prescribed autumn burns as was practical and safe to do so (1-9 days after the last ignitions were made; Walcott 1, Balban 4, Chariup 6, Yackelup 9 days). Bait uptake trials were simultaneously conducted at a comparable contemporarily unburnt site. At three of the four treatment sites (Walcott, Balban and Chariup forest blocks), half of thetransect (25 RSCs) was located along the boundary of the burn and half was located within the burn boundary (i.e. edge and core areas of the burn). The fourth treatment site (Yackelup forest block) involved 30 RSCs/bait stations along a 3 km transect located along the burn boundary.

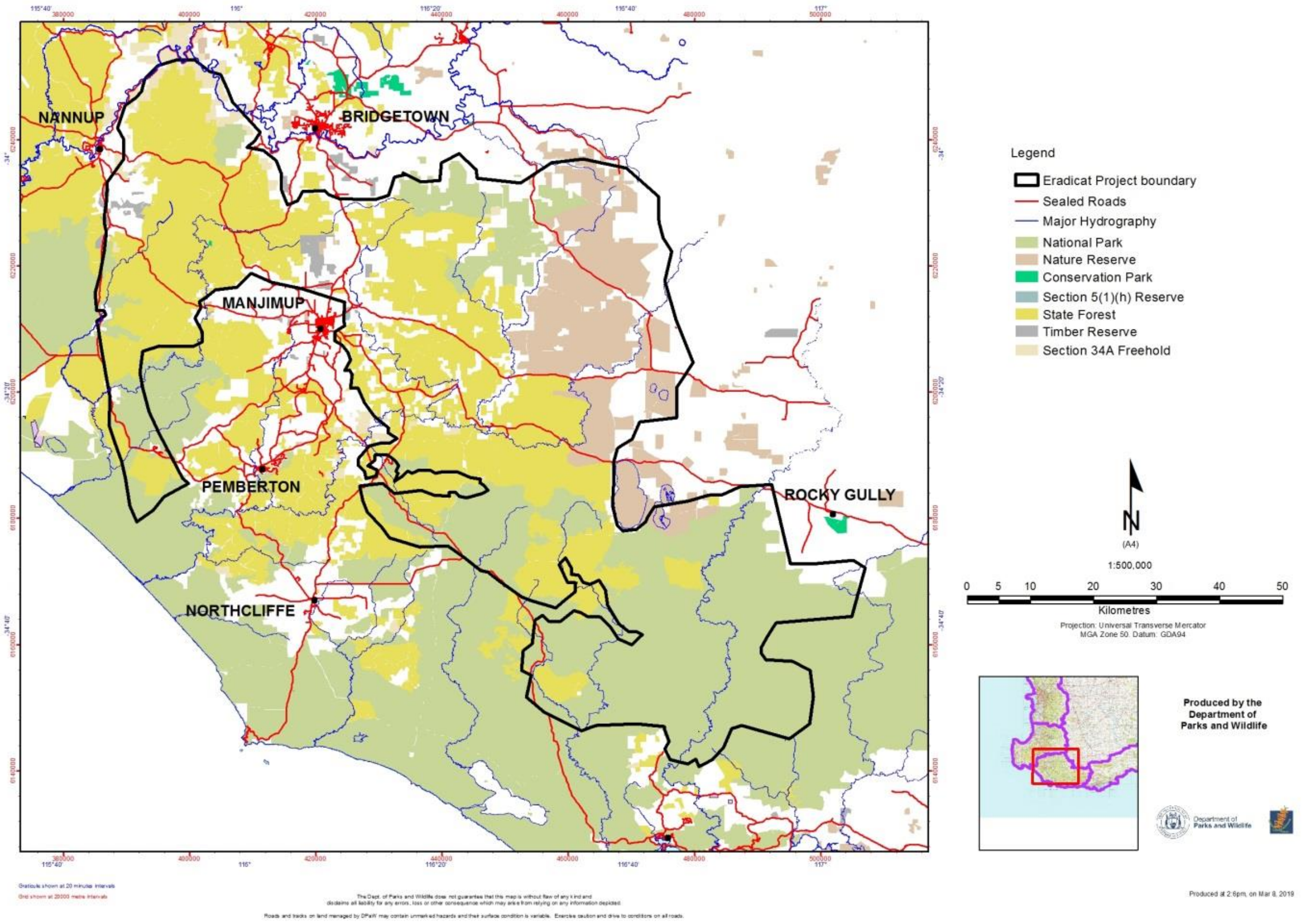

Figure 1. Study area in the southern jarrah forest of Western Australia.

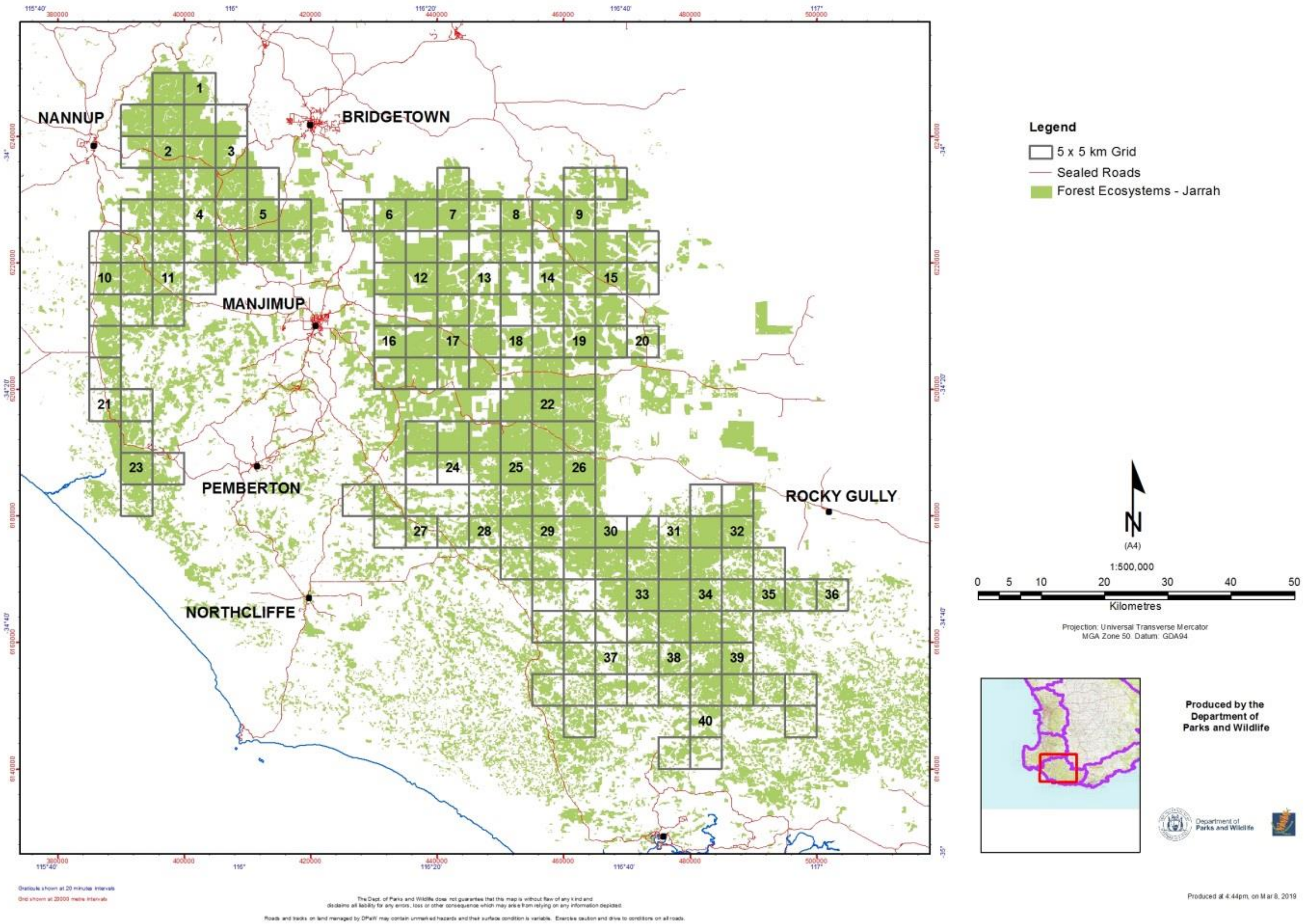

Figure 2. 5 x 5 km grid cells across the study area in the southern jarrah forest of Western Australia used for the selection of 40 sites for the Eradicat® bait uptake trials (September 2016-November 2017).

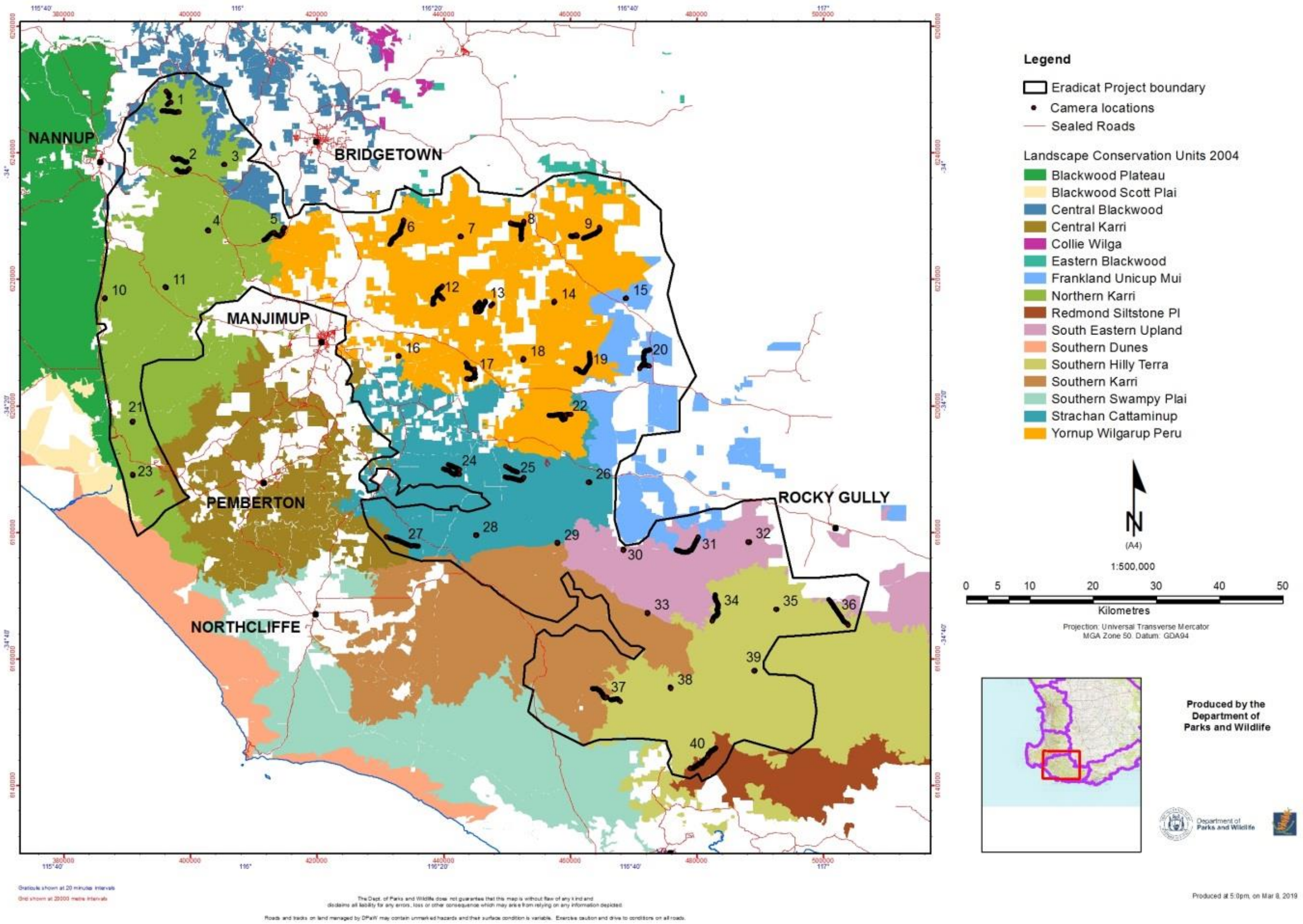

Figure 3. The 40 study sites across the southern jarrah forest of Western Australia used for the Eradicat® bait uptake trials (September 2016-November 2017). Half the sites resembled baiting operations along a transect (i.e. 5 km transects along forest tracks with 100 m intervals between baiting / remote sensor camera locations) and half resembled the spread of a single aerial drop of 50 baits from a baiting aircraft (i.e. 200 m x 40 m plots). The Landscape Conservation Units (LCUs) depict some of the ecological variation recognized within the region.

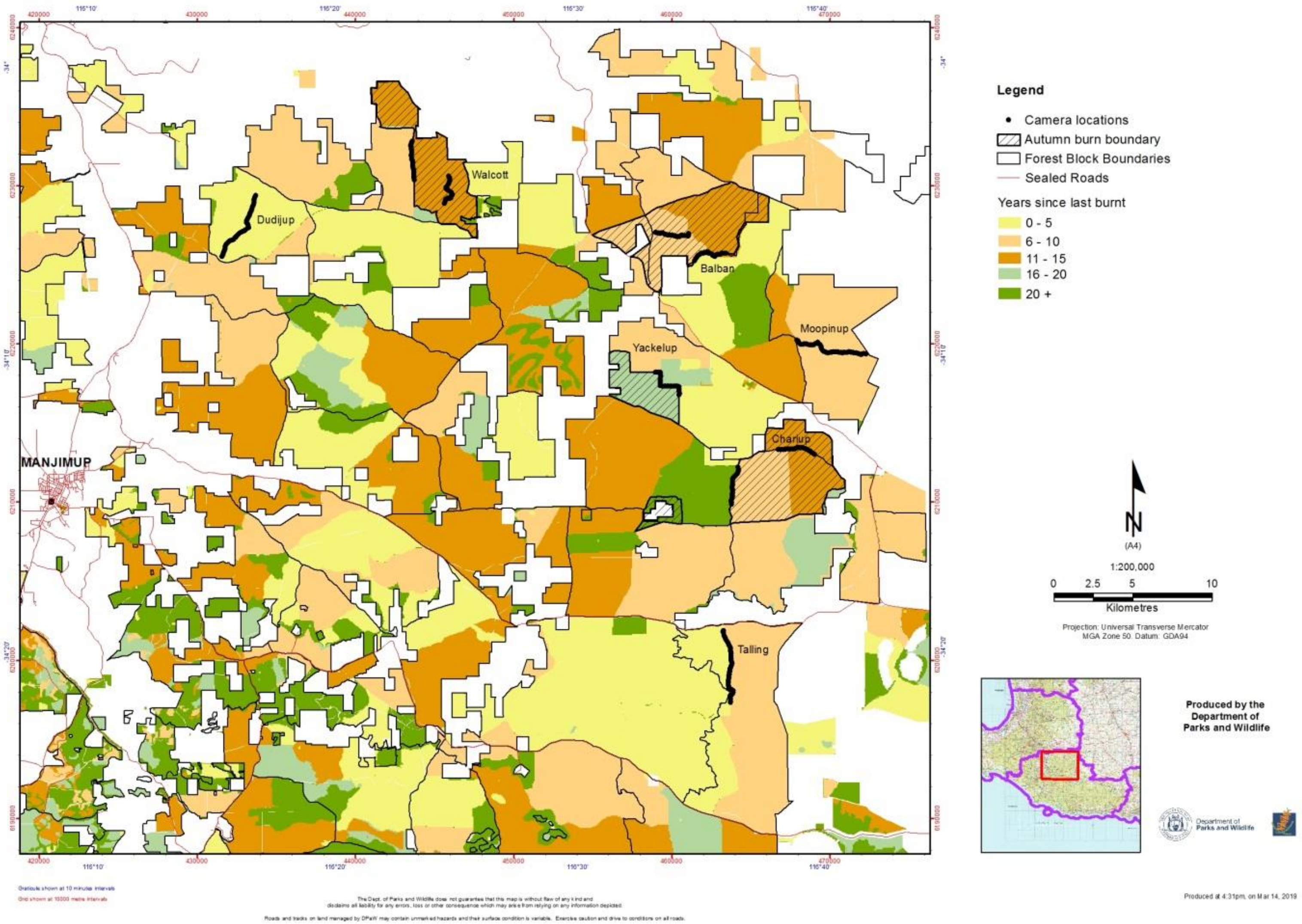

Figure 4. The location of the seven transects used to assess the differences in Eradicat® bait uptake in relation to Autumn burning in the Upper Warren Region in the southern jarrah forest of Western Australia.

2.3 Camera trapping

For the first trials, each bait station had a dummy RSC (i.e. a camera case, with no internal parts, identical to the RSC models being used) deployed for three to four weeks prior to the start of the bait trials; to allow time for the local wildlife to become accustomed to the presence of novel objects in their environment (i.e. to minimise behavioural responses of animals to the RSCs during the trials – i.e. reduce the observer effect). A working RSC (a randomly allocated Reconyx HC 600 or PC900 model) replaced the dummy on the day of deployment of a toxic Eradicat® bait 1.5 m in front of the RSC and at the centre of the field of view (verified by use of test shots by the RSC in position). The RSC set-up, settings and distance from the bait were informed by the experience of other researchers (e.g. Paul Meek) and refined during a pilot trial designed to optimise the effectiveness of the RSC to record wildlife and particularly animal interactions with the baits (Baraud 2016). RSCs were oriented south between southwest and southeast and about 20-30 cm above ground depending on ground slope (Figure 5). The dummies and RSCs were either bolted to a plastic peg hammered into the ground or attached with an elastic cord wrapped around the base of a tree. The RSCs were concealed as practically possible to reduce detection (i.e. within or adjacent to existing natural structures such as vegetation, logs or debris) but adjacent to and focussed on an open area in which the bait could be placed and monitored by the camera. Some minimal modification of the vegetation in front of the camera and around the bait location was done where required (e.g. selective light pruning) to improve camera surveillance of the bait and the animals around the bait. The walk test function of the RSCs were also used to improve the sensitivity of the cameras to detect animals around the bait.

RSC settings included 10 images per trigger, rapid fire with no time delay between triggers, high sensitivity, and motion sensor on. The PC 900 Reconyx RSC models were also programmed to take a time lapse image every six hours, for the purposes of confirming the presence/absence of Eradicat® baits. RSCs were code lock activated, and a small label fixed to the upper surface of the case indicating the RSC was security code protected and engraved and in use for the purpose of monitoring wildlife. Forest tracks involved in transects were closed under Regulation 44.1 of the CALM Regulations (2002) to unauthorised public access to reduce the risk of interference, non-target poisoning of companion animals and the theft of cameras.

a)

b)

Figure 5. Examples of a remote sensor camera secured in place with a (a) peg and (b) bungee cord, in the southern jarrah forest of Western Australia. The yellow arrow indicates the location of the small bush stick marker 1.5m in front of the camera, which is used to direct the centre of the field of view of the camera and where the Eradicat® bait is deployed.

The second (post autumn burn) trials did not involve the dummy cameras because of the likelihood of the equipment being damaged by fire and the priority to deploy the cameras and baits as soon after the burns as possible. Bait/RSC locations were closer to forest tracks than the first bait uptake trial to better reflect the likely distances of bait locations in an operational trial, having been satisfied by the first trials that the risk of theft of cameras was anticipated to be low. Camera setup was otherwise similar to the first trials

2.4 Image and data management

All images from the cameras were managed in the Camera Warehouse database (Colorado Parks and Wildlife). In which all distinguishable mammal, bird, reptile and amphibian taxa detected on camera were recorded, as well as animal interactions with baits and bait status (e.g. estimates of the proportion of bait remaining, when the bait was moved, removed and by what species or the period in which the bait disappeared). The detection/non-detection of selected species at the site level were compared with local DBCA district records. The local records included the readily available data in *Fauna File* databases from the three districts, including trapping records and sighting records. Records with no or clearly spurious spatial co-ordinate data were omitted. No systematic validation or verification of the remaining records was conducted. The district records were also incomplete. For instance, they did not include data from several studies and activities conducted by DBCA and others (e.g. Walpole fire mosaic study, PhD and other university student projects, DBCA feral animal records, other RSC surveys and some spotlight surveys).

For this study, the main focus was on quantifying independent detection events (>60 minutes between the detection of a species). This metric did not consider multiple individuals within a detection event (i.e. there may be more than one individual captured in any one independent detection event). Instances where species identification was not highly confident were either classified as a generalised taxon (e.g. macropod, small mammal, bird, reptile, amphibian, invertebrate) or as ‘unknown’.

Independent detection events are inferred here as evidence of presence (for distribution). The detection history (pattern of independent detection events) for each species or taxon was used for occupancy modelling and to infer spatial and temporal activity patterns. Deriving robust estimates of abundance or density were not attempted here because of the difficulties of meeting the assumptions needed for the models required to do so, such as being able to confidently and consistently distinguish individuals for most species.

2.5 Occupancy modelling

Single season (static) occupancy modelling was conducted using RPresence in R studio (Version 1.1.456) on the RSC detection data from the first trial (September 2016 – November 2017). These models used the detection history data for the first

20 days of monitoring at each site, starting on the day the bait was deployed (i.e. does not include pre-baiting data on the few sites where cameras were activated up to a few days prior to the baits being deployed), discretised into 10 2-day survey periods. The occupancy models estimated species occupancy and detection probabilities considering the effects of treatment (camera deployment method, i.e. 200 m x 40 m plot or along a 5 km transect at 100 m intervals), round (timing of the survey in one of 10 sessions between September 2016 and November 2017) and space/habitat (i.e. regional subunits based on ecosystem types, Landscape Conservation Units, LCU; Figure 3). Note that the 40 sites were originally classified into eight LCUs. However, three LCUs were represented by one or two sites that were on or very close to the boundaries with adjacent LCUs and so were aggregated (sites 15 and 20 in 'Frankland Unicup Muir Complex' were aggregated with 'Yornup Wilgarup Perup' (YWP; n=14), site 37 (Southern Karri) and site 40 (Redmond Siltstone Plain) were aggregated with 'Southern Hilly Terrain' (SHT; n=7), and site 33 (Southern Karri) was aggregated into 'South Eastern Upland' (SEU; n=4)). The other LCUs represented were 'Northern Karri' (NK; n=9) and 'Strachan Cattaminup Jigsaw' (SCJ; n=6). A total of 32 models were created for each species based on eight permutations for detection probability (p: constant; treatment; round; LCU; treatment + round; treatment + LCU; treatment * round; and treatment * LCU; whereby '*' indicates and interaction between terms), combined with each of four simpler models for occupancy (psi: constant; treatment; round; and LCU). The best occupancy models for each species were identified using the information theoretic approach and Akaike's Information Criterion (AIC).

2.6 Spatial activity patterns: Interpolated heat maps

The number of independent detection events for a species (i.e. detections of a species with >1-hour interval between detections) can be used to investigate the spatial characteristics of species activity patterns across the southern jarrah forest. To do so reliably, the raw number of detections per site needed to be standardised to adjust for site differences in detection probability and survey effort. Detection probability was estimated using the occupancy modelling approach described above. The discretisation of detection history data into 10 2-day survey periods were considered a compromise between having enough surveys to reliably estimate p and having values of p that are more robust to the multiplier effects of possible imprecision and inaccuracy in its estimation that may occur as a function of being a small number.

The adjusted detection rate (D_e) for each species at each site, is the expected number of independent detection events over 20 days using 50 cameras (1000 camera trap nights) was calculated thus,

$D_e = d/(1-(1-p)^{10}) * 1000/s$

where,

d= number of independent detection events for the species across the actual survey period at each site, p=estimated detection probability for the species derived from occupancy modelling (based on the first 20 days continuous survey, discretised into 10 x 2d survey periods), and

s = actual survey effort (number of trap nights) at that site

Spatial interpolation was used to graphically characterise spatial variation in species richness and activity across the southern jarrah forest. The adjusted detection rate for each of the 20 most frequently recorded mammal species (i.e. those species with >40 independent detection events) from the first trial (September 2016 – November 2017) were used. The data from the second trial were not used because the study sites were not spatially independent of the sites used in the first trial. The package gstat (Pebesma & Graeler 2019) was used to perform inverted distance weighting (IDW) interpolation in the statistical programme environment R (R Core Team 2018). This method uses weighted averages from the observation points to extrapolate across prediction points such that points closer to observation points have higher weighting that those further away. A power value of p=3 was applied with the effect of diminishing weighting at prediction points with increasing distance from observations. This value was decided as appropriate due to the large distances between sample sites and on the basis that it produced more readily ecologically interpretable outputs than lower power values. No spatial covariates were included in the IDW models.

Groups of mammals were spatially modelled in relation to species richness, combined activity and relative activity. Mammals groups included currently-listed (i) threatened (*Critically Endangered, Endangered* and *Vulnerable*) and (ii) Priority 4 (Rare, Near Threatened and other species in need of monitoring) species under Part 2 of the Western Australian *Biodiversity Conservation Act 2016*, and taken from the *Wildlife Conservation (Specially Protected Fauna) Notice 2018* (September 2018); (iii) arboreal mammals; (iv) medium-sized native mammals (i.e. species most vulnerable to introduced predators);(v) all native mammals; and (vi) introduced mammals. Combined activity was the sum of the adjusted detection rates (D_e) across the species within a given group. 'Relative activity' was the sum of the individual species' *relative activity* values (i.e. D_e at a given site divided by the maximum recorded D_e at any site) within a given group. Therefore, the combined activity is an absolute measure of activity making no distinction between the different activity rates between species, whereas relative activity provides equal weighting for each species within the group and is in part a function of species richness (i.e. the more species present the higher the potential maximum value for the site). In effect, relative activity helps to identify those areas that have a relatively high level of activity for the most number of species within the group. This metric is, therefore, useful for helping to identify the areas where the greatest conservation values or management priorities may be.

2.7 Temporal activity patterns

Diel activity patterns for each species were investigated using the data combined from the first (September 2016 – November 2017) and second trials (May – July 2018). The frequency/count of independent detection events per hour within a 24-hour period were used to look at seasonal differences in diel activity patterns within a species. Within a given season the activity for each hour was expressed as the proportion of the total number of records across 24-hours. Between species comparisons in activity were based on the proportion of the total number of records across 24-hours for all seasons combined. Differences in the diel activity patterns due to the autumn burns were also investigated by comparing the data from burnt and unburnt treatments.

3 Results

3.1 General

The first trial resulted in a 65-week field program involving Eradicat® bait uptake trials on 40 sites across the southern jarrah forest between September 2016 and November 2017 (Table 1). The trials ran for an average of 27.3 days per site (SD=2.7; range 19-33 days). Two sites ran for less than 24 days. Both were in the first round of trials in October-November 2016 (aerial plots Flybrook and Crossing).

A total of 54,361 camera trap nights at 2,000 camera/bait sites were involved in the first bait uptake trials (September 2016 – November 2017). A total of 1.98 million images were recorded on remote sensor cameras, including ~ 790,000 blank, time lapse and personnel images; 1,621 unknown images and 1,184,358 images of fauna. At least 25 mammal taxa were identified in the images (*Sminthopsis* were only identified to genus level; Table 2). At least 28 bird taxa and four reptiles were identified. Some frogs and invertebrates were also detected.

The second, post autumn burn trials (May – July 2018) ran for an average of 44 days per site (SD=4.1; range 39-49 days), resulting in 15,032 camera trap nights at 330 camera/bait sites. A total of 663,698 images were recorded; 233,336 blank, time-lapse and personnel images; 834 unknown and 429, 528 fauna images involving at least 18 mammal, 17 bird and 2 reptile taxa (Table 2).

With respect to the 'unknown' images, 1.3 % and 1.9 % of all independent detection events could not be identified to species level for the first and second trials, respectively. This was either because of incomplete images, (e.g. fur only), blurred images or lack of clarity due to distance from camera.

3.2 Species richness and distributions

Based on the data from the first trials only, Meribup recorded the highest number of native mammal species (15 out of 17 native mammals detected), while nearby Tone and Kin Kin as well as Warrup ranked equal second (13 species) and Balban third (12 species; Appendix 1). The highest number of introduced mammal species (five out of eight species detected) was recorded at Ellis Creek, Kingston, Chitelup, Karara and Table Hill (Appendix 1).

A comparison of the detection records between this study and readily available local DBCA records in *Fauna File* were conducted for some species. These included those which had insufficient data to conduct occupancy modelling and spatial interpolations (*Ca. hircus, Cercartetus concinnus* (mandada or western pygmy possum)*, Ce. elaphus, Oryctolagus cuniculus* (rabbit)*, Tarsipes rostratus* (ngoolboongoor or honey possum) and others that may have been of general interest.

There was a strong spatial match between RSC records from this study and other recent records for *Antechinus flavipes* (mardo)*, B. penicillata, M. fasciatus, N. eugenii, R. fuscipes,* and *S. brachyurus* (Figures 6, 7, 9, 10, 11, 12, respectively). The RSC also confirmed recent records and contemporary range extensions of *A.*

flavipes in the Upper Warren (Dudijup and Meribup). However, the RSC did not detect *A. flavipes* at Easter and Lewin where other records exist from as recent as 2000 and 2015, respectively (Figure 6). The RSC did not detect *B. penicillata* at Easter where there are nearby records from 1998 – 2000. Similarly, there were no detections of *B. penicillata* from RSC at Mindanup, Poorginup or Chitelup where it was last recorded nearby in 2003-2004 (Figure 7). However, *B. penicillata* were captured in cage-traps five kilometres to the north as recently as 2014. Interestingly, *N. eugenii* were also not recorded by RSC at these three sites where they were last recorded in the area by other means in 2009, 2015 and 2004 respectively (Figure 10). The RSC detected *M. fasciatus* within the existing known core range for this species, but did not detect them further south where there have been only a few sightings over the years (e.g. Poorginup in 1993, Stoate in 2003 and Curtin in 2010; Figure 9).

There had been only two records of *R. fuscipes* in the Upper Warren Region north of the Muir Highway since 2005, having been frequently recorded during a study in and around Kingston forest block in the 1990s. In 2017 the species was recorded twice in Boyicup on a trapping transect. The RSC from this study has further confirmed their persistence in the region having detected *R. fuscipes* 14 times at Warrup, Chariup and Meribup, combined (Figure 11).

While the distribution of RSC records of *S. brachyurus* closely correspond to those from other sources, the 32 independent detection events in Meribup represent the first contemporary and reliable records north of the Muir Highway and a range extension of more than 5 km (Figure 12). The veracity of the three public sighting records of *S. brachyurus* close to Manjimup town site (in 1996, 2004 and 2018), remains unknown.

The detections from RSC in this study have substantially increased the number of records for several species across the SJF including *Ce. concinnus, Tachyglossus aculeatus* (nyingarn or echidna)*, Tar. rostratus* (Figures 8, 13 and 14, respectively). The RSC detected *Ce. concinnus* in many areas where no other records exist and indicate that this species is relatively widespread. However, they were not detected by RSC at Dudijup, Cardac or Peak where the latest records from other sources indicate that they were present nearby in 1995, 1996 and 2009, respectively. It is interesting to note the sparseness of DBCA records for *Tac. aculeatus* in the SJF and that the records from RSCCA in this study roughly doubles the locations where it has now been recorded. The increase in the number of locations of *Tar. rostratus* has also resulted in a 15 km range extension to the north compared with the DBCA records currently available in *Fauna File*.

With respect to the seldom-detected introduced mammals in the SJF, *O. cuniculus* was widespread and generally detected relatively close to private property (Figure 14). However, it was also detected at Karara, more than 10 km from private property. The detection of *Ce. elaphus* south of Lake Muir and *Ca. hircus* at Weinup and Meribup is consistent with recent local knowledge (these species are not recorded in *Fauna File* in Donnelly District).

Table 1a. *Study sites used in the first Eradicat® bait uptake trials in the southern jarrah forest (September 2016-November 2017). Sites were located in the DBCA Districts of Blackwood (BWD), Donnelly (DON) and Frankland (FRK). Aggregated Landscape Conservation Unit (LCU) categories were 'Yornup Wilgarup Perup' (YWP), 'Southern Hilly Terrain' (SHT), 'South Eastern Upland' (SEU), 'Northern Karri' (NK) and 'Strachan Cattaminup Jigsaw' (SCJ). Baiting treatment: 'aerial' plots (200 m x 40 m) or ground transects (100m intervals along 5 km). Survey effort details include number of days and total number of camera trap nights per site.*

Site	Forest block	District	LCU	Treatment	Round	Start date	End date	Days	Trap nights
1	Ellis Creek	BWD	NK	Ground	8	2/08/2017	30/08/2017	28	1400
2	Gregory	BWD	NK	Ground	7	19/06/2017	18/07/2017	29	1450
3	Dalgarup	BWD	NK	Aerial	10	26/10/2017	27/11/2017	32	1600
4	Netic	DON	NK	Aerial	3	6/01/2017	30/01/2017	24	1200
5	Carter	DON	NK	Ground	5	27/03/2017	27/04/2017	31	1529
6	Dudijup	DON	YWP	Ground	1	18/10/2016	15/11/2016	28	1435
7	Kingston	DON	YWP	Aerial	6	12/05/2017	6/06/2017	25	1250
8	Dwalgan	DON	YWP	Ground	1	18/10/2016	15/11/2016	28	1347
9	Balban	DON	YWP	Ground	2	21/11/2016	20/12/2016	29	1445
10	Easter	DON	NK	Aerial	4	15/02/2017	14/03/2017	27	1350
11	Lewin	DON	NK	Aerial	2	24/11/2016	19/12/2016	25	1250
12	Warrup	DON	YWP	Ground	4	14/02/2017	14/03/2017	28	1400
13	Yerramin	DON	YWP	Ground	10	23/10/2017	22/11/2017	30	1500
14	Yackelup	DON	YWP	Aerial	8	4/08/2017	29/08/2017	25	1450
15	Moopinup	DON	YWP	Aerial	9	13/09/2017	10/10/2017	27	1350
16	Cardac	DON	YWP	Aerial	2	23/11/2016	19/12/2016	26	1278
17	Yeticup	DON	YWP	Ground	3	4/01/2017	1/02/2017	28	1334
18	Weinup	DON	YWP	Aerial	7	23/06/2017	17/07/2017	24	1226
19	Boyicup	DON	YWP	Ground	2	22/11/2016	20/12/2016	28	1389
20	Chariup	DON	YWP	Ground	3	3/01/2017	1/02/2017	29	1348
21	Carey	DON	NK	Aerial	5	30/03/2017	24/04/2017	25	1250
22	Meribup	DON	YWP	Ground	8	1/08/2017	30/08/2017	29	1450
23	Flybrook	DON	NK	Aerial	1	20/10/2016	8/11/2016	19	950
24	Kin Kin	DON	SCJ	Ground	6	9/05/2017	7/06/2017	29	1442
25	Tone	DON	SCJ	Ground	9	12/09/2017	11/10/2017	29	1450
26	Stoate	DON	SCJ	Aerial	5	29/03/2017	26/04/2017	28	1400
27	Poole	DON	SCJ	Ground	9	11/09/2017	11/10/2017	30	1500
28	Curtin	DON	SCJ	Aerial	8	3/08/2017	29/08/2017	26	1300
29	Mindanup	FRK	SCJ	Aerial	3	5/01/2017	30/01/2017	25	1250
30	Poorginup	DON	SEU	Aerial	10	25/10/2017	27/11/2017	33	1650
31	Chitelup	DON	SEU	Ground	4	17/02/2017	13/03/2017	24	1376
32	Hiker	FRK	SEU	Aerial	7	21/06/2017	17/07/2017	26	1278
33	Long	FRK	SEU	Aerial	6	11/05/2017	6/06/2017	26	1300
34	Karara	FRK	SHT	Ground	10	24/10/2017	22/11/2017	29	1434
35	Northumberland	FRK	SHT	Aerial	9	14/09/2017	10/10/2017	26	1300
36	Table Hill	FRK	SHT	Ground	7	20/06/2017	18/07/2017	28	1400
37	O'Donnell	FRK	SHT	Ground	6	10/05/2017	7/06/2017	28	1400
38	Peak	FRK	SHT	Aerial	4	16/02/2017	13/03/2017	25	1250
39	Crossing	FRK	SHT	Aerial	1	19/10/2016	8/11/2016	20	1000
40	Collis	FRK	SHT	Ground	5	28/03/2017	26/04/2017	29	1450

Table 1b. *Summary of study sites used for the second (post autumn burn) Eradicat® bait uptake trial in the Upper Warren Region, Western Australia (May – July 2018). All sites were ground transects with 50 remote sensor cameras (100m intervals along 5 km transect) with the exception of Yackelup, 30 cameras along a 3 km transect.*

Site	Forest Block	Yrs since burnt	Treatment	Start date	End date	Days	Trap nights
1	Balban	10 - 14	Burn	15/05/2018	27/06/2018	43	2104
2	Moopinup	10	Control	9/05/2018	27/06/2018	49	2364
3	Chariup	9 - 48	Burn	14/05/2018	28/06/2018	45	2120
4	Talling	3 - 8	Control	10/05/2018	28/06/2018	49	2396
5	Walcott	14	Burn	21/05/2018	29/06/2018	39	1928
6	Dudijup	4	Control	21/05/2018	29/06/2018	39	1950
7	Yackelup	18	Burn	22/05/2018	5/07/2018	44	2170

Table 2a. *Summary of the mammal taxa detected during i) the first Eradicat® bait uptake trials and the ii) the second (post autumn burn) trials in the southern jarrah forest, Western Australia. Conservation status: CR=Critically Endangered, EN=Endangered, VU=Vulnerable, CD= Conservation Dependent, P4=Priority 4, NL=Not listed and Introduced species.*

Species: Scientific name	Indigenous or Common name	Status	i) Images	i) Events	ii) Images	ii) Events
Antechinus flavipes	Mardo	NL	3929	345	20	4
Bettongia penicillata	Woylie	CR	301225	10362	103746	4979
Capra hircus	Goat	Introduced	800	20	0	0
Cercartetus concinnus	Mandada	NL	342	30	0	0
Cervus spp.	Deer	Introduced	72	6	0	0
Dasyurus geoffroii	Chuditch	VU	34507	1426	25068	965
Felis catus	Cat	Introduced	2663	100	692	43
Isoodon fusciventer	Quenda	P4	29871	1029	7113	338
Macropus fuliginosus	Yongka	NL	111417	1756	21649	411
Mus musculus	House mouse	Introduced	2507	216	704	63
Myrmecobius fasciatus	Numbat	EN	2576	213	725	95
Notamacropus eugenii derbianus	Tammar	P4	85945	1443	38759	941
Notamacropus irma	Kwara	P4	69306	1237	7531	149
Oryctolagus cuniculus	Rabbit	Introduced	393	24	158	11
Phascogale tapoatafa wambenger	Wambenger	CD	2018	190	3660	322
Pseudocheirus occidentalis	Ngwayir	CR	2117	110	409	31
Rattus fuscipes	Mootit	NL	55020	2469	0	0
Rattus rattus	Black Rat	Introduced	9515	424	0	0
Setonix brachyurus	Quokka	VU	70941	1366	0	0
Sminthopsis spp.	Dunnart	NL	4511	567	1662	229
Sus scrofa	Pig	Introduced	1179	43	312	15
Tachyglossus aculeatus	Nyingarn	NL	2598	80	666	23
Tarsipes rostratus	Ngoolboongoor	NL	129	30	0	0
Trichosurus vulpecula hypoleucus	Koomal	NL	286857	6079	186599	4284
Vulpes vulpes	Fox	Introduced	3178	154	3231	184
	Macropod		335	81	76	18
	Small mammal		799	260	33	17

Table 2b. *Summary of the avian taxa detected during i) the first Eradicat® bait uptake trials and the ii) the second (post autumn burn) trials in the southern jarrah forest, Western Australia. Conservation status: EN=Endangered, NL=Not listed and Introduced species.*

Species: Scientific name	Common name	Status	i) Images	i) Events	ii) Images	ii) Events
Dromaius novaehollandiae	Emu	NL	11517	890	301	48
Strepera versicolor	Grey Currawong	NL	33408	1211	5217	179
Cracticus tibicen dorsalis	Australian Magpie	NL	81	6	1910	34
Corvus coronoides	Australian Raven	NL	9566	276	2165	52
Barnardius zonarius	Australian Ringneck	NL	508	51	0	81
Phaps chalcoptera	Common Bronzewing	NL	758	53	5623	295
Malurus splendens	Splendid Fairy-wren	NL	567	108	884	132
Podargus strigoides	Tawny Frogmouth	NL	152	14	32	3
Climacteris rufa	Rufous Treecreeper	NL	523	59	1264	185
Petroica sp	Red-breasted Robin	NL	76	14	948	84
Dacelo novaeguineae	Laughing Kookaburra	Introduced	876	55	91	9
Colluricincla harmonica	Grey Shrike-thrush	NL	1344	169	1754	218
Turnix varia	Painted Button-quail	NL	506	38	1878	85
Eopsaltria georgiana	White-breasted Robin	NL	6624	600	380	46
Pachycephala occidentalis	Western Whistler	NL	189	25	800	78
Purpureicephalus spurius	Red-capped Parrot	NL	170	21	337	21
Eopsaltria griseogularis	Western Yellow Robin	NL	158	27	728	66
Aegotheles cristatus	Australian Owlet-nightjar	NL	1429	84	143	12
Malurus elegans	Red-winged Fairywren	NL	664	124	135	23
Stagonopleura oculata	Red-eared Firetail Finch	NL	1919	73	20	1
Sericornis frontalis	White-browed Scrubwren	NL	1353	199	267	34
Zosterops lateralis	Silvereye	NL	115	18	53	12
Rhipidura fuliginosa	Grey Fantail	NL	104	16	6	2
Platycercus icterotis	Western Rosella	NL	162	14	468	25
Calyptorhynchus sp	Black-Cockatoo	EN	25	3	0	0
	Waterbird		19	2	0	0
	Raptor		43	3	595	2
	Bird sp		2473	435	591	105

Table 2c. *Summary of the herpetofauna and invertebrates detected during i) the first Eradicat® bait uptake trials and the ii) the second (post autumn burn) trials in the southern jarrah forest, Western Australia. Conservation status: NL=Not listed.*

Species: Scientific name	Common name	Status	i) Images	i) Events	ii) Images	ii) Events
Egernia kingii	King's Skink	NL	322	37	0	0
Egernia napoleonis	Southwestern Crevice Skink	NL	903	101	0	0
Tiliqua rugosa	Western Bobtail	NL	2578	153	10	1
Varanus rosenbergi	Southern Heath Goanna	NL	20311	998	85	4
	Reptile sp	NL	21	8	0	0
	Snake sp	NL	62	8	0	0
	Amphibian		97	11	12	3
	Invertebrate		20	5	18	2

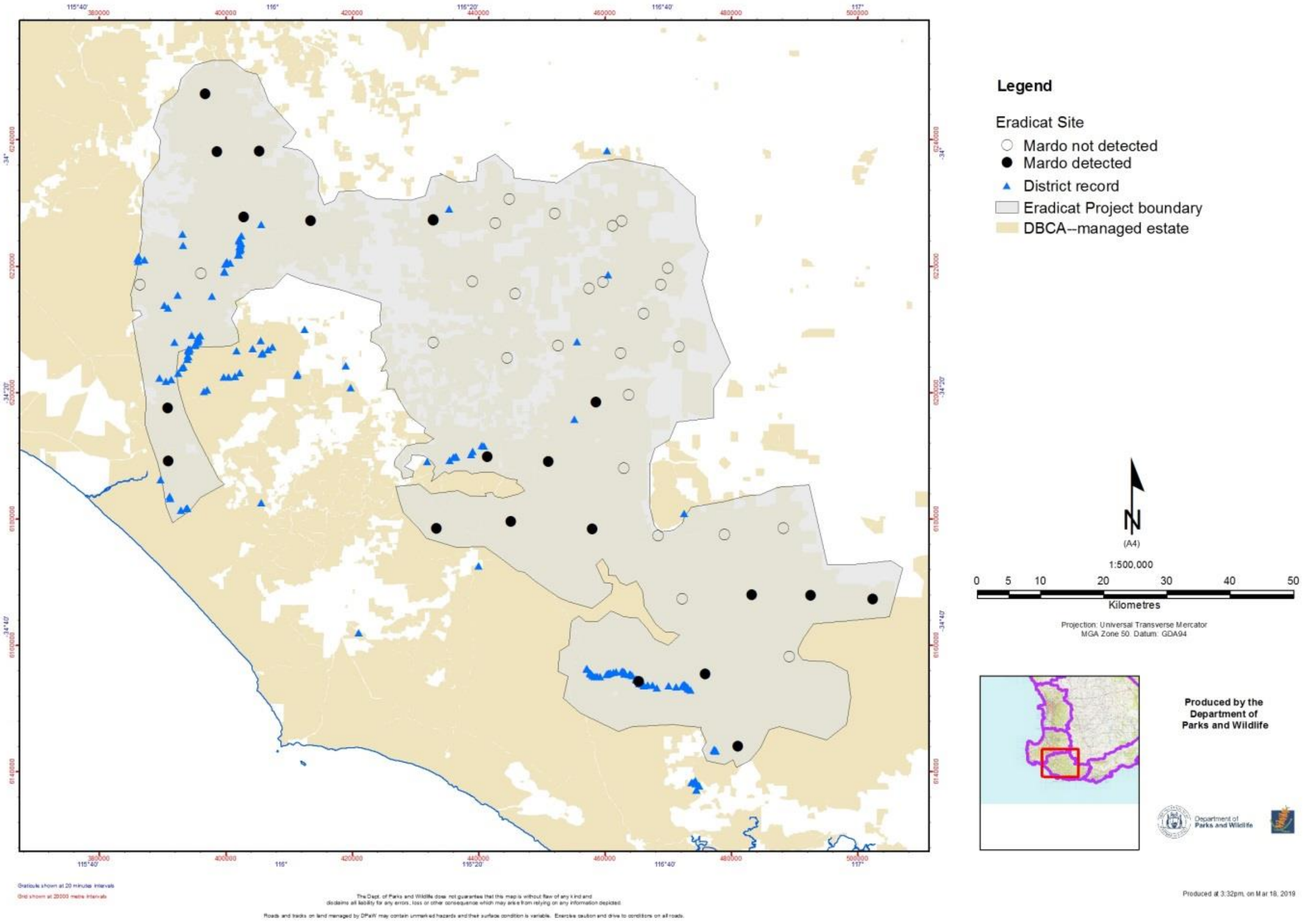

Figure 6. Antechinus flavipes records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

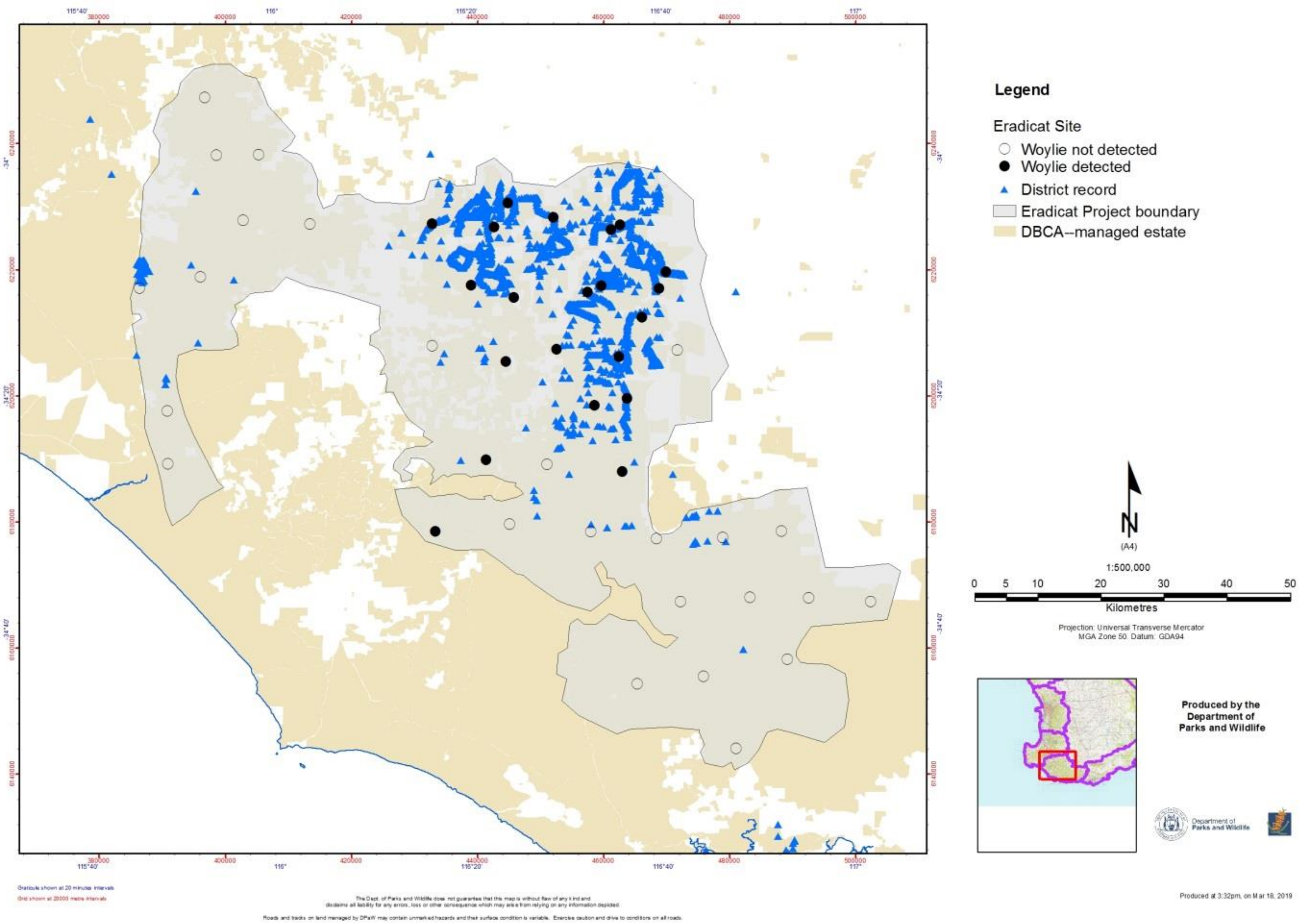

Figure 7. Bettongia penicillata records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

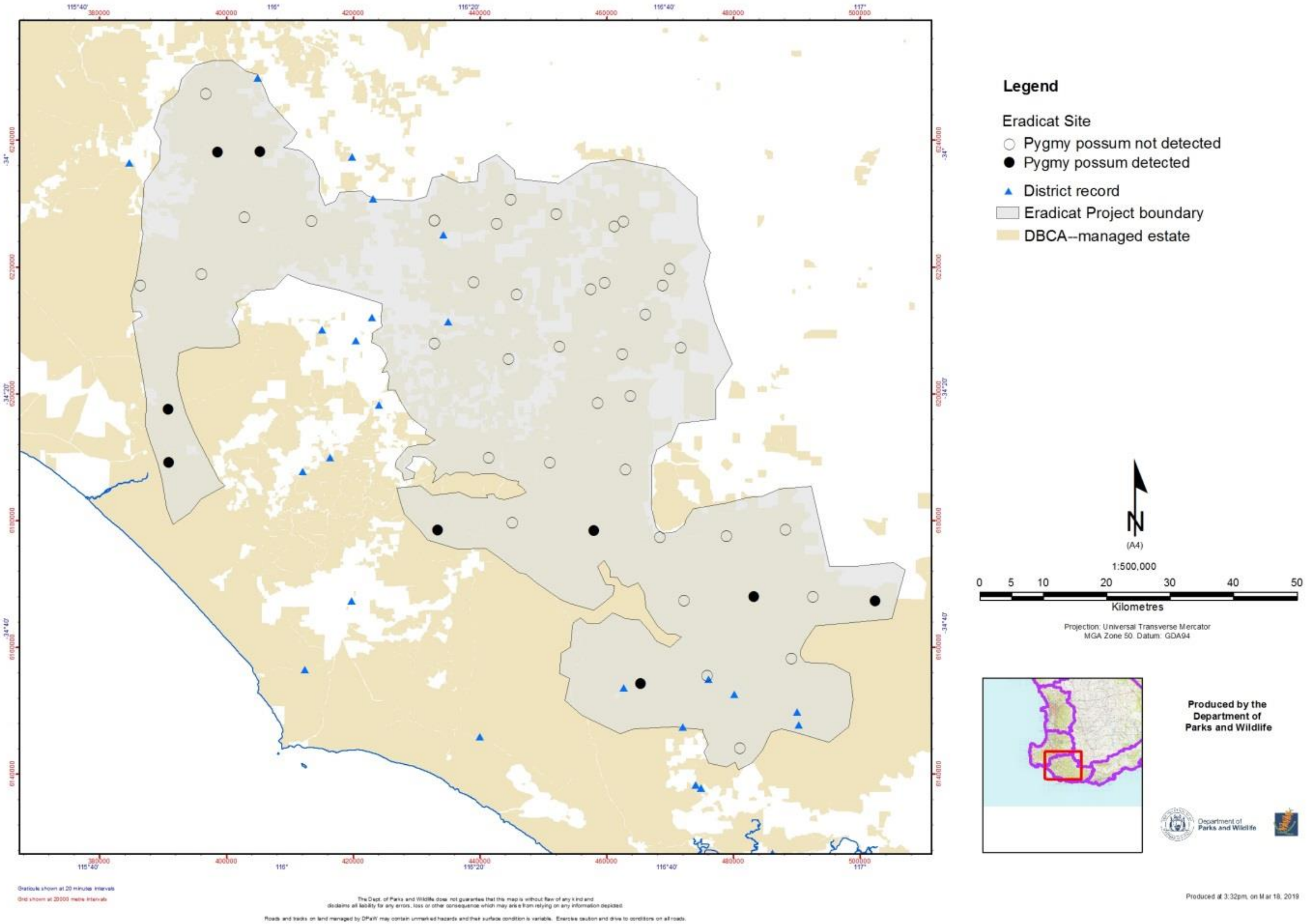

Figure 8. Cercartetus concinnus records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

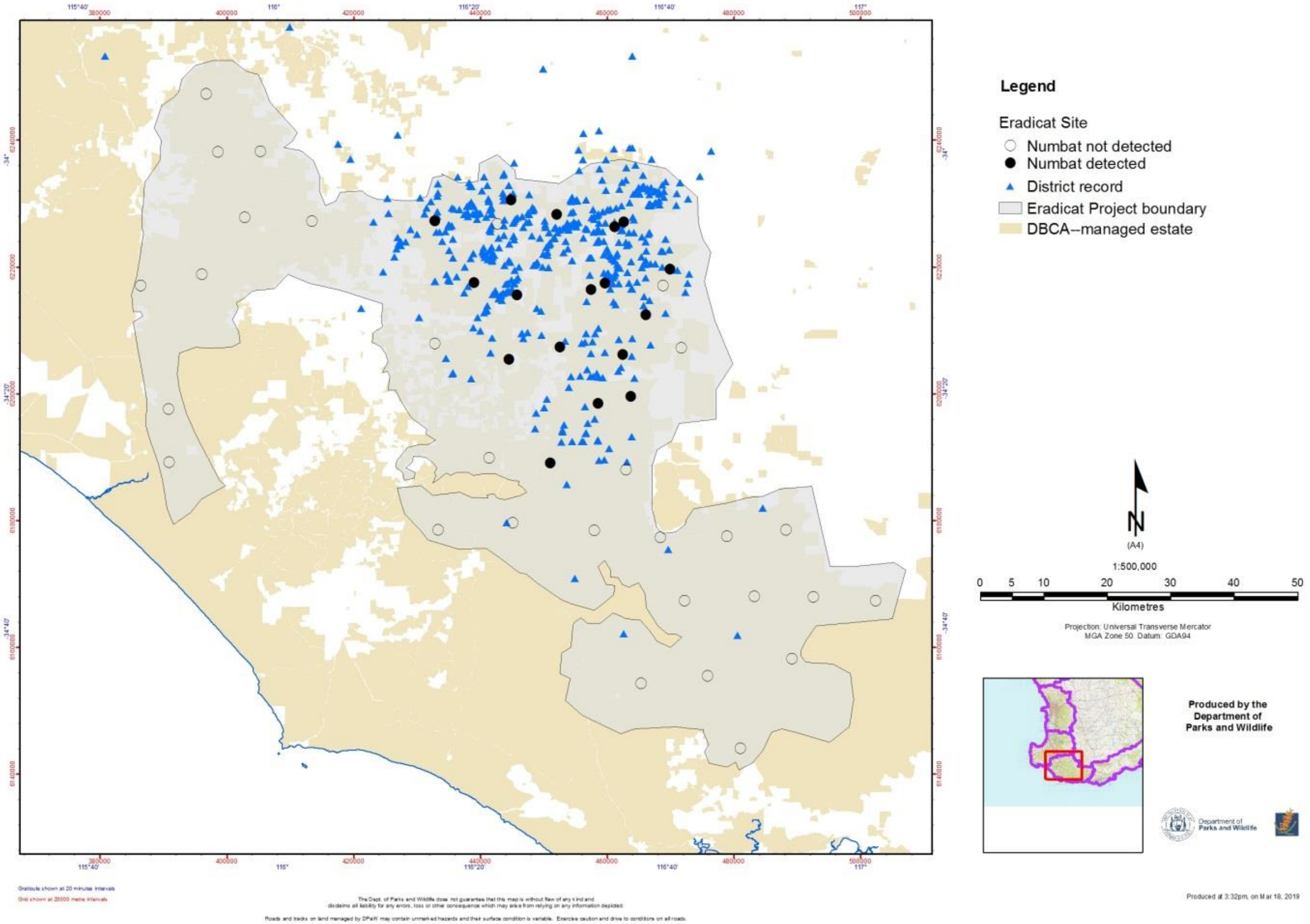

Figure 9. Myrmecobius fasciatus records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

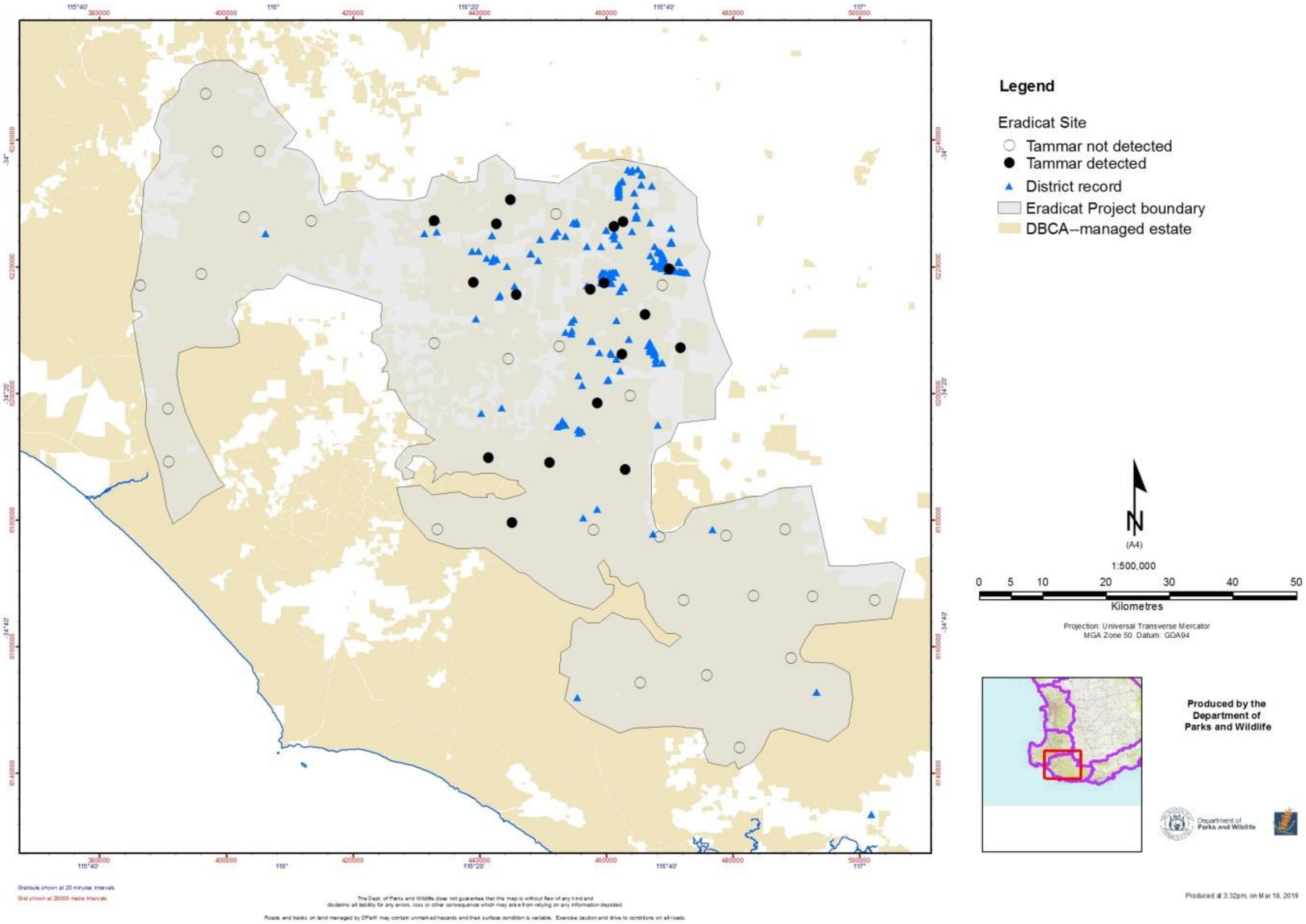

Figure 10. Notamacropus eugenii records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

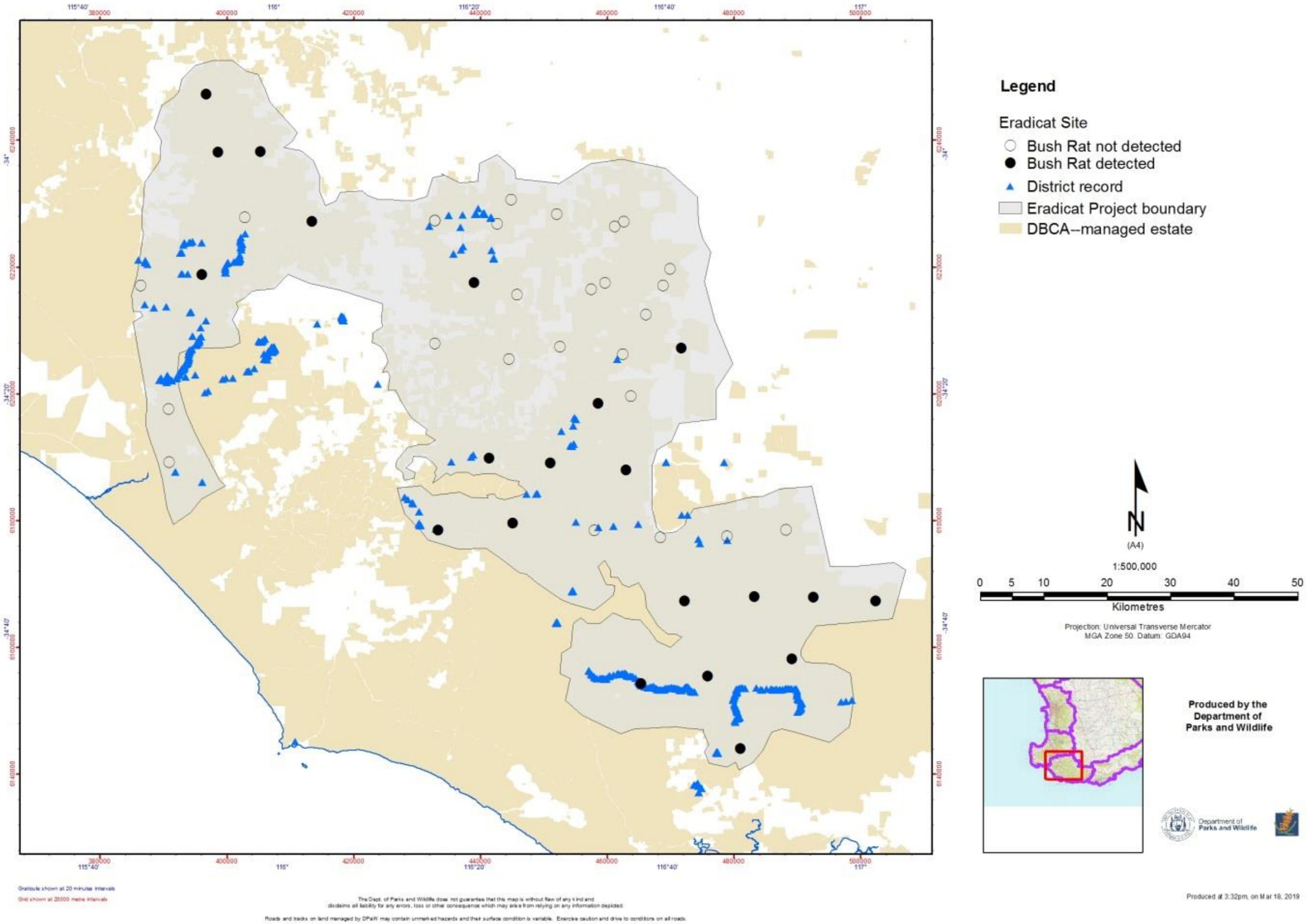

Figure 11. Rattus fuscipes records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

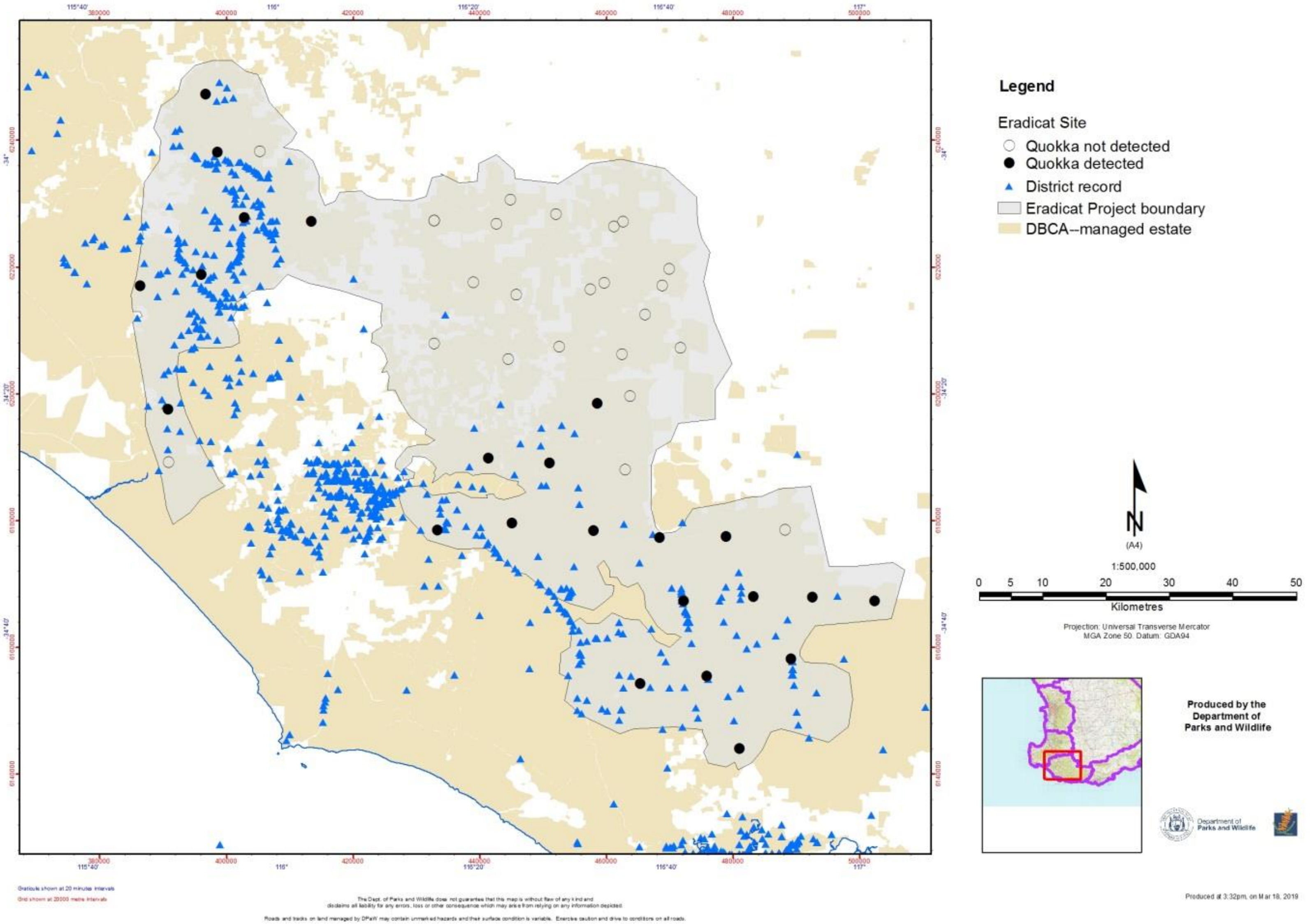

Figure 12. Setonix brachyurus records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

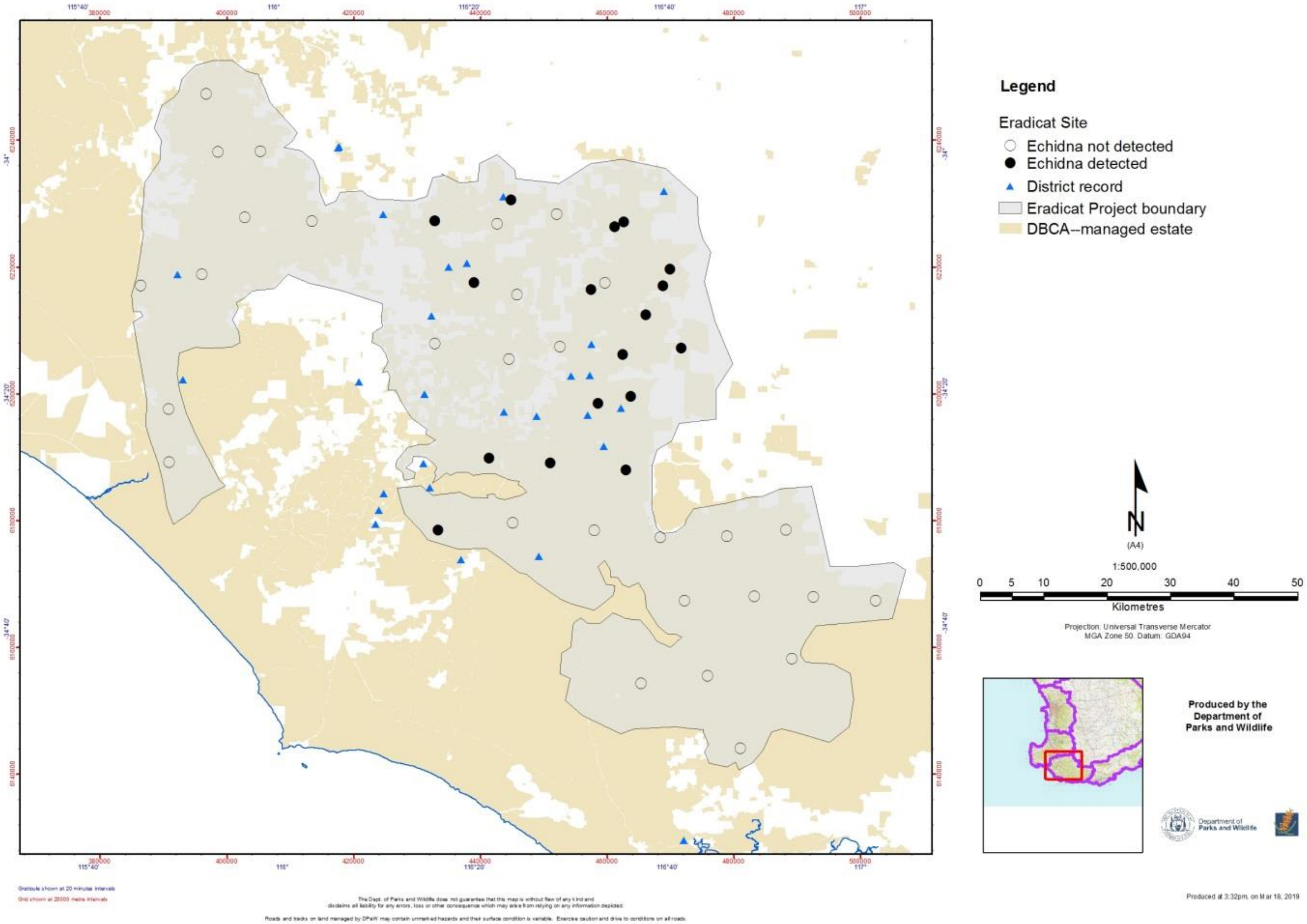

Figure 13. Tachyglossus aculeatus records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

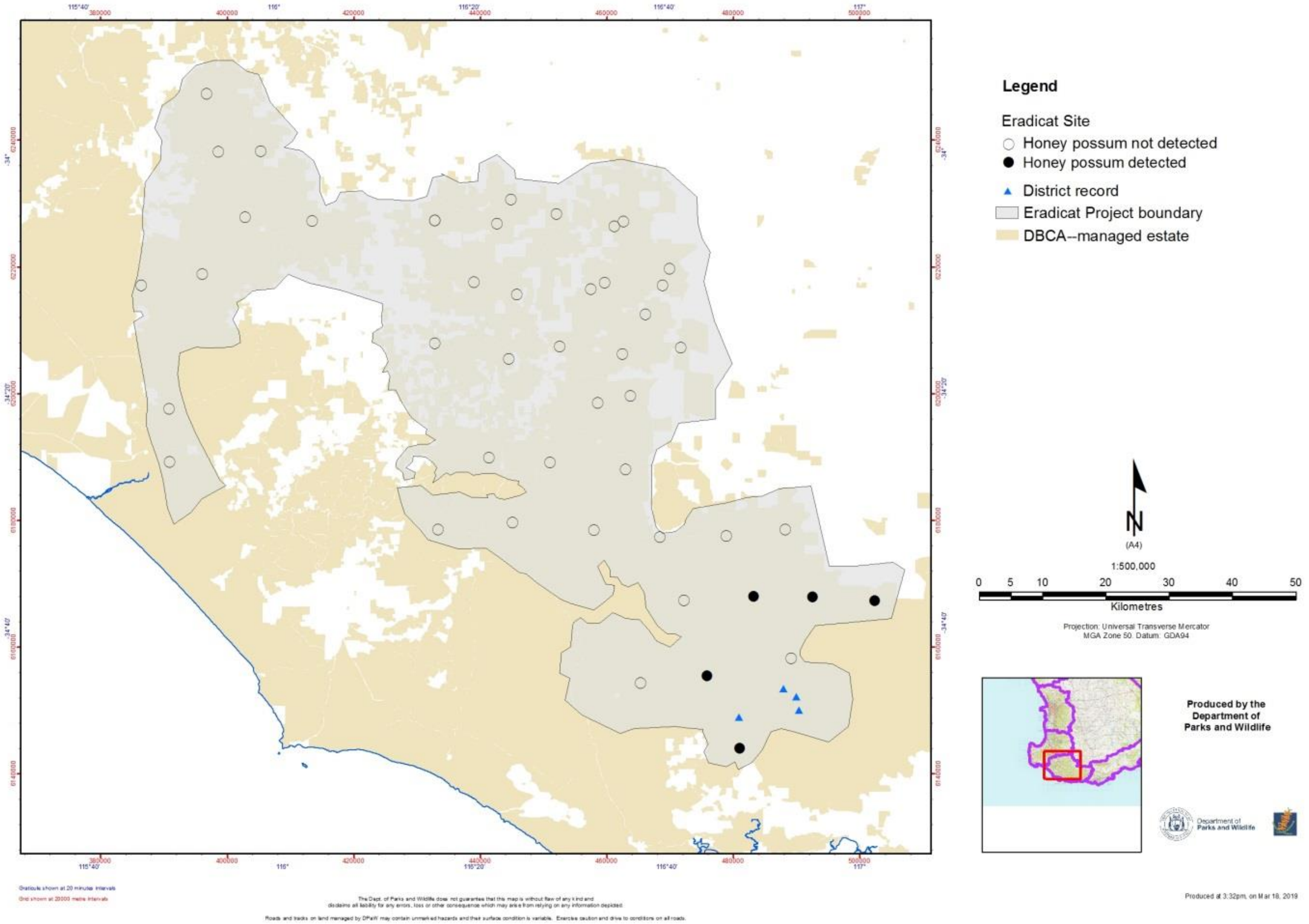

Figure 14. Tarsipes rostratus records from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid black circles = detected, hollow circles = not detected) and historical local DBCA records (blue triangles = location of district record).

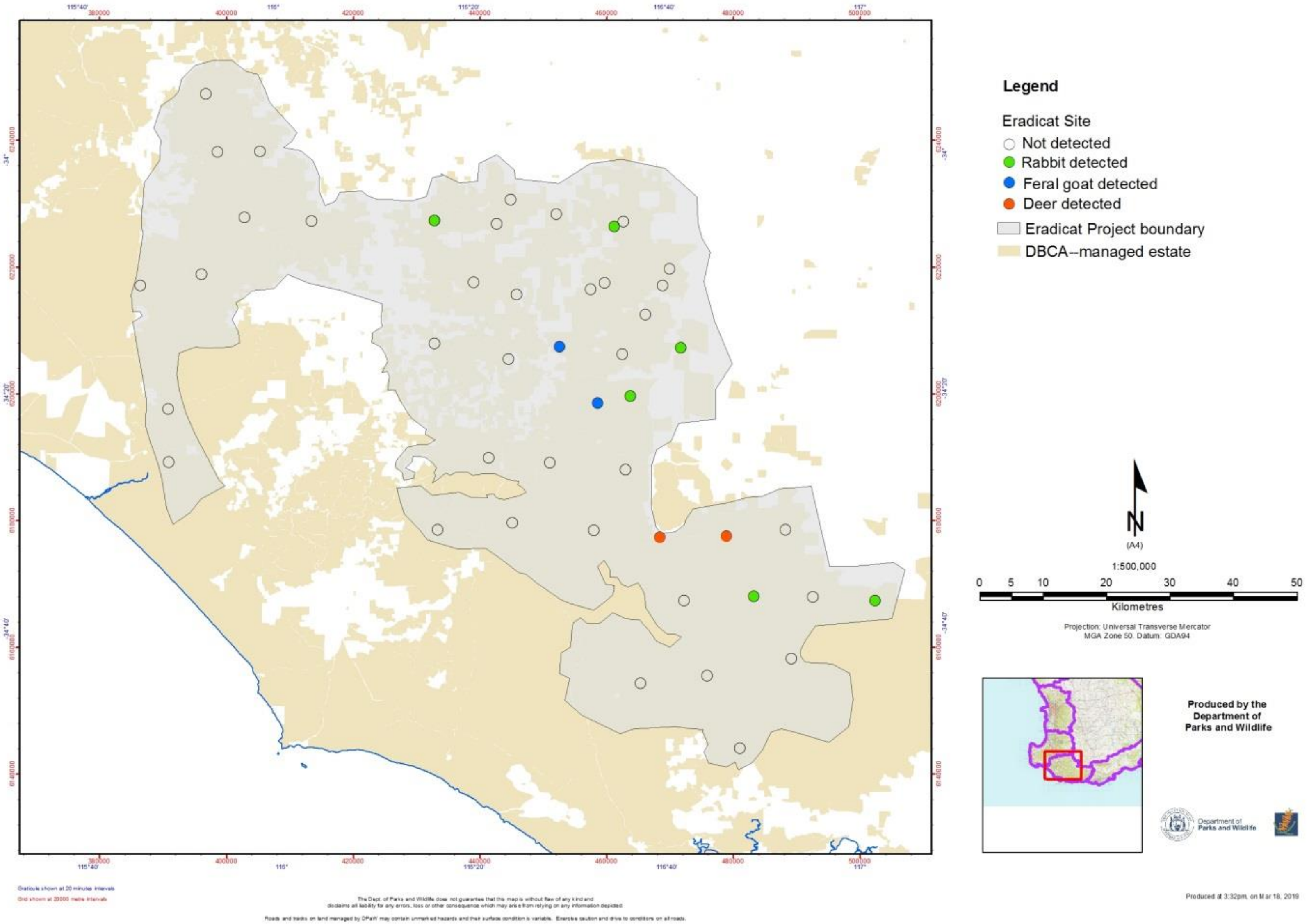

Figure 15. Records of seldom detected introduced mammals (Capra hircus, Cervus elaphus, Oryctolagus cuniculus) from remote sensor cameras deployed as part of the Eradicat® study (2016-2018; solid coloured circles = detected, hollow circles = not detected).

3.3 Occupancy

Occupancy models were constructed for the 20 most abundant mammal taxa, from *B. penicillata* with 10,362 independent detection events to *S. scrofa* with 43 in the first camera/bait trial only. Species occupancy estimates were substantially greater than naïve occupancy estimates for more than half of the species examined (i.e. those species that had lower detection probabilities; Table 3). Average occupancy estimates (psi) ranged from 0.34 to 0.99 and average detection probabilities (p) over 2-day survey periods ranged from 0.09 to 0.89. The best model for most species indicated that the five aggregated Landscape Conservation Unit (LCU) categories ('Yornup Wilgarup Perup' (YWP), 'Southern Hilly Terrain' (SHT), 'South Eastern Upland' (SEU), 'Northern Karri' (NK) and 'Strachan Cattaminup Jigsaw' (SCJ)) helped to explain variation in occupancy rates between sites. All but three of the species' best models (*Trichosurus vulpecula hypoleucus* (koomal or common brushtail possum), *Mus musculus* (house mouse) and *Rattus rattus* (black rat)) included treatment as an explanatory factor in detection probability (p), as was expected. Survey round was also included as an explanatory factor in detection probability (p) in most of the best models for each species.

Table 3. *Summary of occupancy and detection probability statistics for mammals detected by camera trapping in the southern jarrah forest, Western Australia (September 2016 – November 2017).*

Species: Scientific name	**Naïve occupancy (all available data)**	**Naïve occupancy (20 days per site)**	**Occupancy (psi) average across sites (SD)**	**2-day Detection probability (p) average across sites (SD)**	**Best model**
Antechinus flavipes	0.475	0.475	0.731 (0.186)	0.265 (0.261)	psi(AggLCU)p(Treatment P AggLCU)
Bettongia penicillata	0.375	0.375	0.401 (0.411)	0.888 (0.278)	psi(AggLCU)p(Treatment P AggLCU)
Dasyurus geoffroii	0.575	0.575	0.609 (0.378)	0.589 (0.350)	psi(AggLCU)p(Treatment X Round)
Felis catus	0.675	0.65	0.988 (0.008)	0.117 (0.060)	psi()p(Treatment)
Isoodon fusciventer	0.725	0.725	0.856 (0.256)	0.481 (0.335)	psi(AggLCU)p(Treatment X Round)
Macropus fuliginosus	0.95	0.95	0.972 (0.015)	0.659 (0.226)	psi()p(Treatment X AggLCU)
Mus musculus	0.325	0.275	0.602 (0.208)	0.220 (0.295)	psi(Treatment)p(Round)
Myrmecobius fasciatus	0.275	0.275	0.565 (0.192)	0.255 (0.219)	psi(Treatment)p(Treatment P AggLCU)
Notamacropus eugenii derbianus	0.325	0.325	0.342 (0.342)	0.752 (0.269)	psi(AggLCU)p(Treatment P Round)
Notamacropus irma	0.7	0.675	0.759 (0.156)	0.627 (0.299)	psi(AggLCU)p(Treatment X Round)
Phascogale tapoatafa wambenger	0.55	0.475	0.687 (0.186)	0.265 (0.198)	psi(AggLCU)p(Treatment X Round)
Pseudocheirus occidentalis	0.275	0.25	0.555 (0.483)	0.171 (0.252)	psi(AggLCU)p(Treatment P Round)
Rattus fuscipes	0.525	0.525	0.559 (0.336)	0.632 (0.296)	psi(AggLCU)p(Treatment X AggLCU)
Rattus rattus	0.525	0.45	0.748 (0.039)	0.304 (0.315)	psi()p(AggLCU)
Setonix brachyurus	0.575	0.55	0.585 (0.382)	0.687 (0.336)	psi(AggLCU)p(Treatment X Round)
Sminthopsis spp.	0.825	0.775	0.858 (0.162)	0.509 (0.265)	psi(AggLCU)p(Treatment X Round)
Sus scrofa	0.3	0.3	0.765 (0.043)	0.092 (0.146)	psi()p(Treatment P Round)
Tachyglossus aculeatus	0.3	0.3	0.408 (0.004)	0.320 (0.271)	psi()p(Treatment P Round)
Trichosurus vulpecula	0.725	0.625	0.648 (0.247)	0.630 (0.287)	psi(AggLCU)p(AggLCU)
Vulpes vulpes	0.675	0.65	0.942 (0.031)	0.179 (0.137)	psi()p(Treatment X Round)

3.4 Spatial activity patterns

Variations and patterns in species activity, inferred from the rate of independent detection events (adjusted for differences in detection probability and survey effort; Appendix 1) are evident from the spatial interpolation models using IDW methods (Figures 16 - 53). The Upper Warren region (UWR) had peak activity centres for many species including *B. penicillata*, *D. geoffroii*, *I. fusciventer*, *Macropus fuliginosus* (yongka or western grey kangaroo), *My. fasciatus*, *N. eugenii*, *Ph. tapoatafa*, *Ps. occidentalis*, *S. scrofa*, *Tac. aculeatus*, *Tr. vulpecula* and *V. vulpes*. More prevalent in the western areas of SJF were the *A. flavipes*, *Mu. musculus* and *R. rattus*. *Felis catus*, *R. fuscipes* and *S. brachyurus* were most active in the southern SJF. *Sminthopsis spp.* activity was most prevalent in the eastern and north eastern margins of the SJF and *N. irma* activity was widespread across the study area with a relatively very high peak of activity at Easter block in the western node.

Species richness of threatened mammals (*Critically Endangered, Endangered, Vulnerable*), Priority 4 species, medium-sized native mammals (MSM) and all native mammals was clearly greatest in the UWR (Figures 36, 39, 45, and 48, respectively). Species richness of arboreal mammals was similarly greatest in the UWR but also in the adjacent eastern part of the study area's western node (i.e. Carter block; Figure 42). Meribup had the highest number of threatened and MSM species and the only site to have all 15 of the mammal species involved in spatial interpolation.

The areas of peak combined activity for these mammal groups were also all in the UWR, however they tended to be more localised. For instance, the greatest combined activity of threatened mammals, MSM and all native mammals was greatest in the north east of UWR (Figures 37, 46, 49, respectively; mostly due to high detection rates of *B. penicillata*), and Priority 4 and arboreal species were greatest in the north of UWR (Figures 40, and 43, respectively).

The areas of high relative activity were generally more widespread than those for the combined activity for the same species groupings, because each species had effectively equal weighting in the relative activity metric (i.e. it incorporates species richness to some extent in the metric). The relative activity for threatened mammals was greatest in the central and north eastern parts of the UWR (Figure 38). The heatmap for the relative activity of Priority 4 species incorporates the peak activity site for each of the species in this group (Figure 41); *N. irma* at Easter block in the western node, the peak *N. eugenii* activity areas in northern UWR and the *I. fusciventer* peak in central UWR (Weinup). The peak areas of relative activity of arboreal mammals was widespread throughout the UWR (Figure 44) and slightly more confined to the central and northern areas of the UWR (with the distinct exception of Yackelup and Moopinup forest blocks) for MSM (Figure 47) and all native mammals (Figure 50).

Species richness of commonly encountered introduced mammals was relatively high across the entire SJF (Figure 51). The combined and relative activity of commonly-detected introduced mammals was particularly high at Ellis Creek because of a high detection rate of *R. rattus* and *Mu. musculus* (Figures 52 and 53). The relative activity of commonly-detected introduced mammals was greatest in Kingston and Dudijup in NW UWR and Ellis Creek and Carey in the western node. The relative activity of introduced mammals was highest in Kingston because all five species were present and included the highest recorded activity levels for *S. scrofa*, near highest activity of *V. vulpes* and above average activity of *F. catus* and *Mu. musculus*.

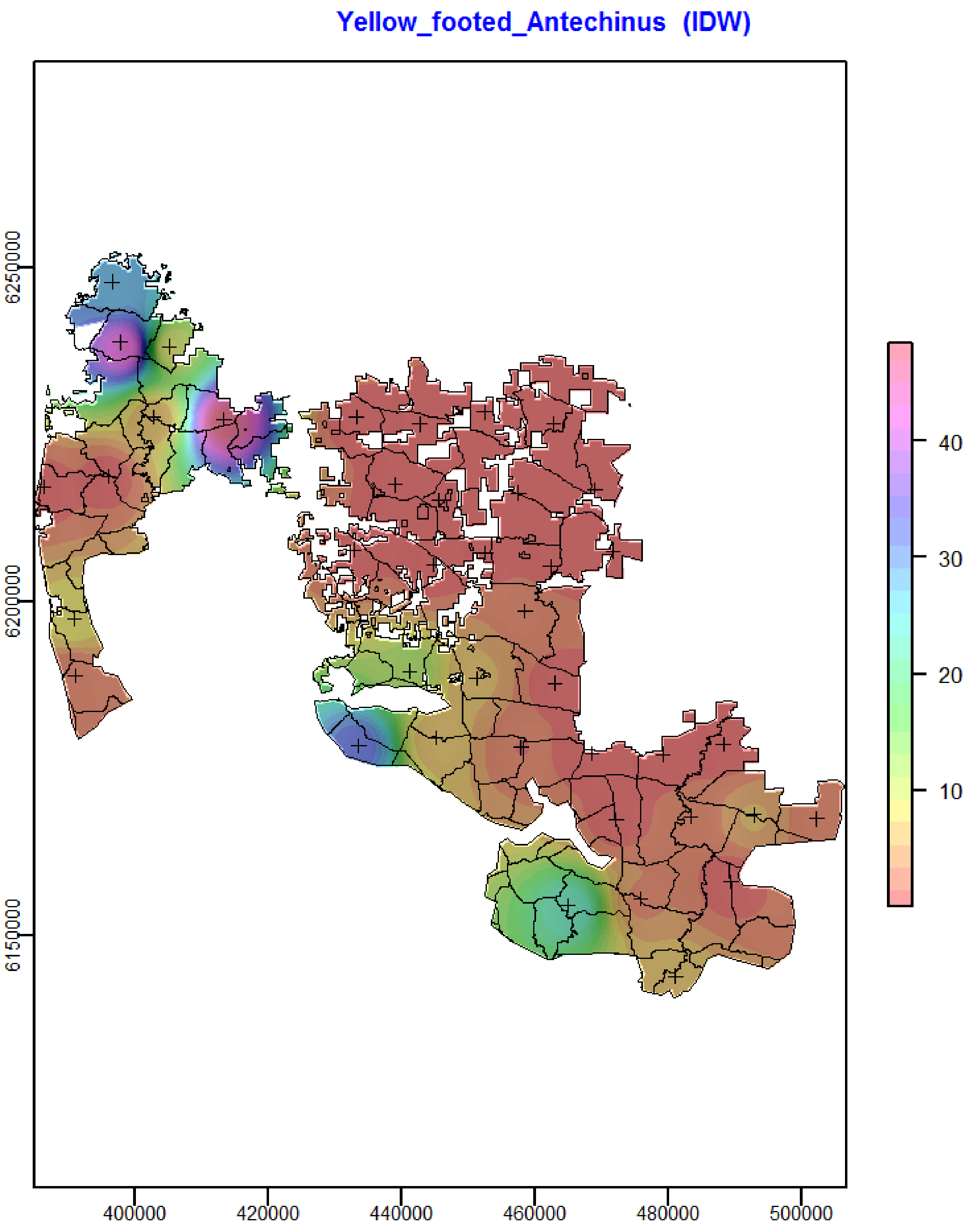

Figure 16. Antechinus flavipes activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

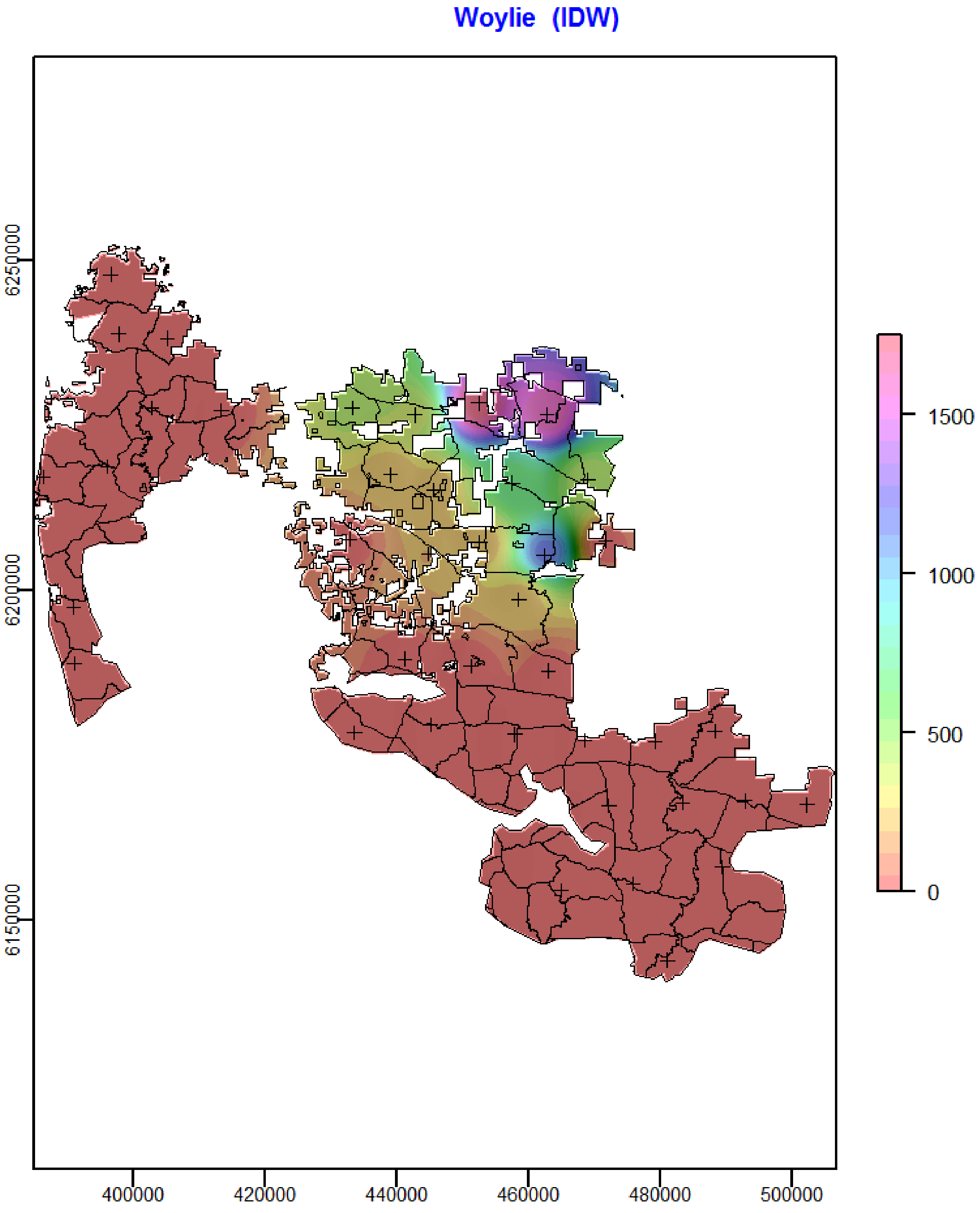

Figure 17. Bettongia penicillata activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

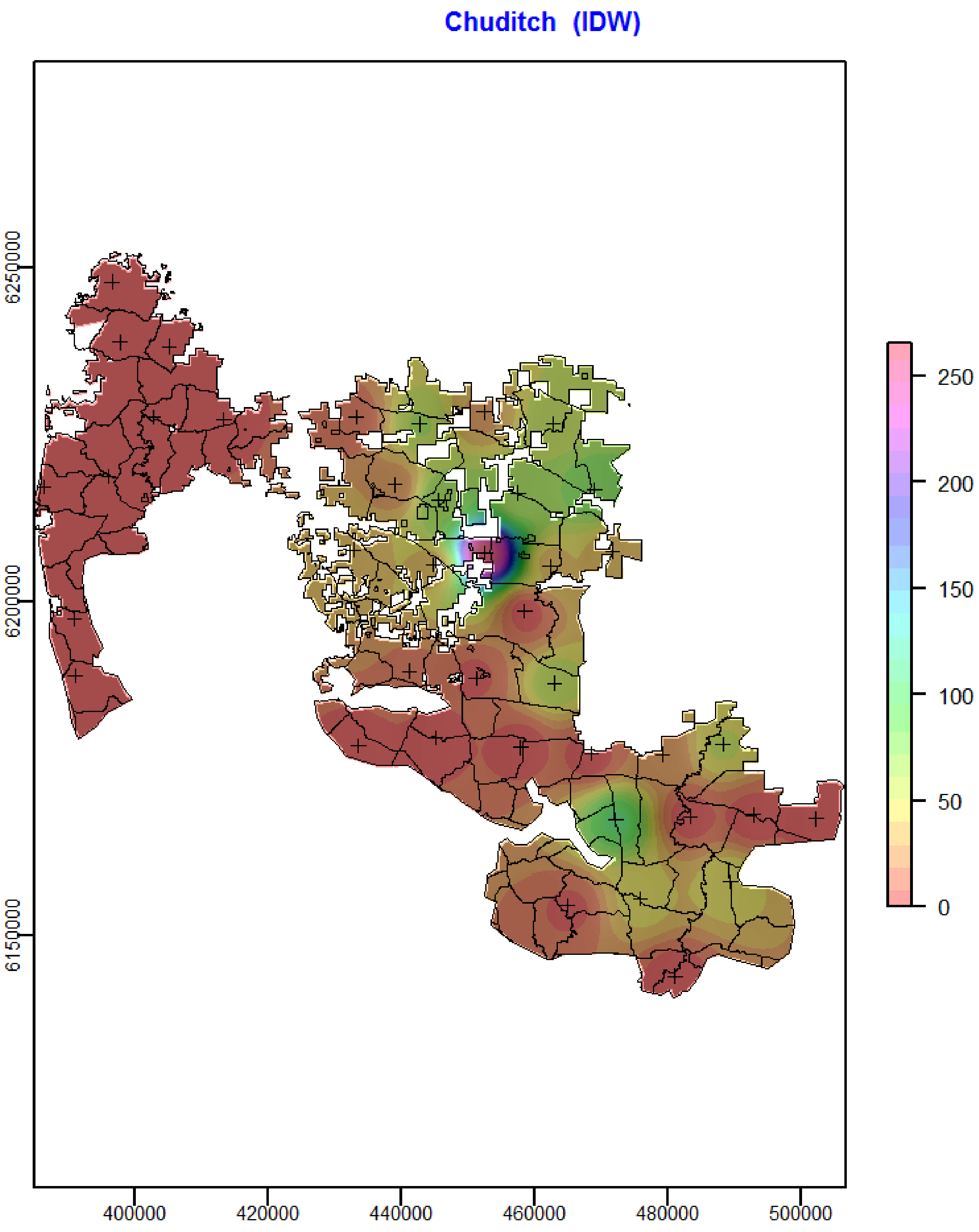

Figure 18. Dasyurus geoffroii activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

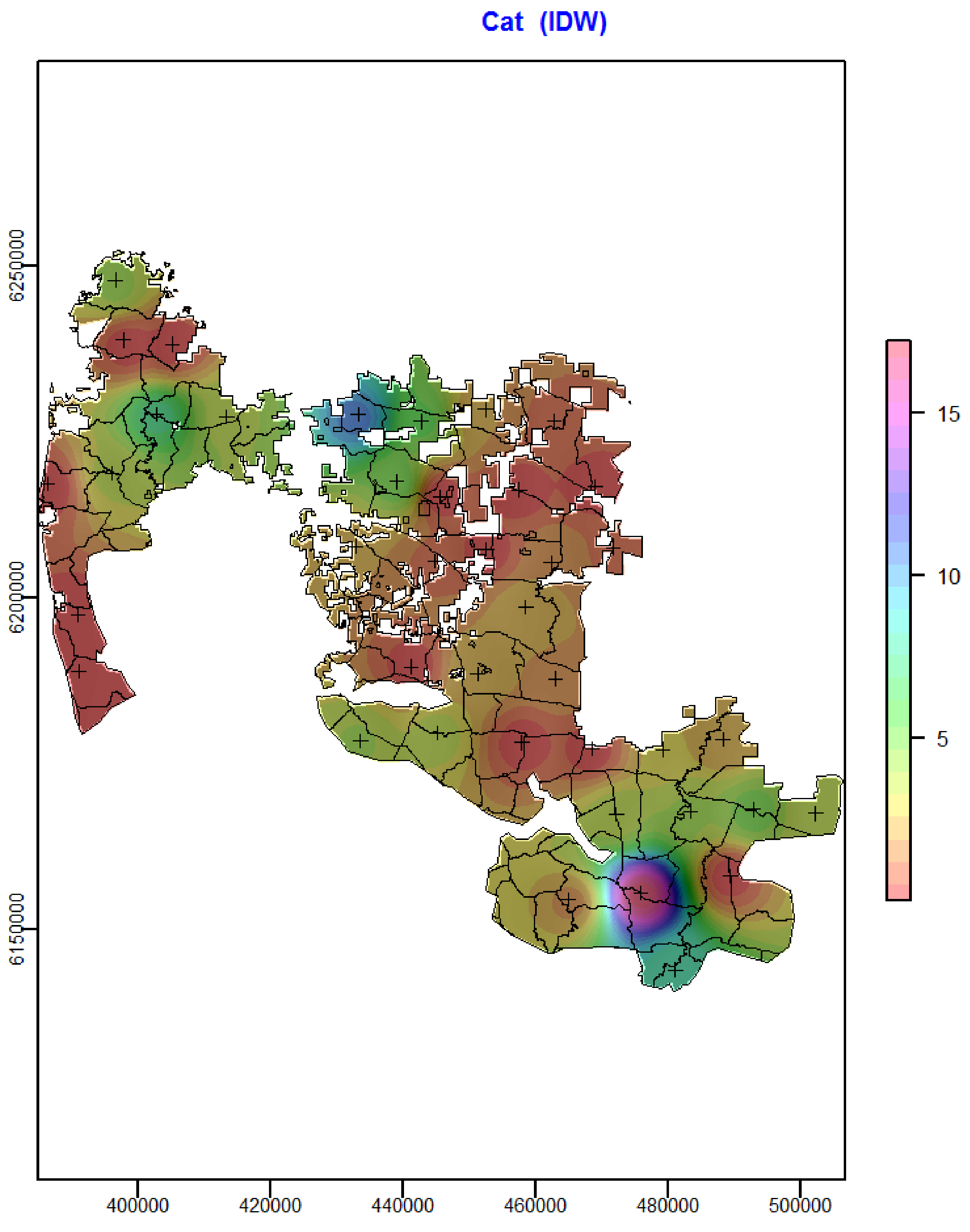

Figure 19. Felis catus activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

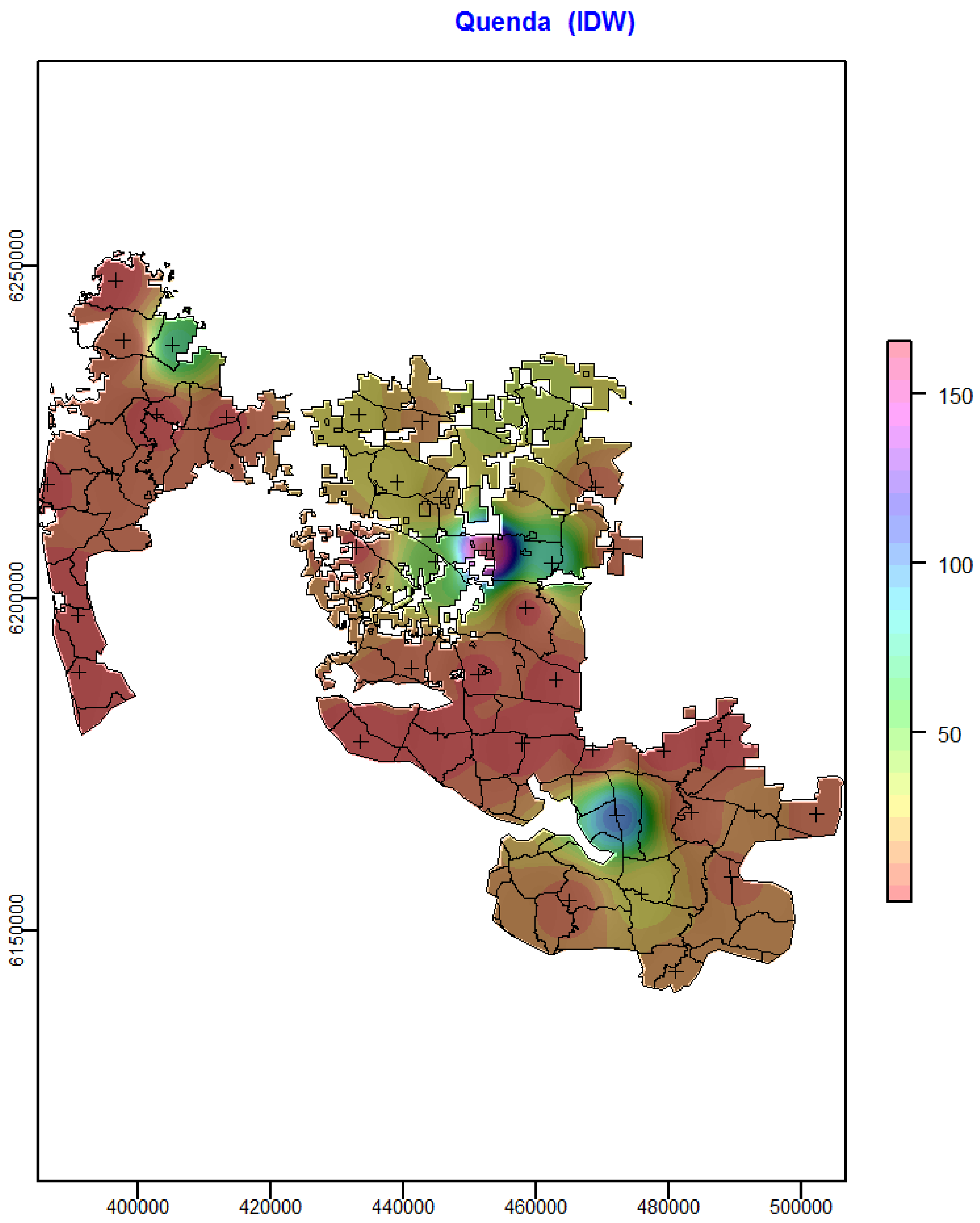

Figure 20. Isoodon fusciventer activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

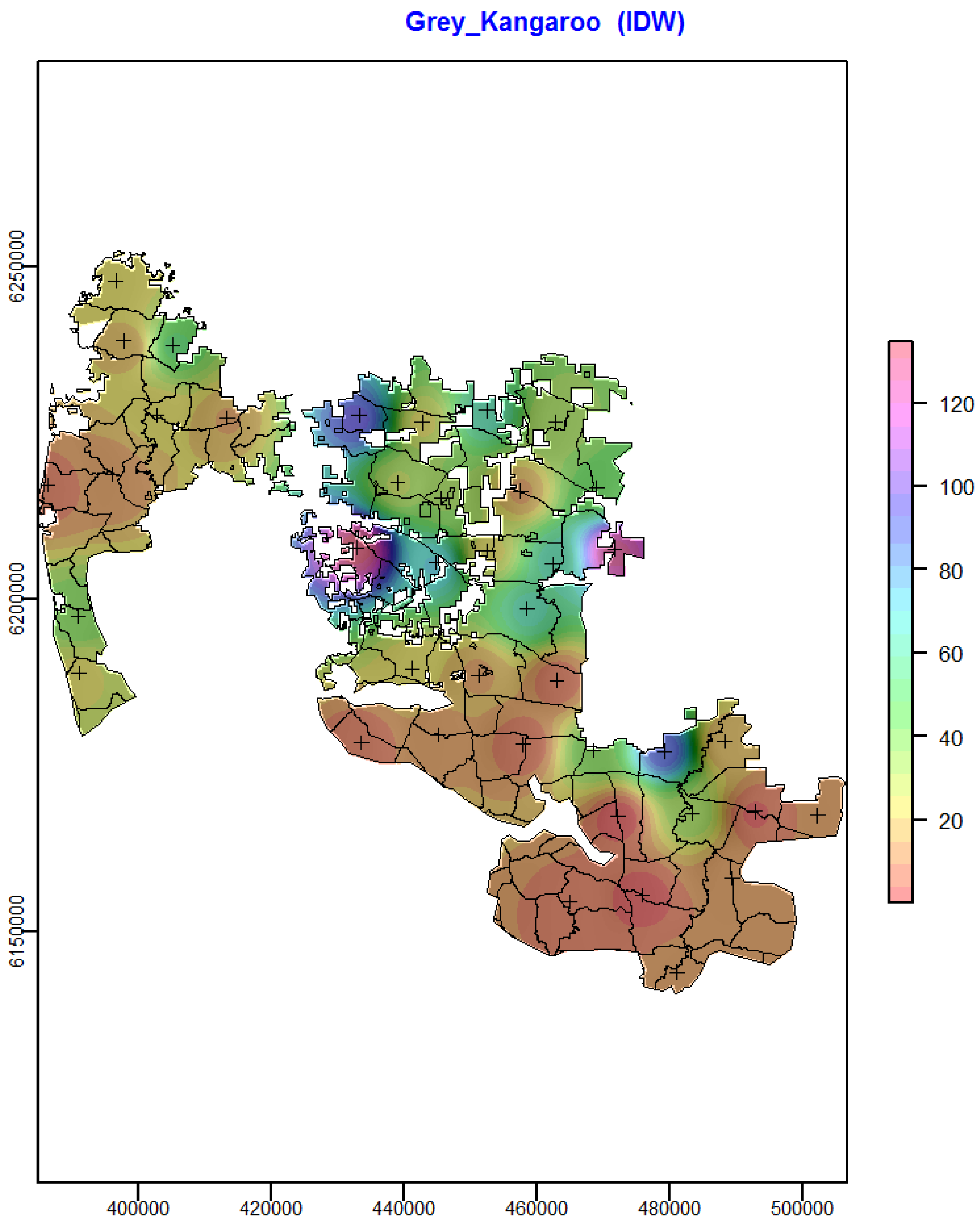

Figure 21. Macropus fuliginosus activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

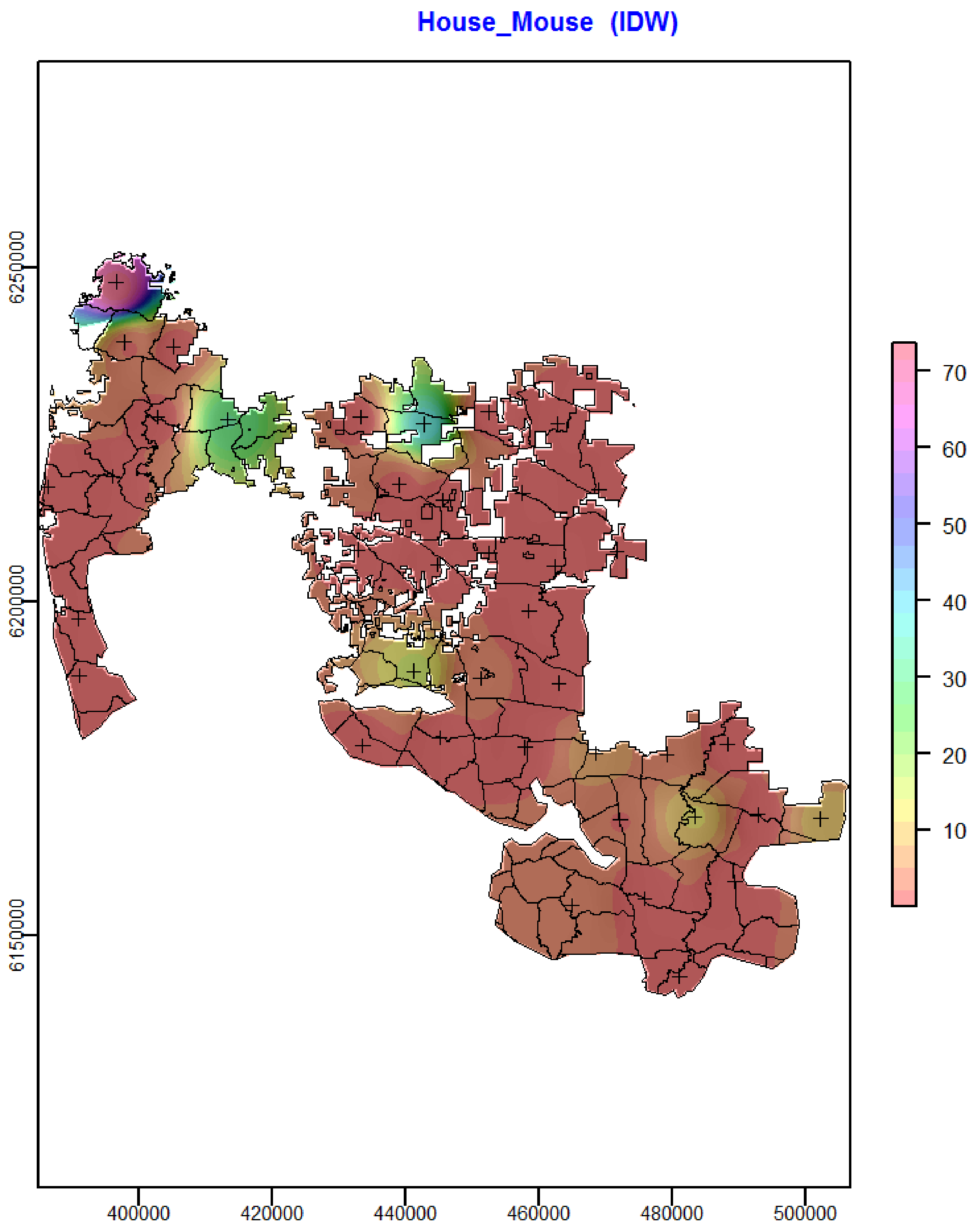

Figure 22. Mus musculus activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

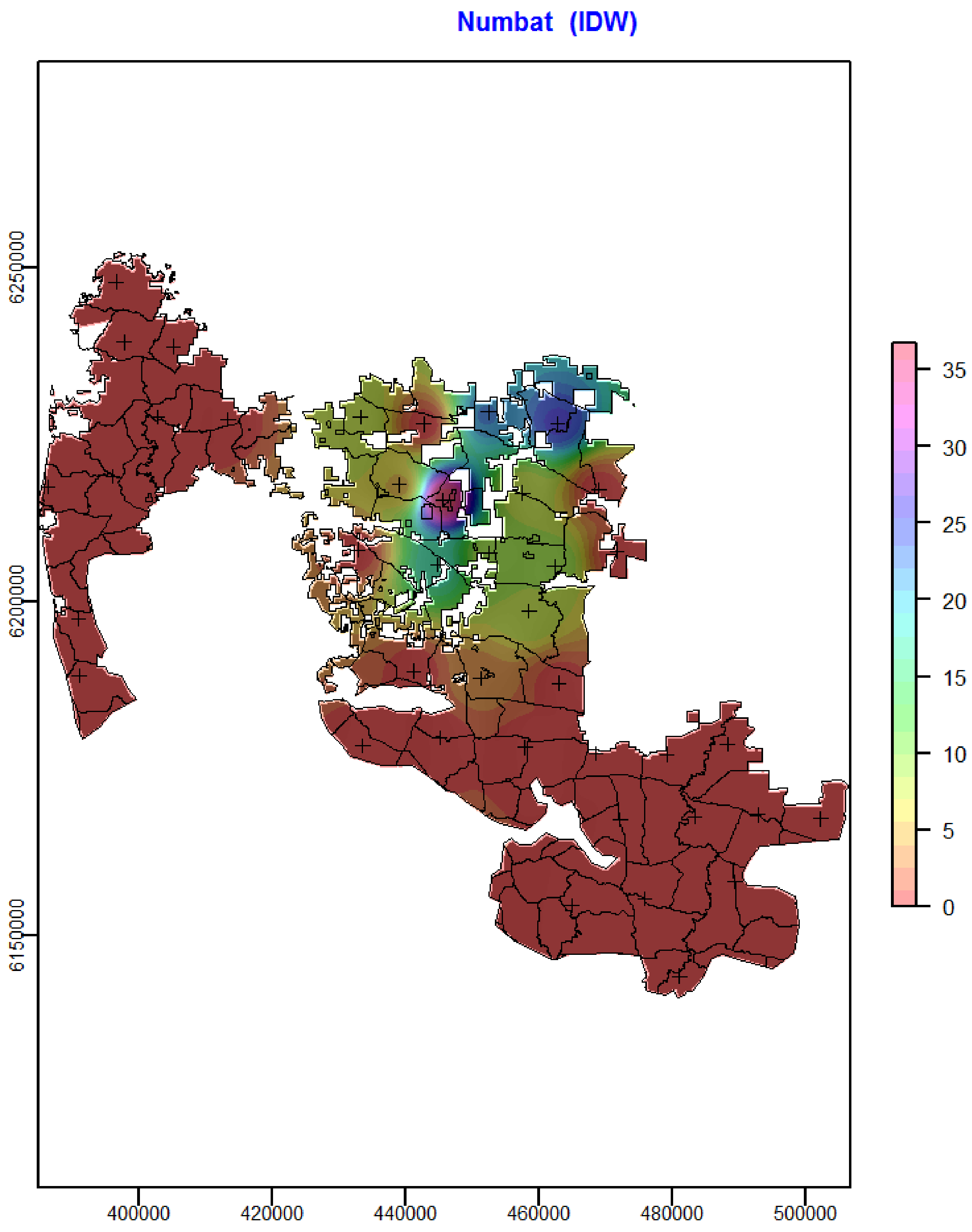

Figure 23. Myrmecobius fasciatus activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

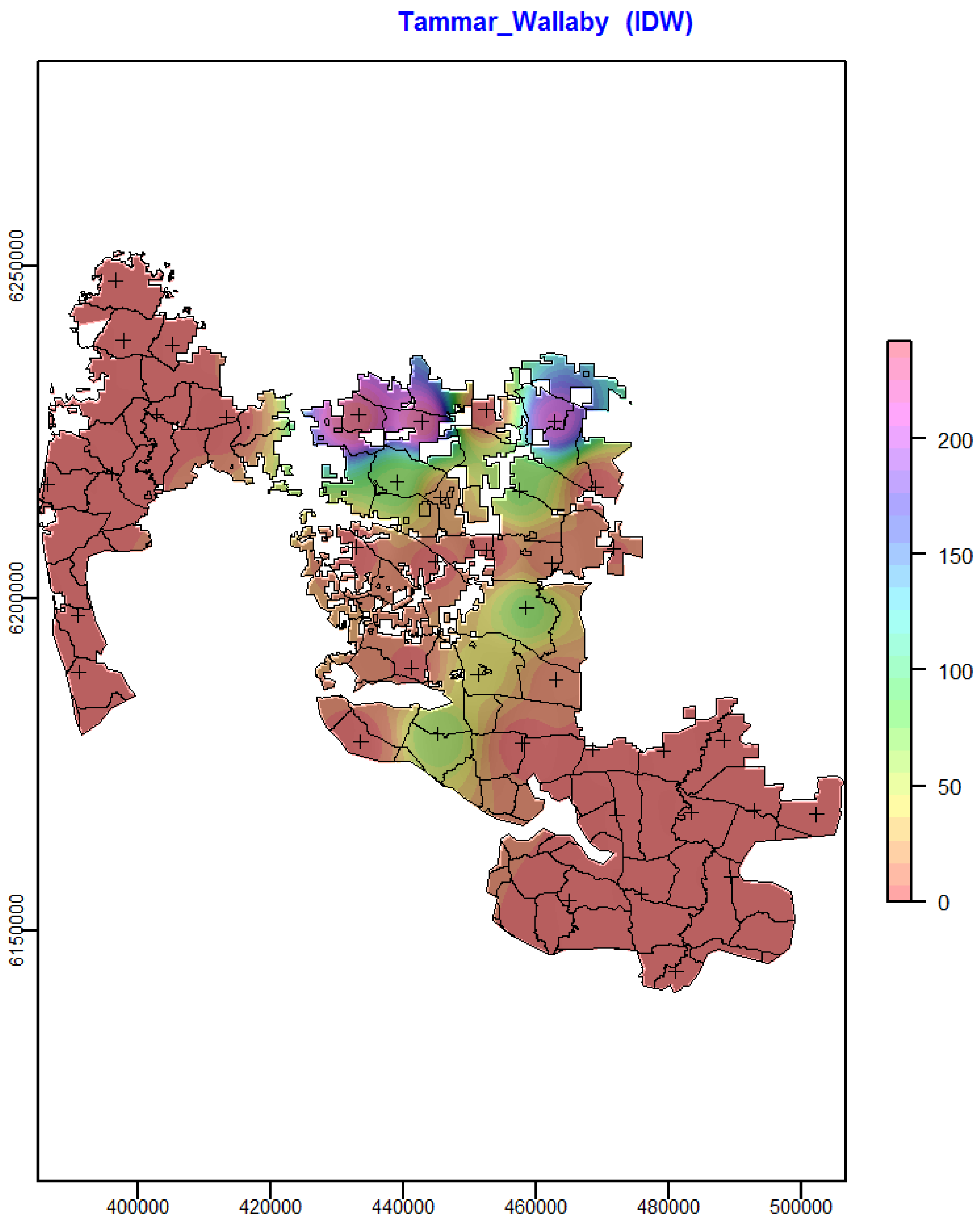

Figure 24. Notamacropus eugenii activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

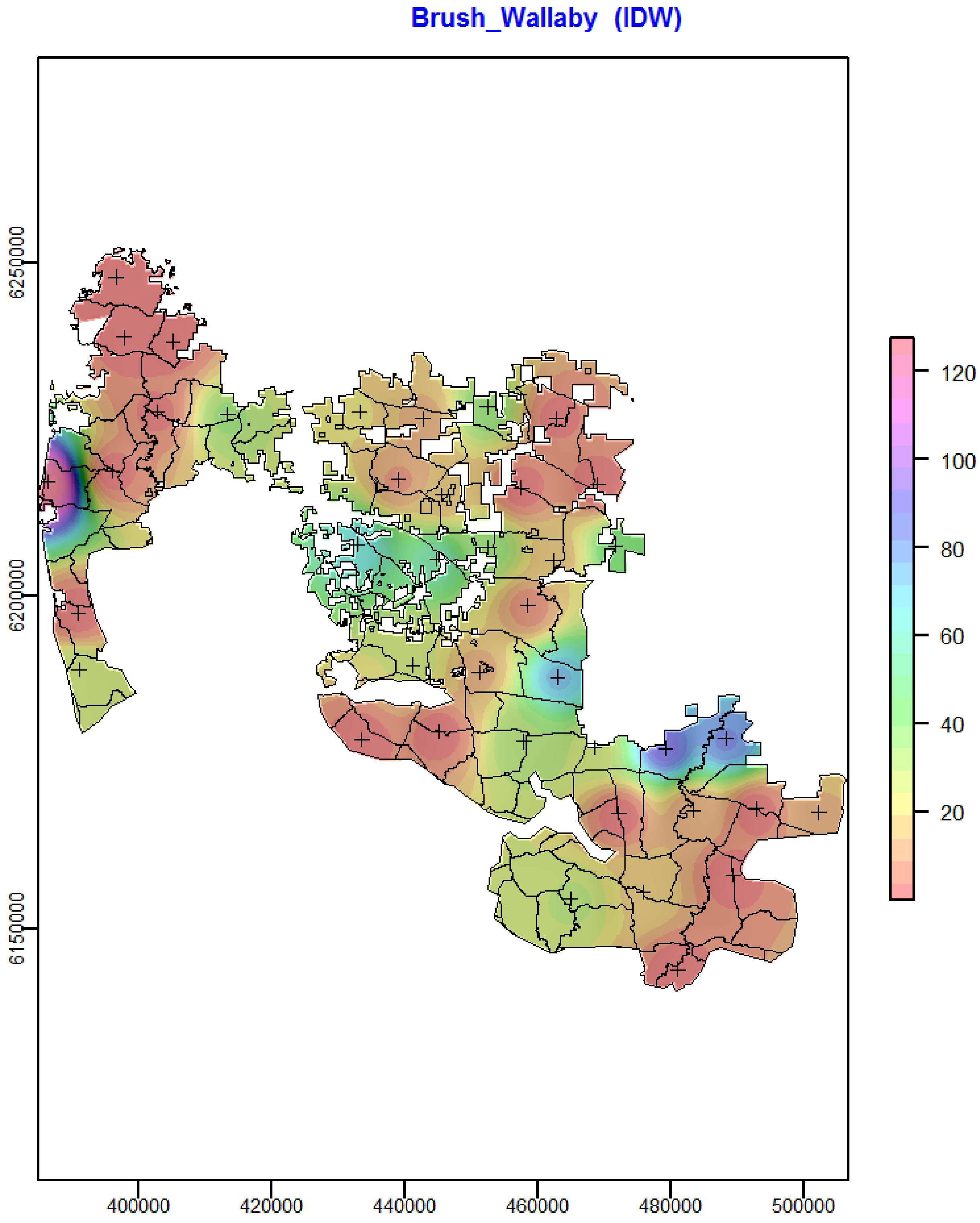

Figure 25. Notamacropus irma activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

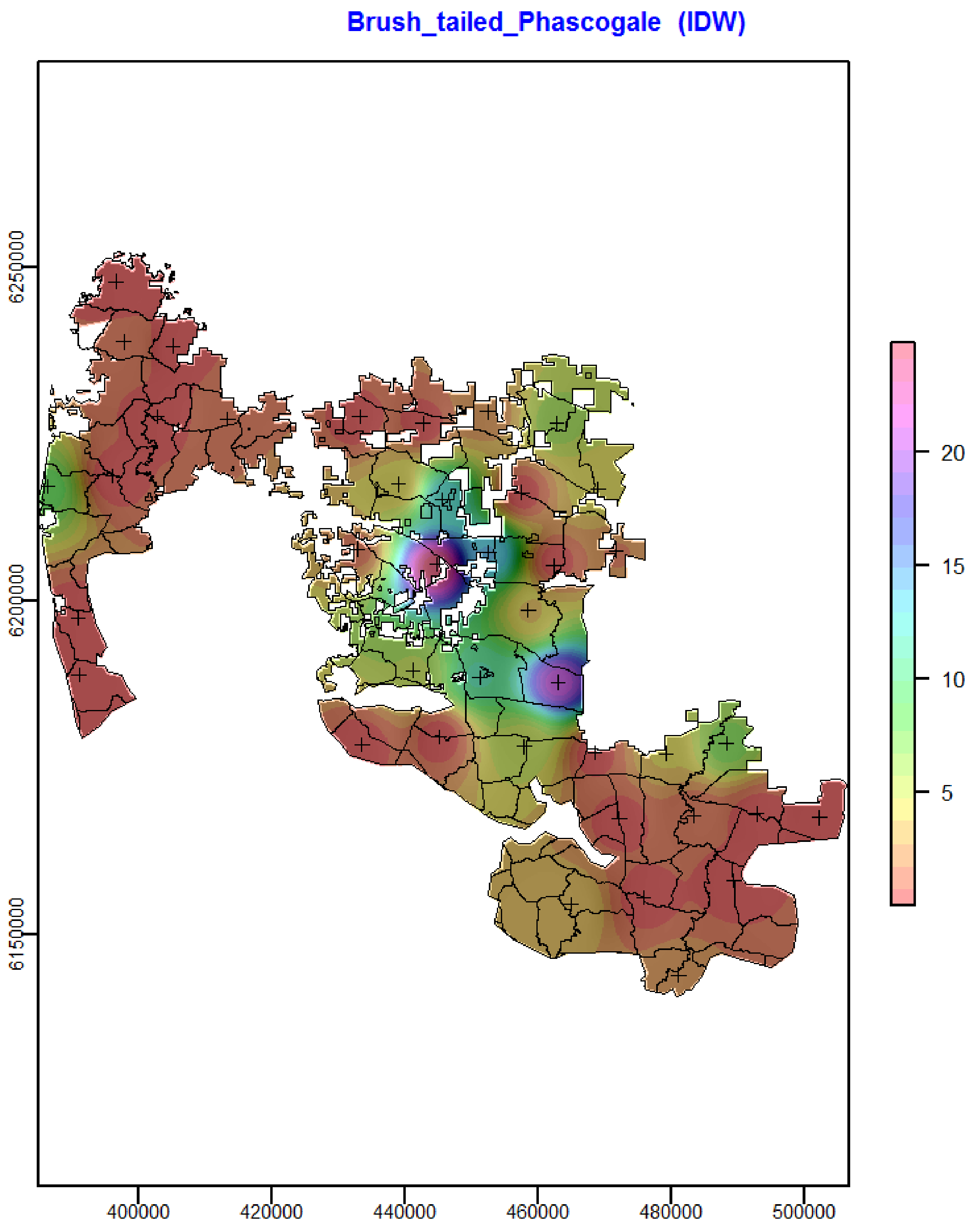

Figure 26. Phascogale tapoatafa wambenger activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

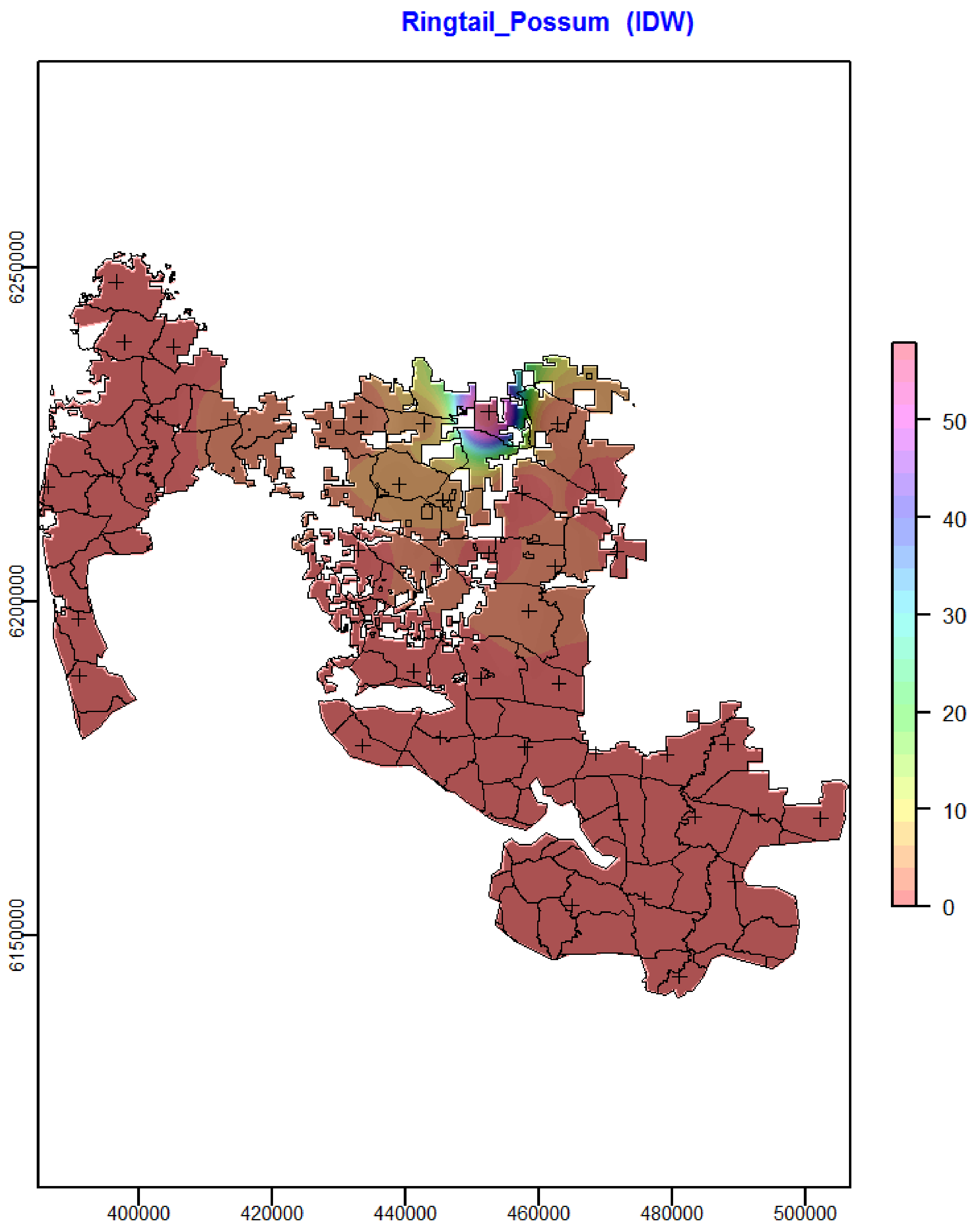

Figure 27. Pseudocheirus occidentalis activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

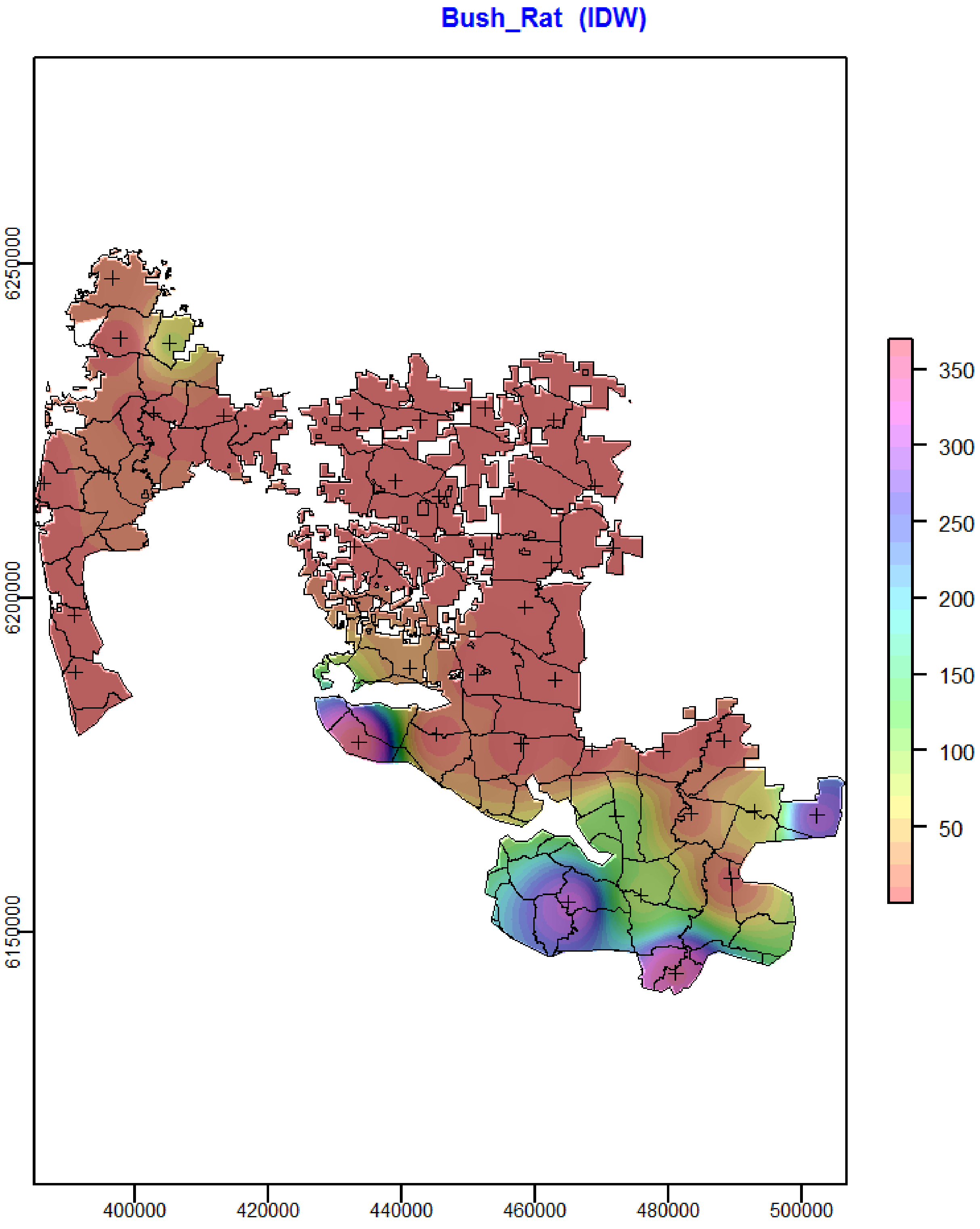

Figure 28. Rattus fuscipes activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

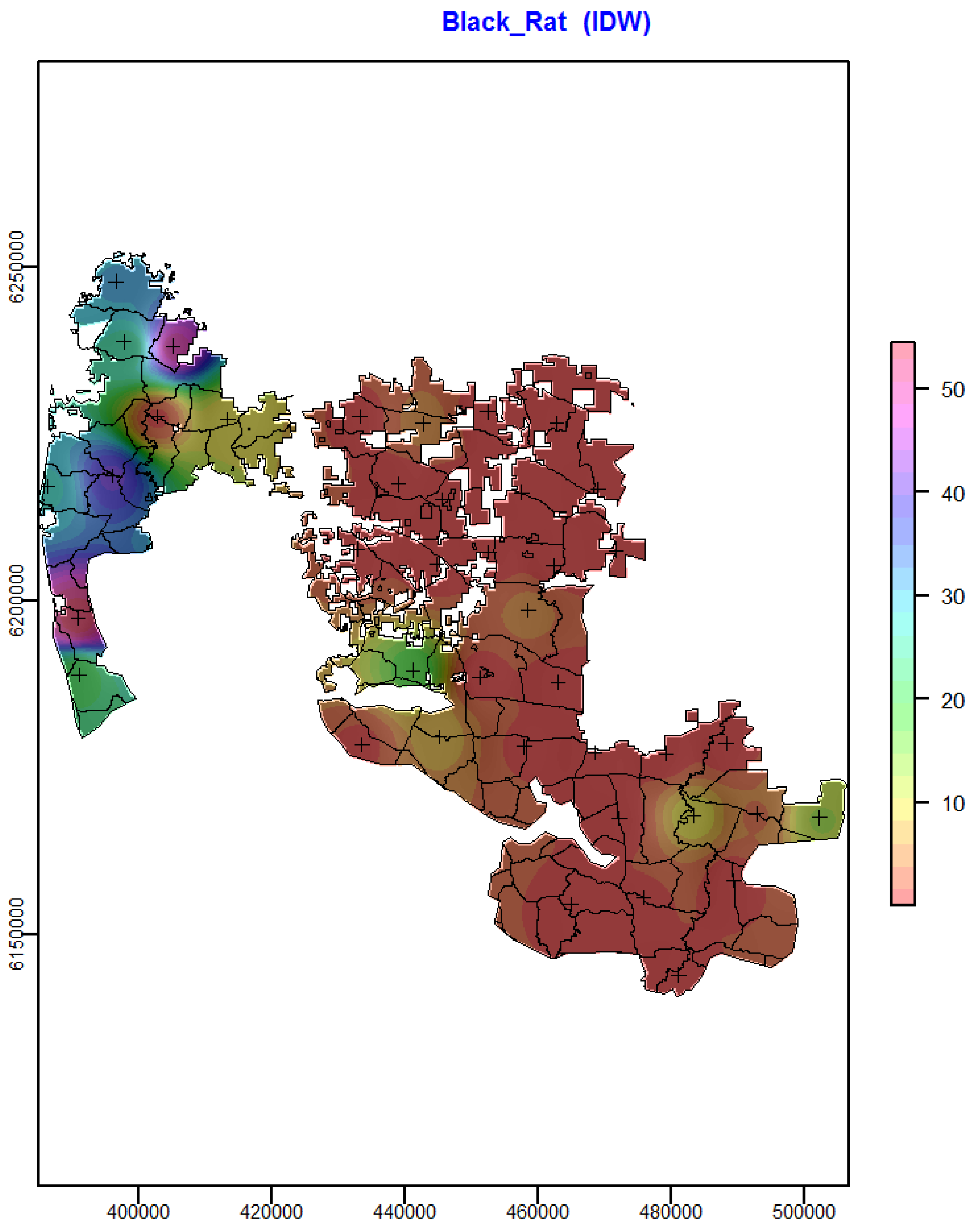

Figure 29. Rattus rattus activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

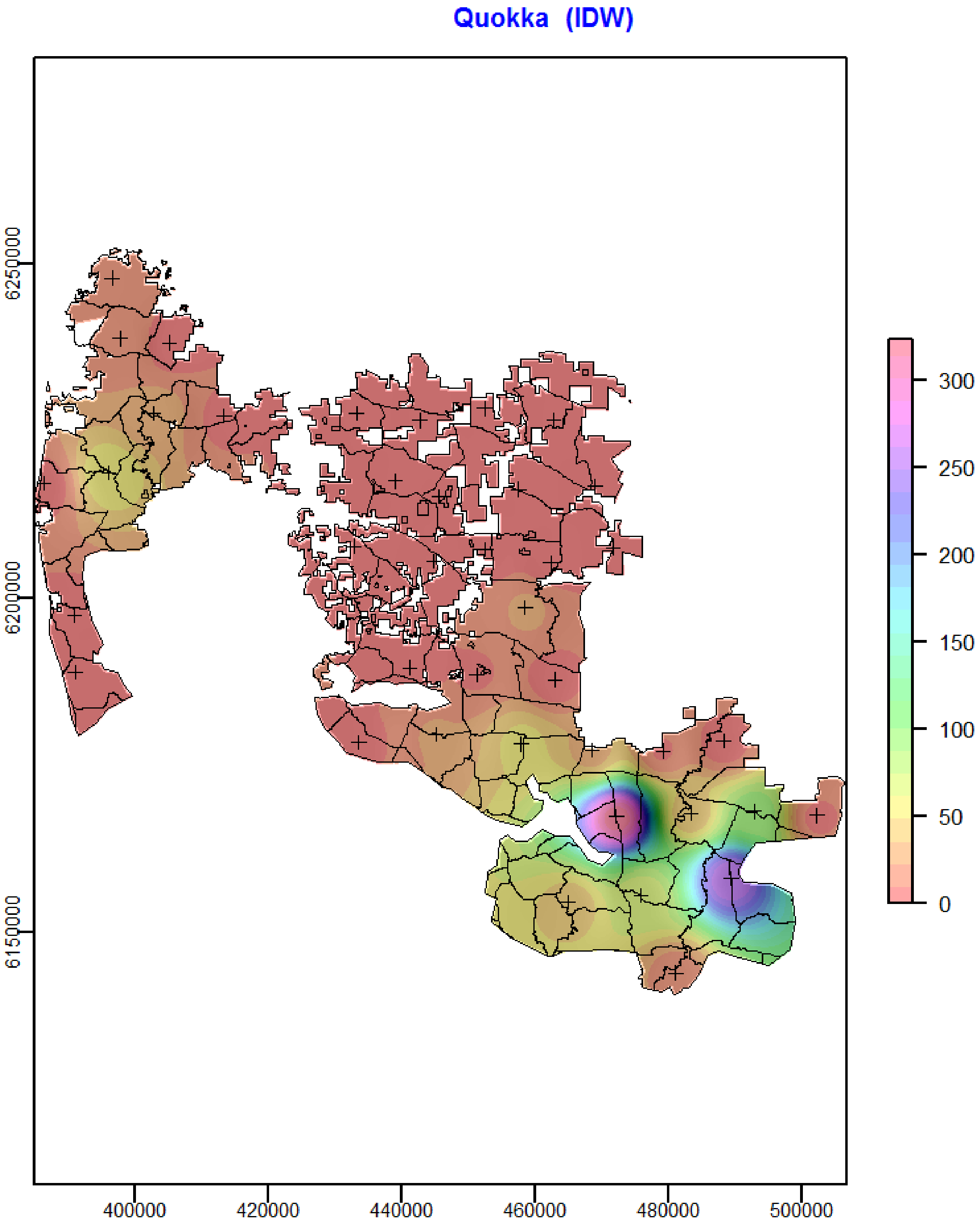

Figure 30. Setonix brachyurus activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

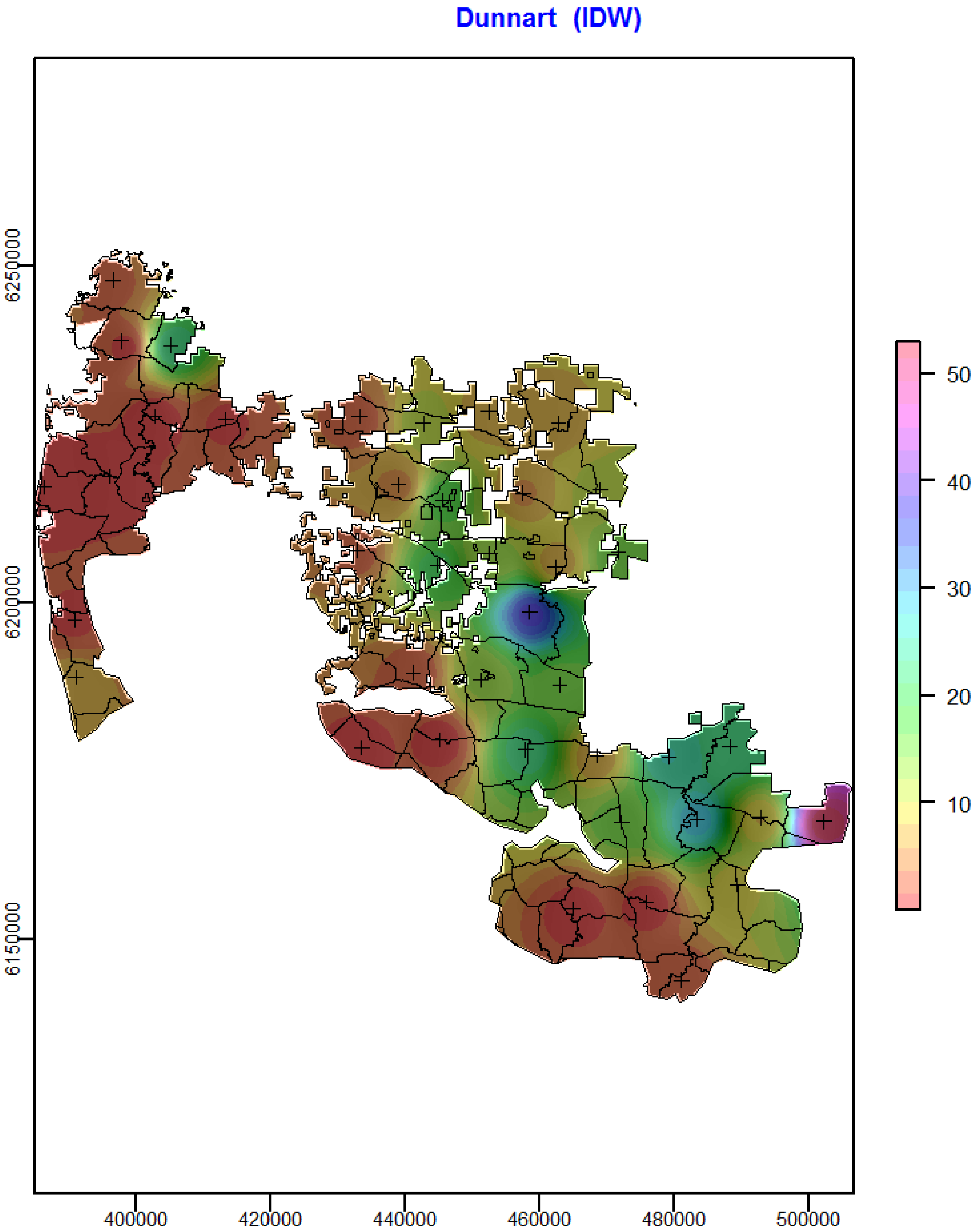

Figure 31. Sminthopsis spp. activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

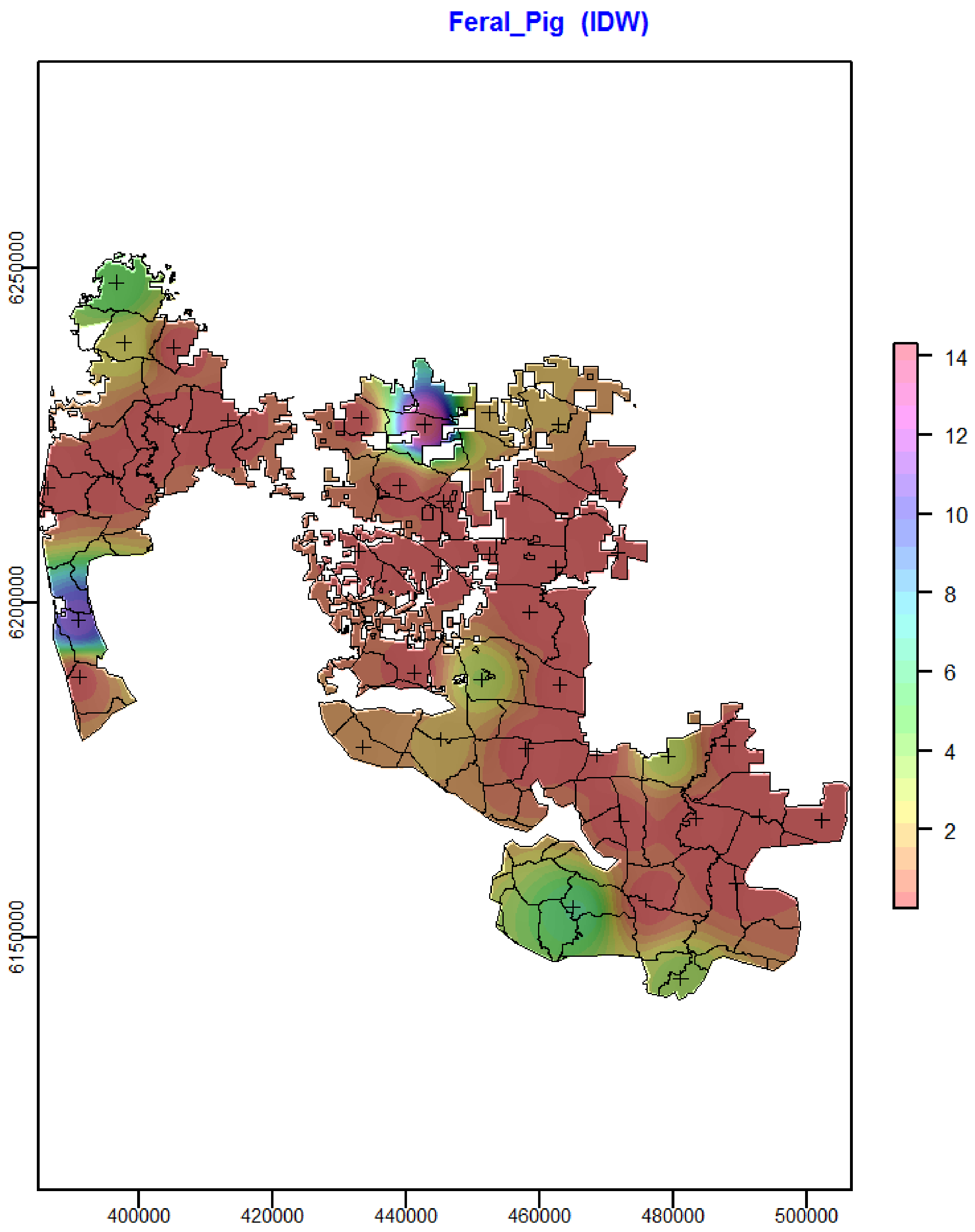

Figure 32. Sus scrofa activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

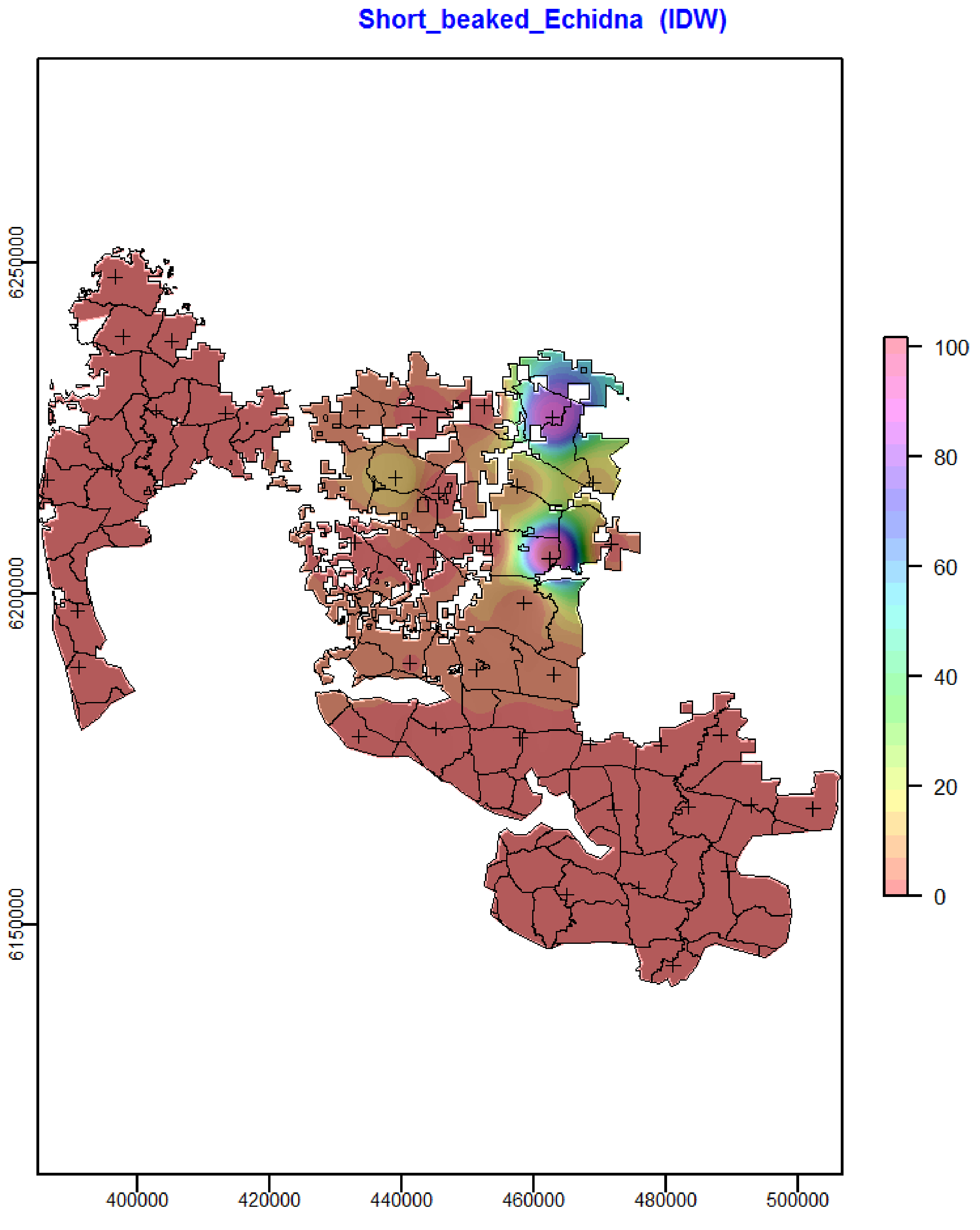

Figure 33. Tachyglossus aculeatus activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

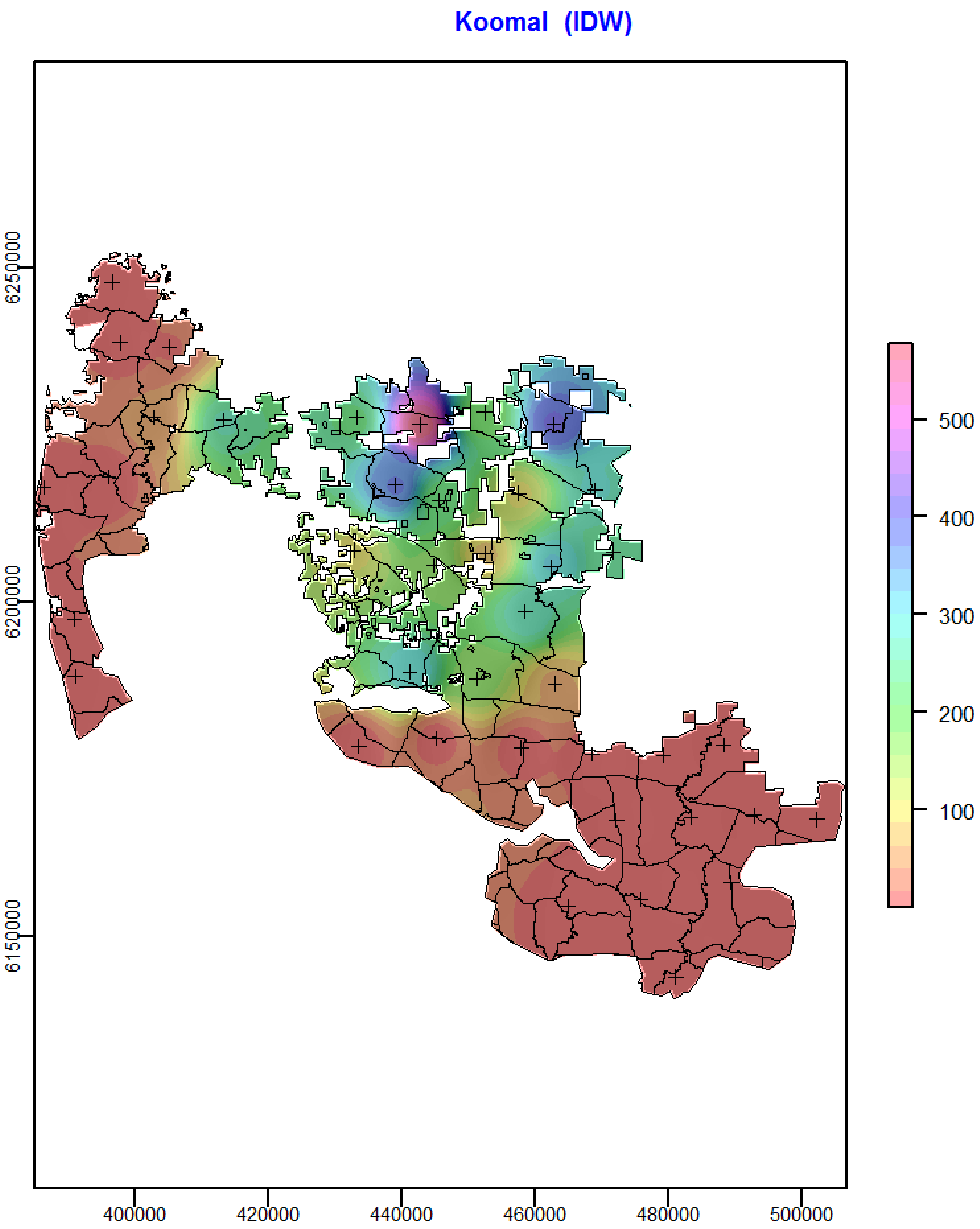

Figure 34. Trichosurus vulpecula activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

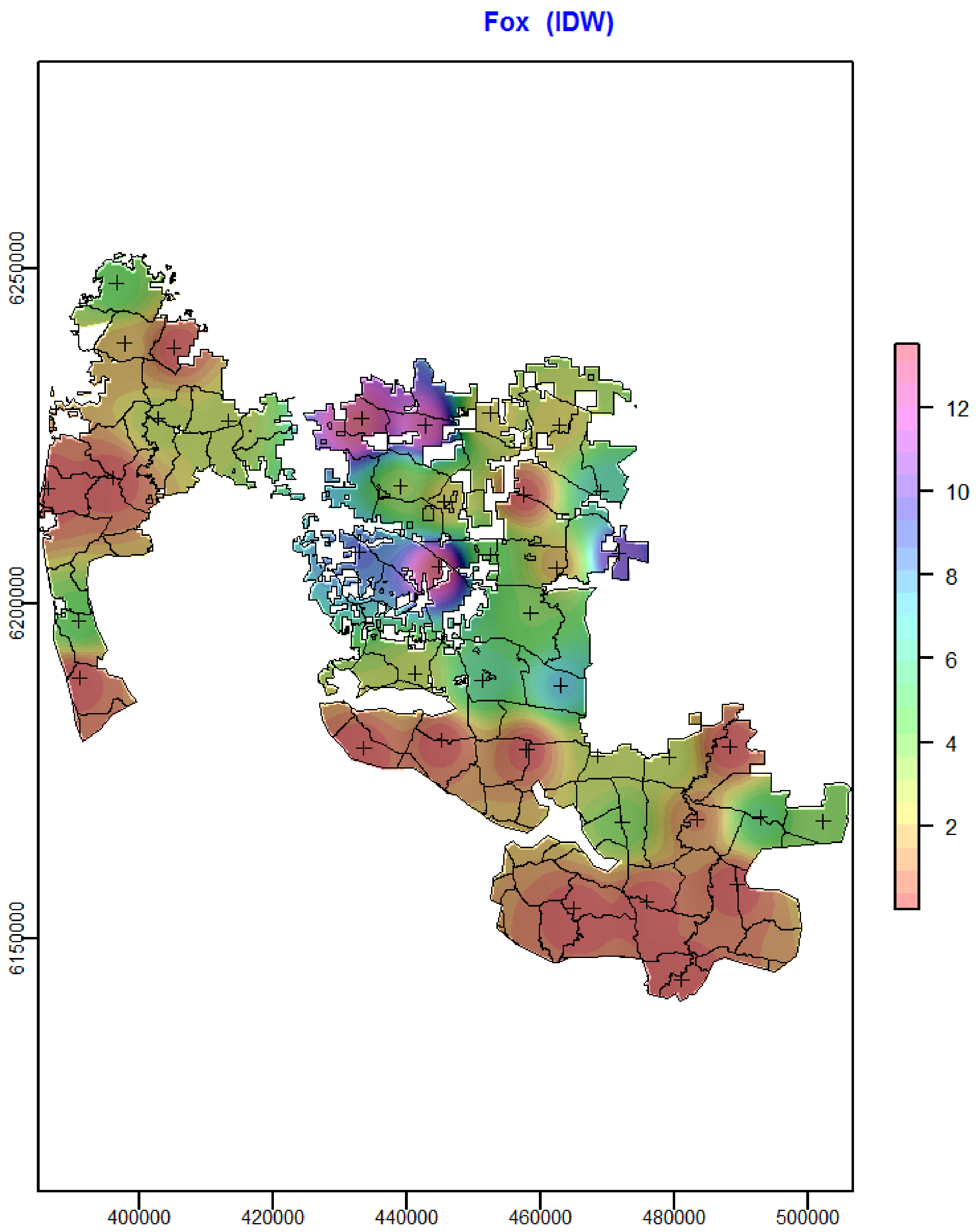

Figure 35. Vulpes vulpes activity across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation

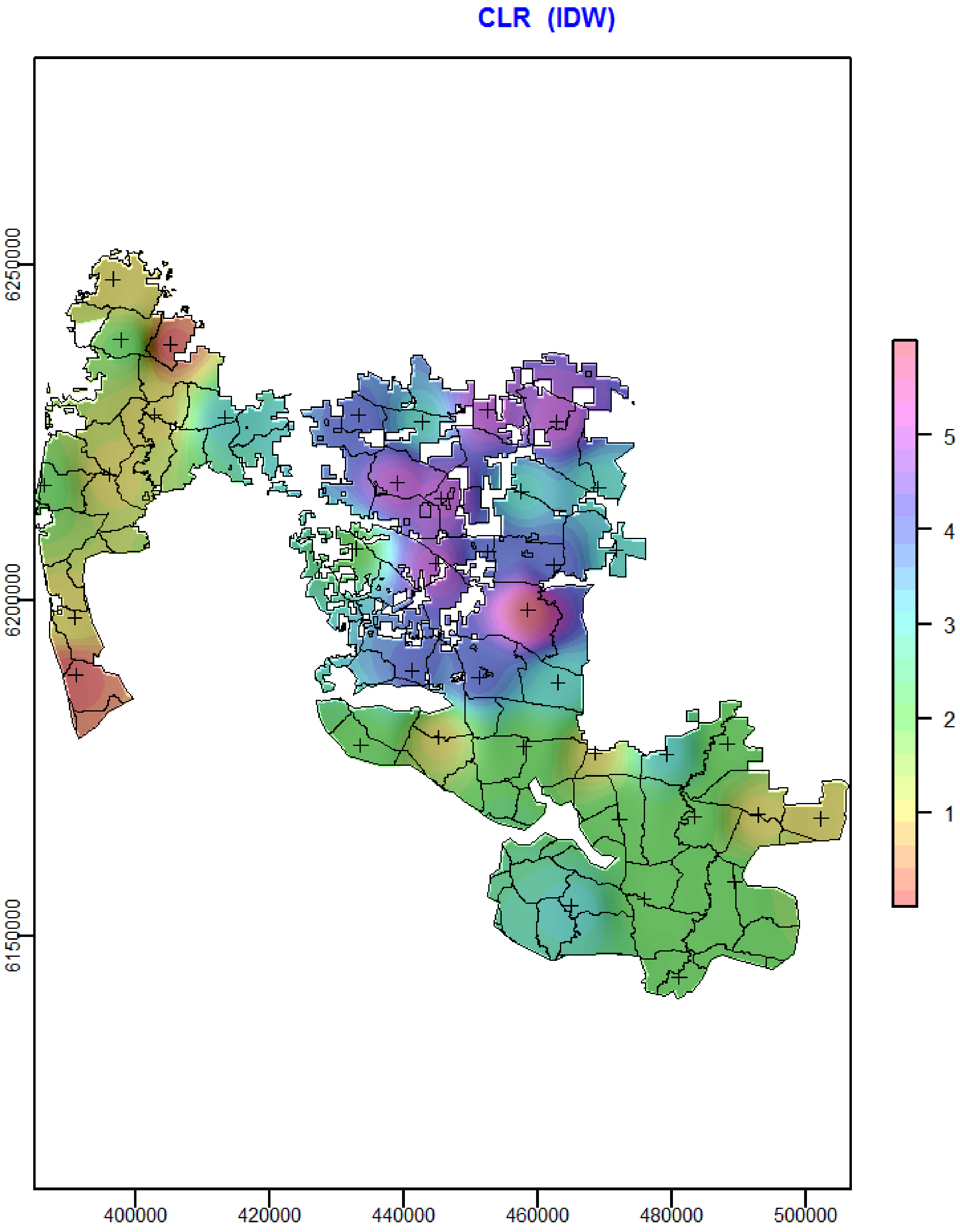

Figure 36. Species richness of threatened mammals (B. penicillata, D. geoffroii, M. fasciatus, Ph. tapoatafa wambenger, Ps. occidentalis, S. brachyurus) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

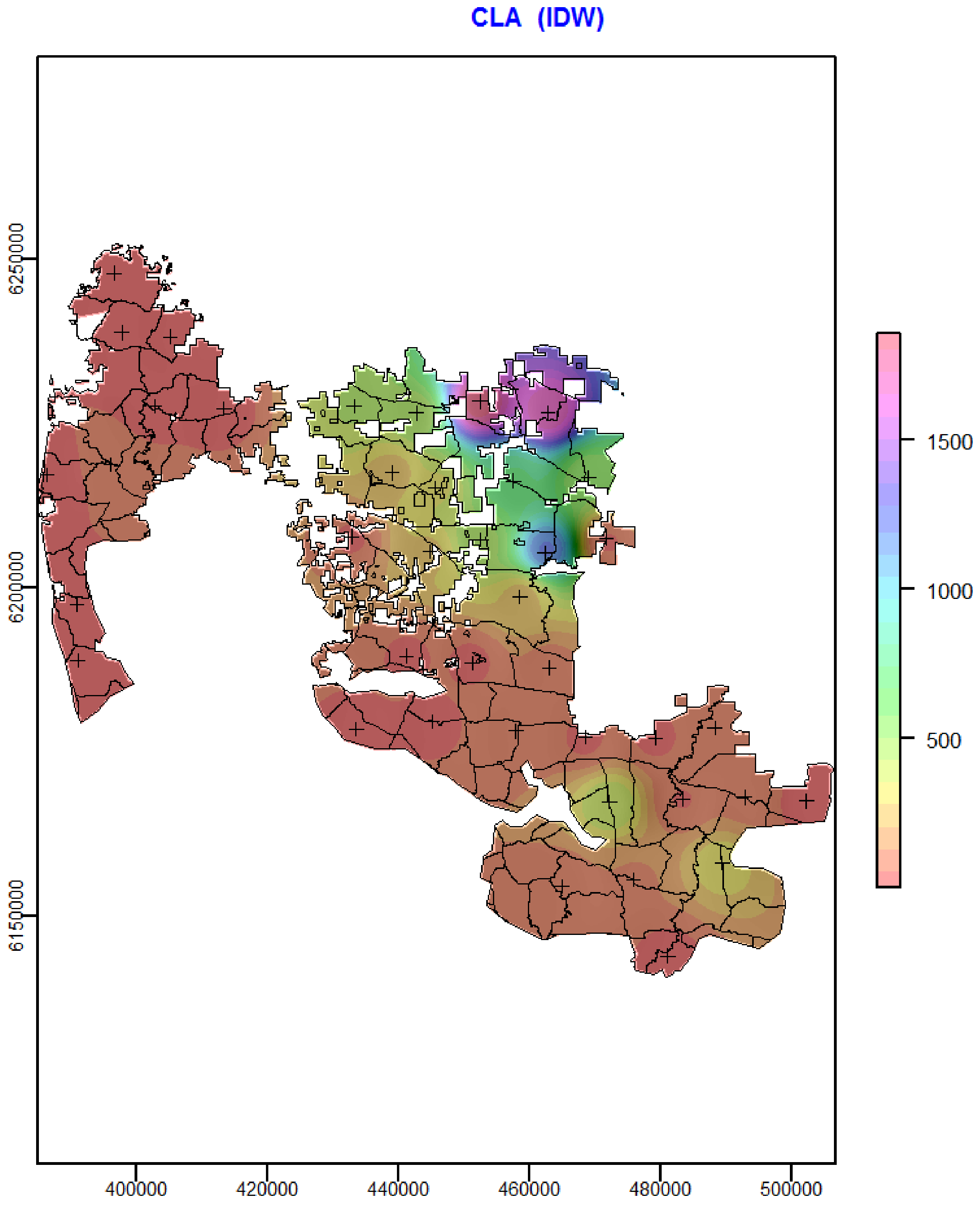

Figure 37. Combined activity of threatened mammals (B. penicillata, D. geoffroii, M. fasciatus, Ph. tapoatafa wambenger, Ps. occidentalis, S. brachyurus) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

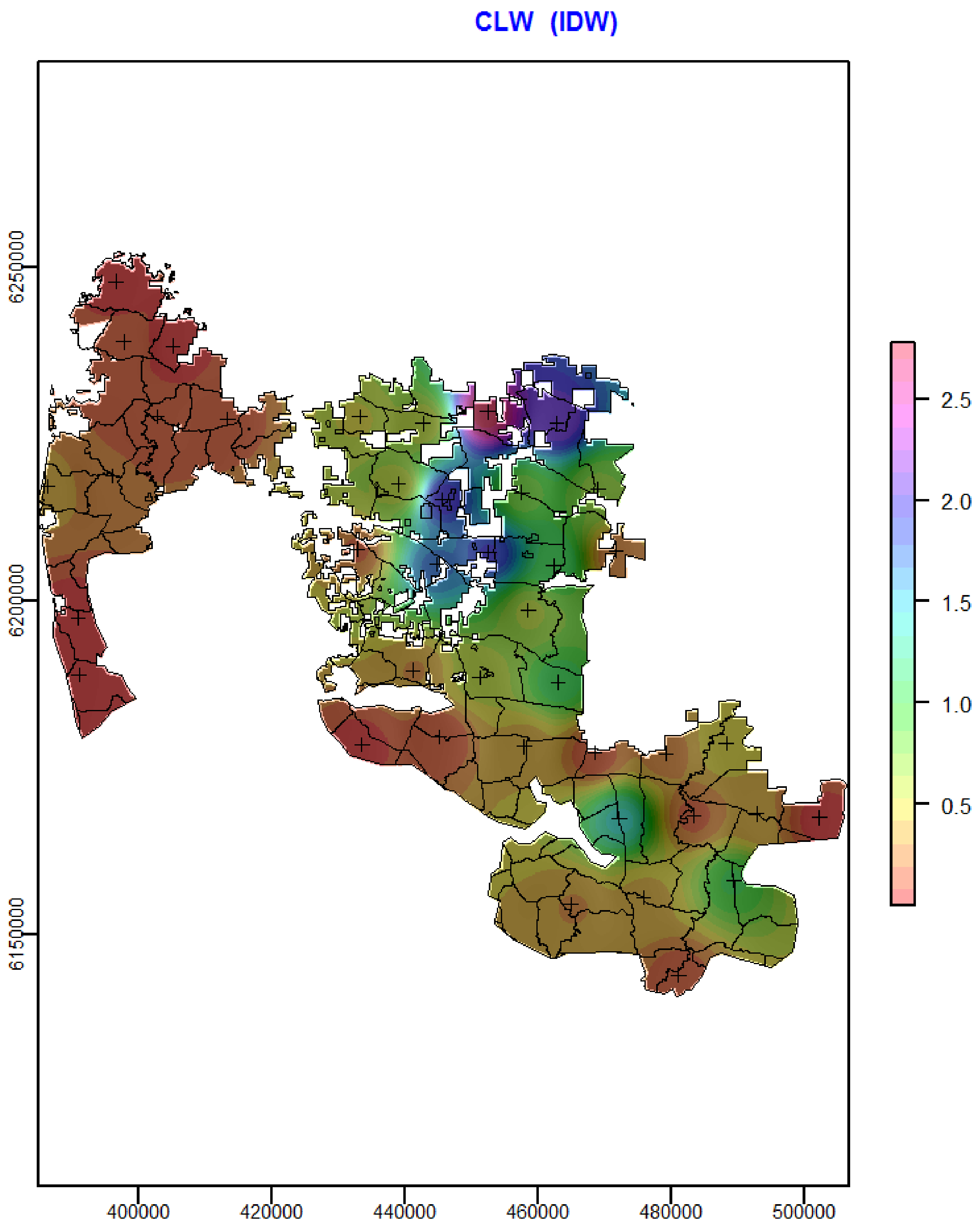

Figure 38. Relative activity of threatened mammals (B. penicillata, D. geoffroii, M. fasciatus, Ph. tapoatafa wambenger, Ps. occidentalis, S. brachyurus) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

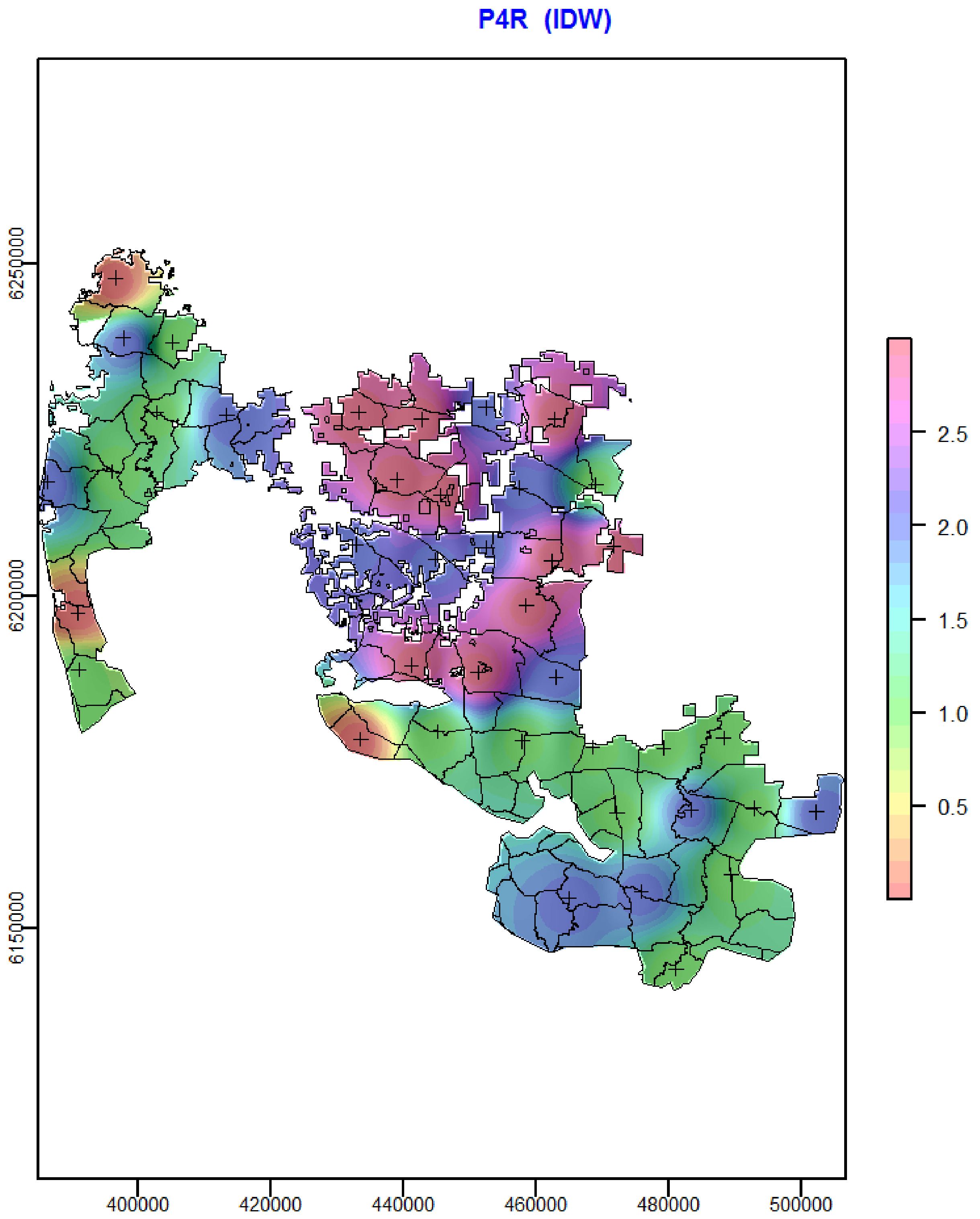

Figure 39. Species richness of 'Priority 4' mammals (I. fusciventer, N. irma, N. eugenii) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

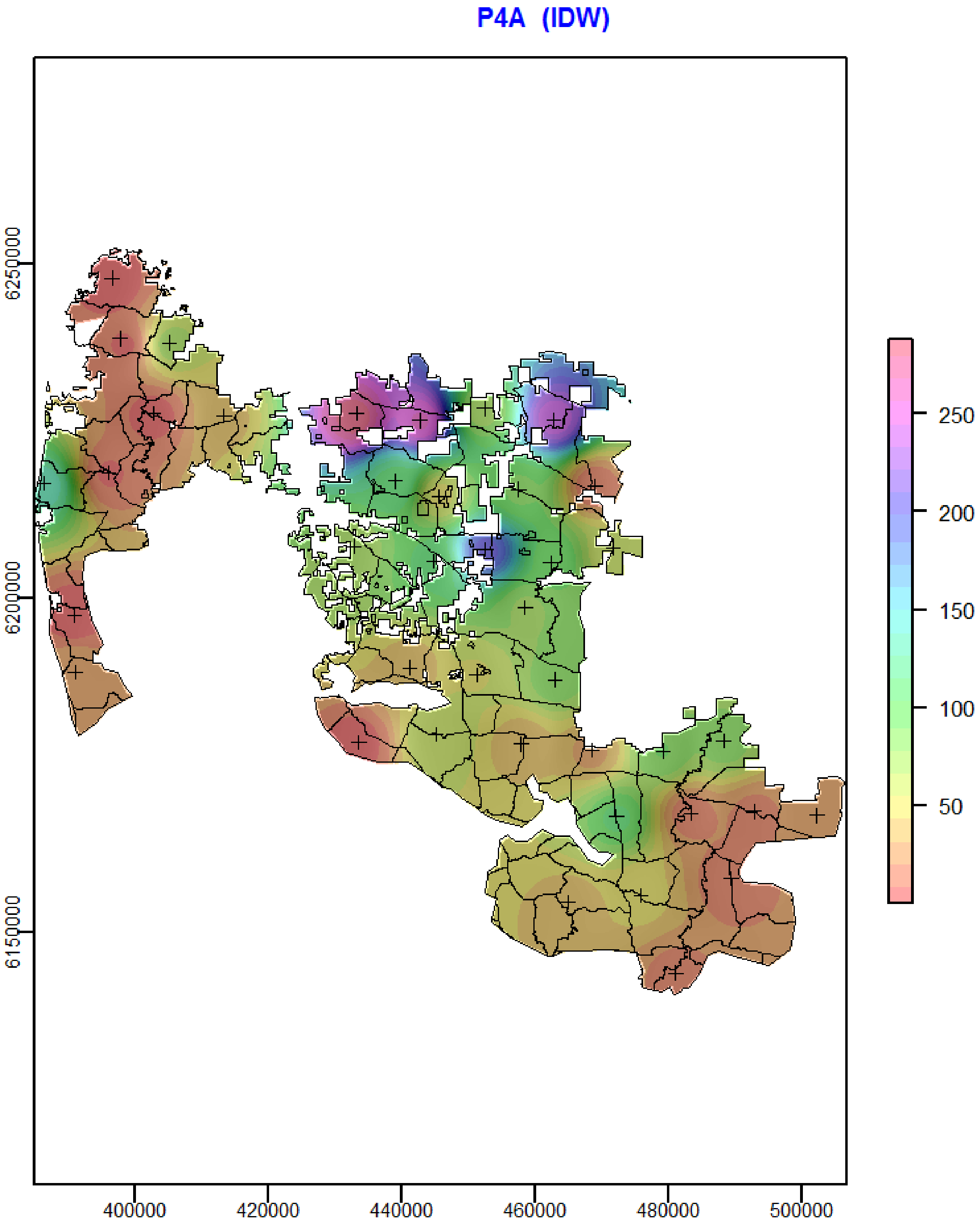

Figure 40. Combined activity of 'Priority 4' mammals (I. fusciventer, N. irma, N. eugenii) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

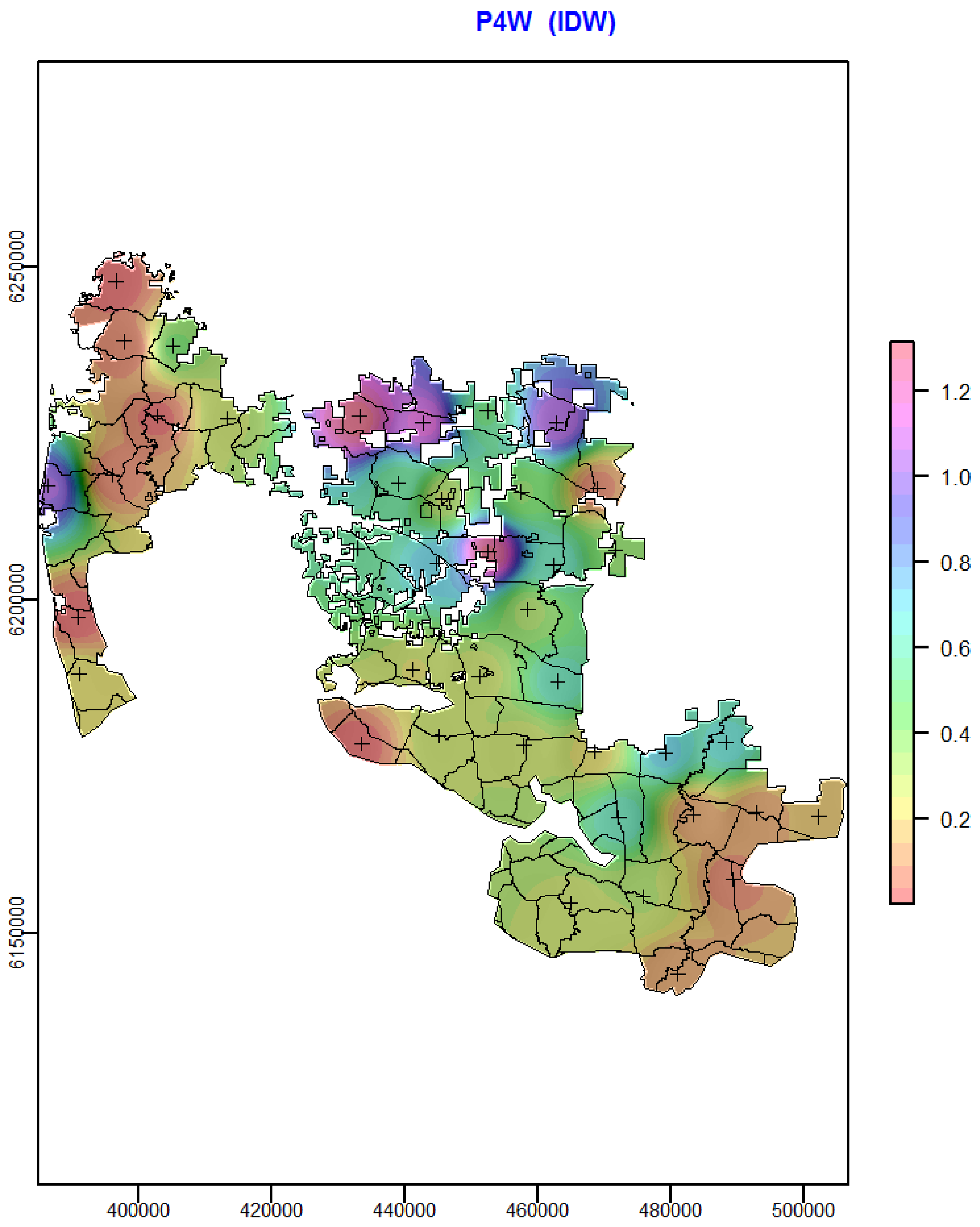

Figure 41. Relative activity of 'Priority 4' mammals (I. fusciventer, N. irma, N. eugenii) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

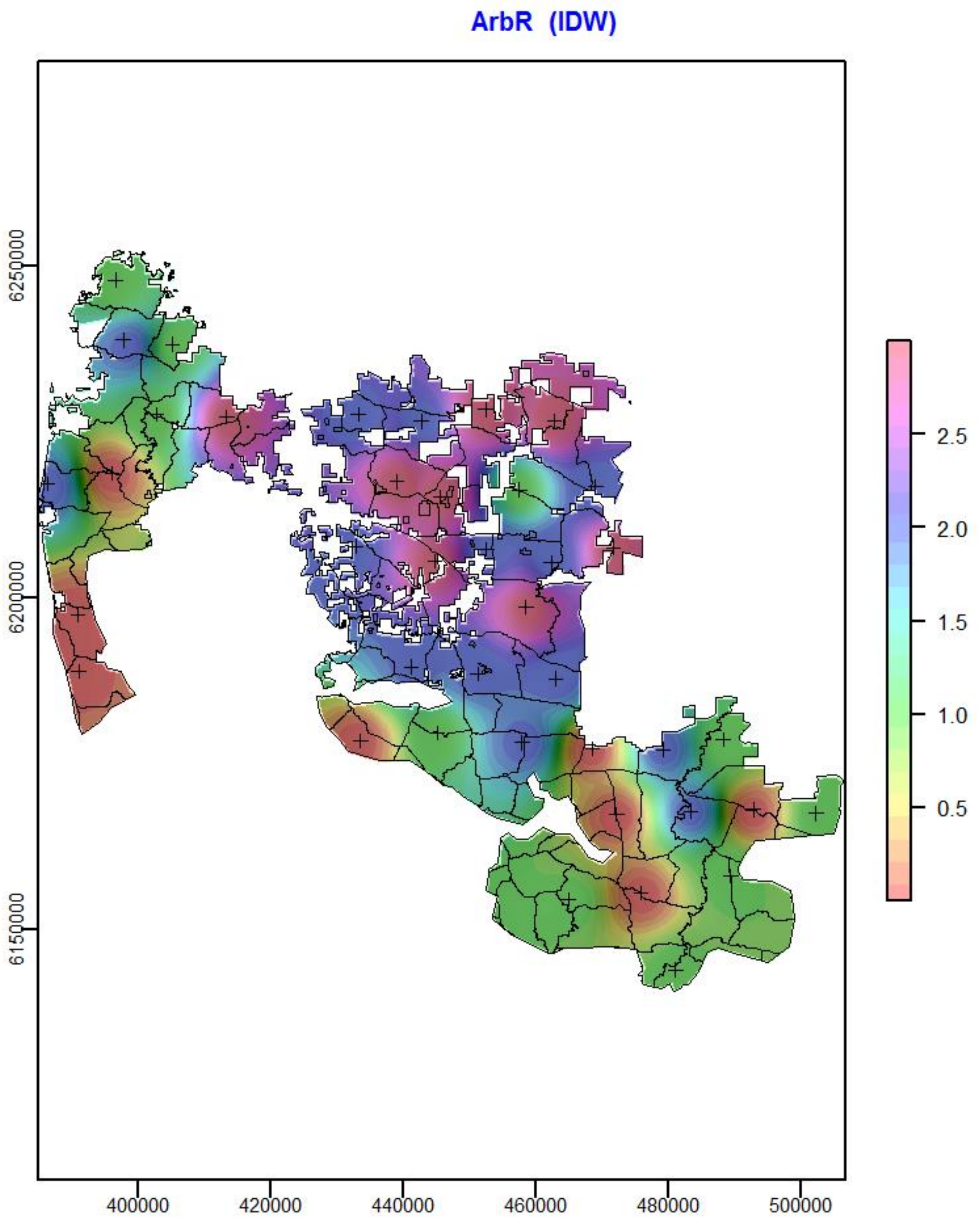

Figure 42. Species richness of arboreal mammals (Ph. tapoatafa wambenger, Ps. occidentalis, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

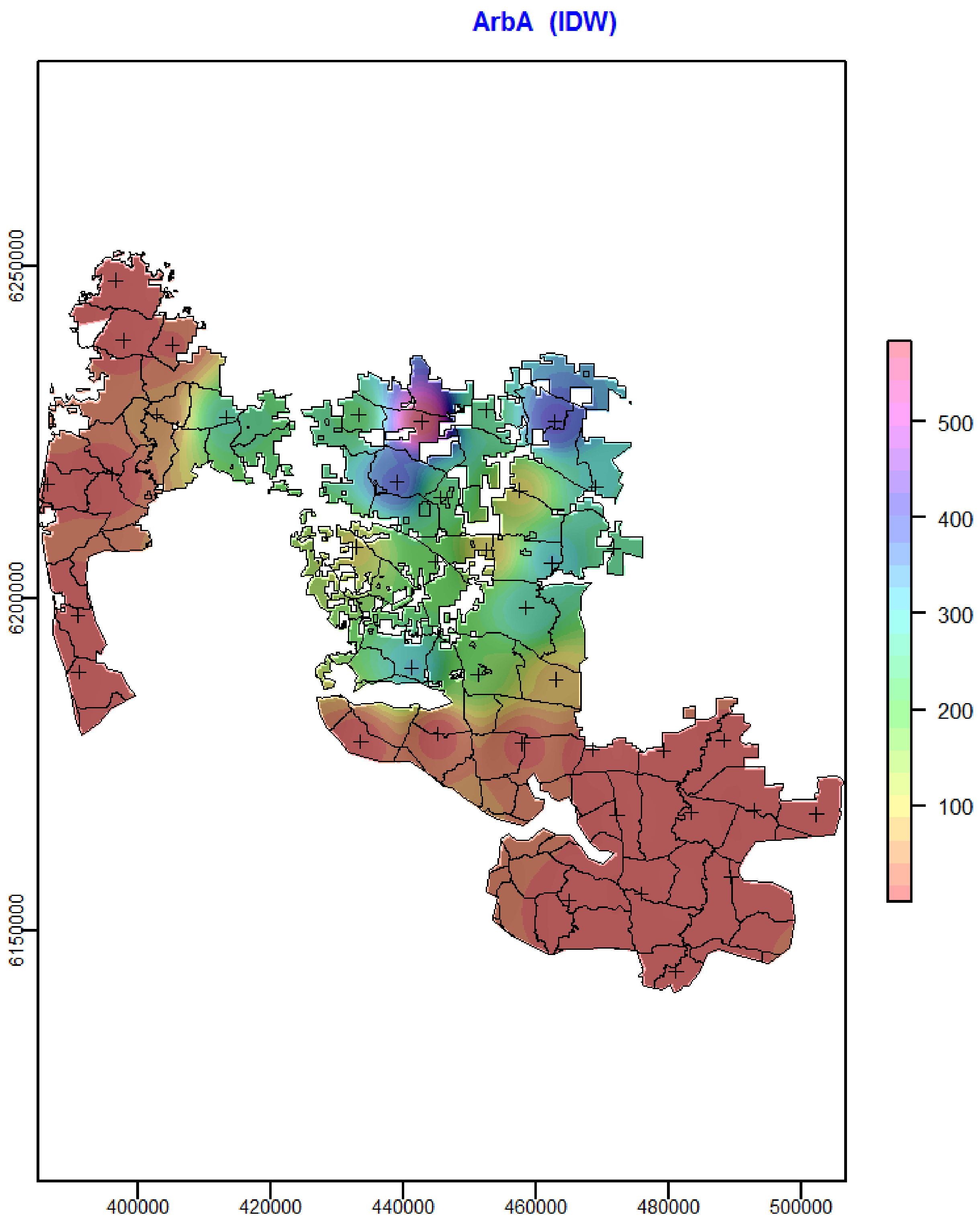

Figure 43. Combined activity of arboreal mammals (Ph. tapoatafa wambenger, Ps. occidentalis, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

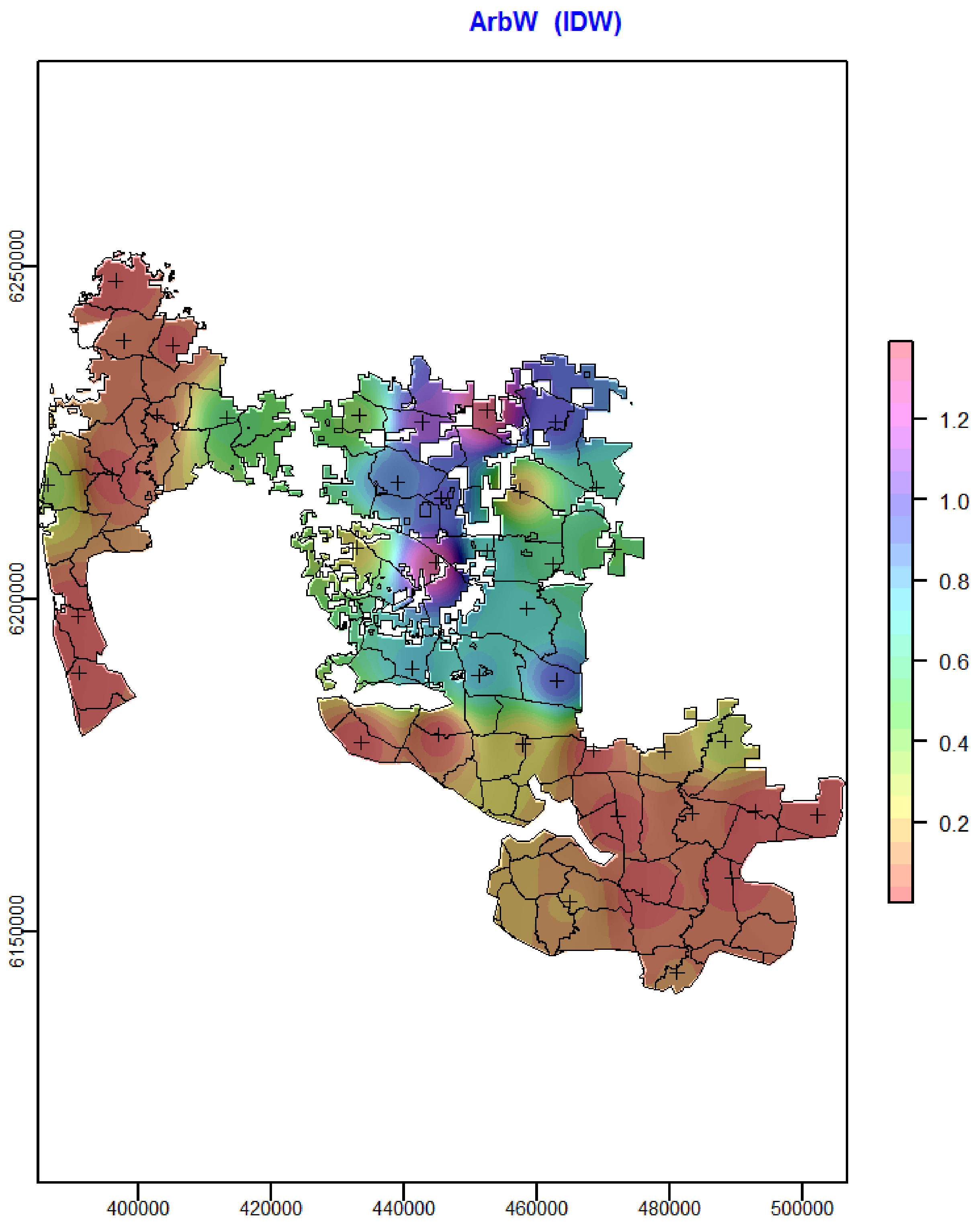

Figure 44. Relative activity of arboreal mammals (Ph. tapoatafa wambenger, Ps. occidentalis, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

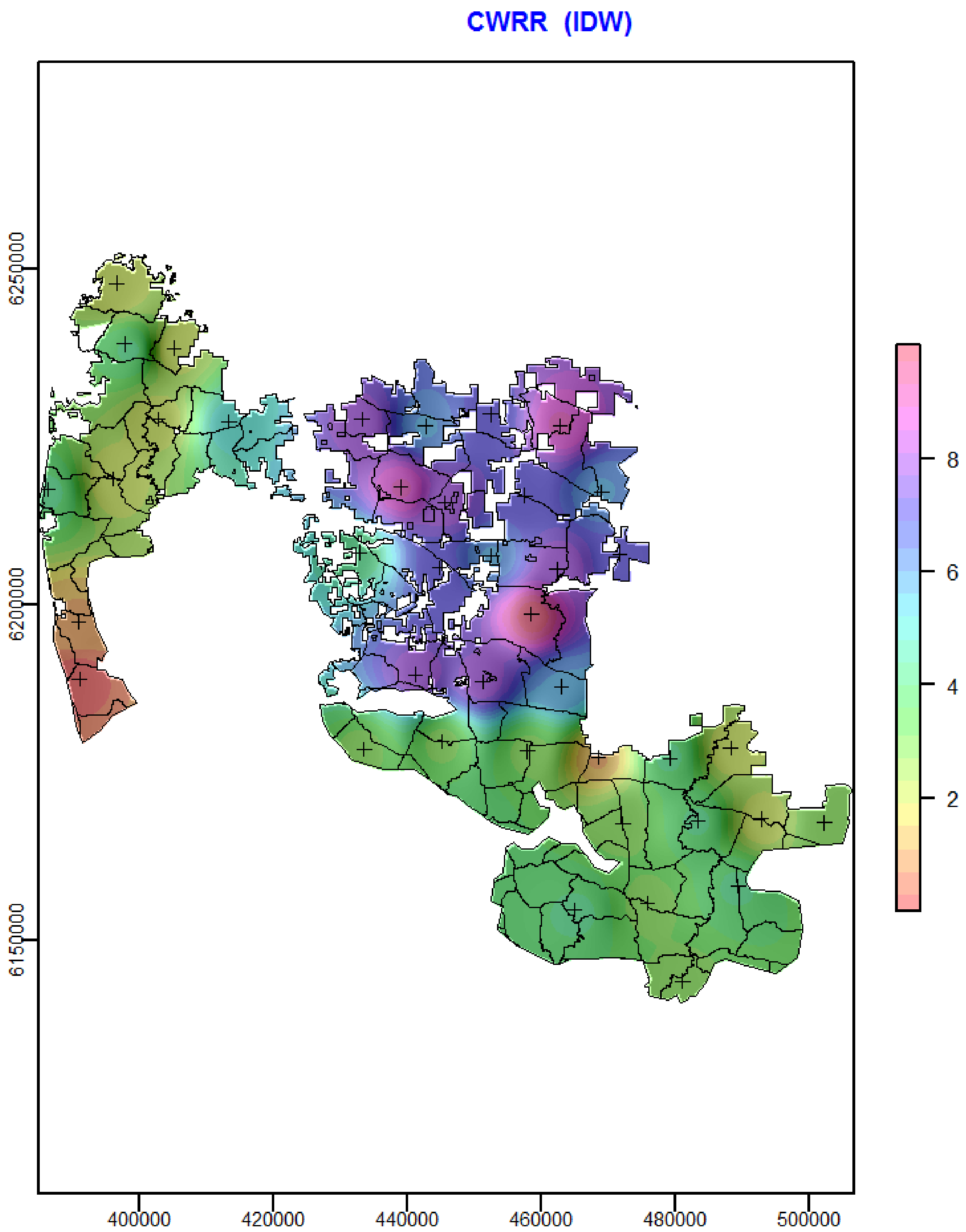

Figure 45. Species richness of medium-sized native mammals (B. penicillata, D. geoffroii, I. fusciventer, M. fasciatus, N. irma, N. eugenii , Ph. tapoatafa wambenger, Ps. occidentalis, S. brachyurus, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

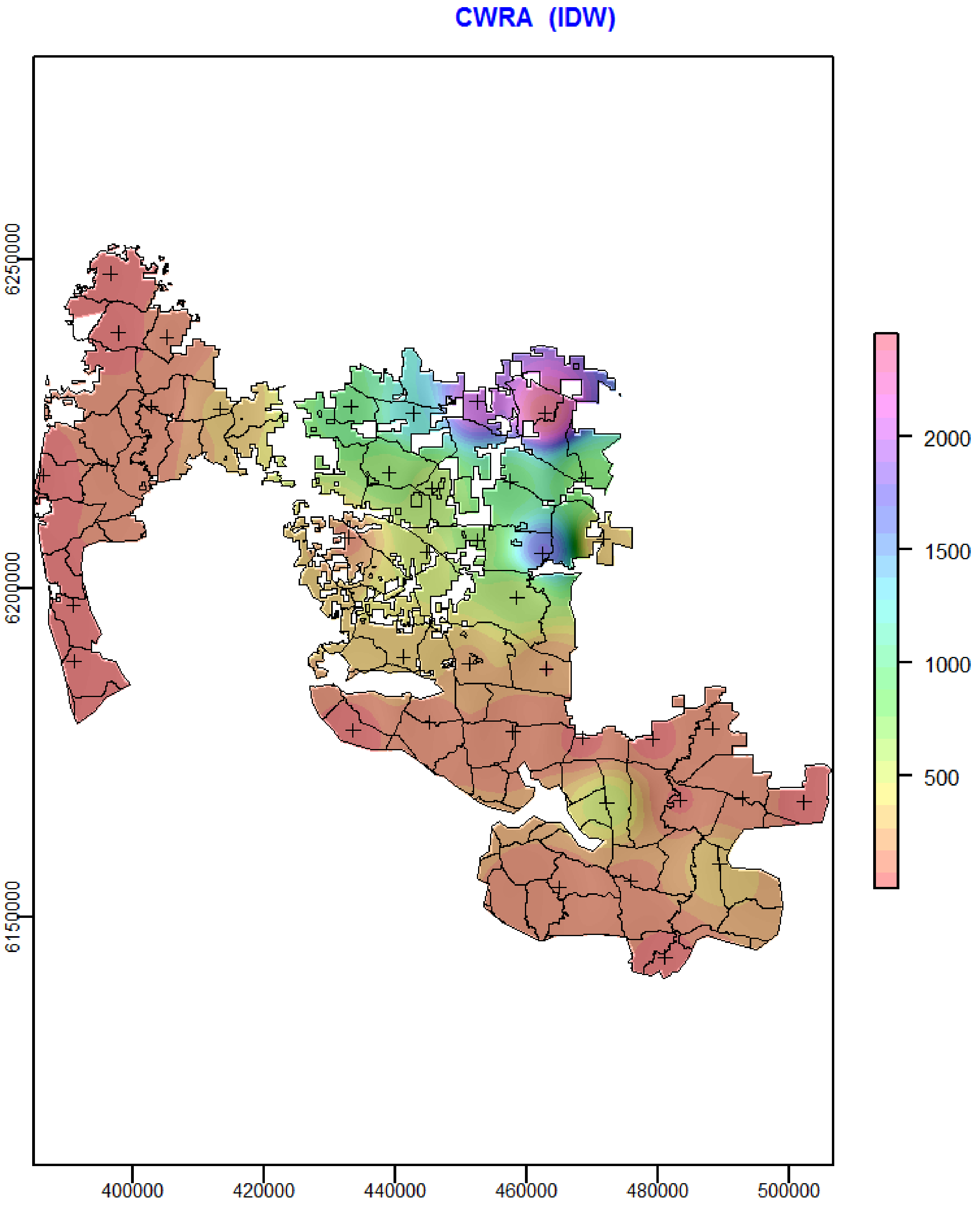

Figure 46. Combined activity of medium-sized native mammals (B. penicillata, D. geoffroii, I. fusciventer, M. fasciatus, N. eugenii , Ph. tapoatafa wambenger, Ps. occidentalis, S. brachyurus, Ta. aculeatus, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

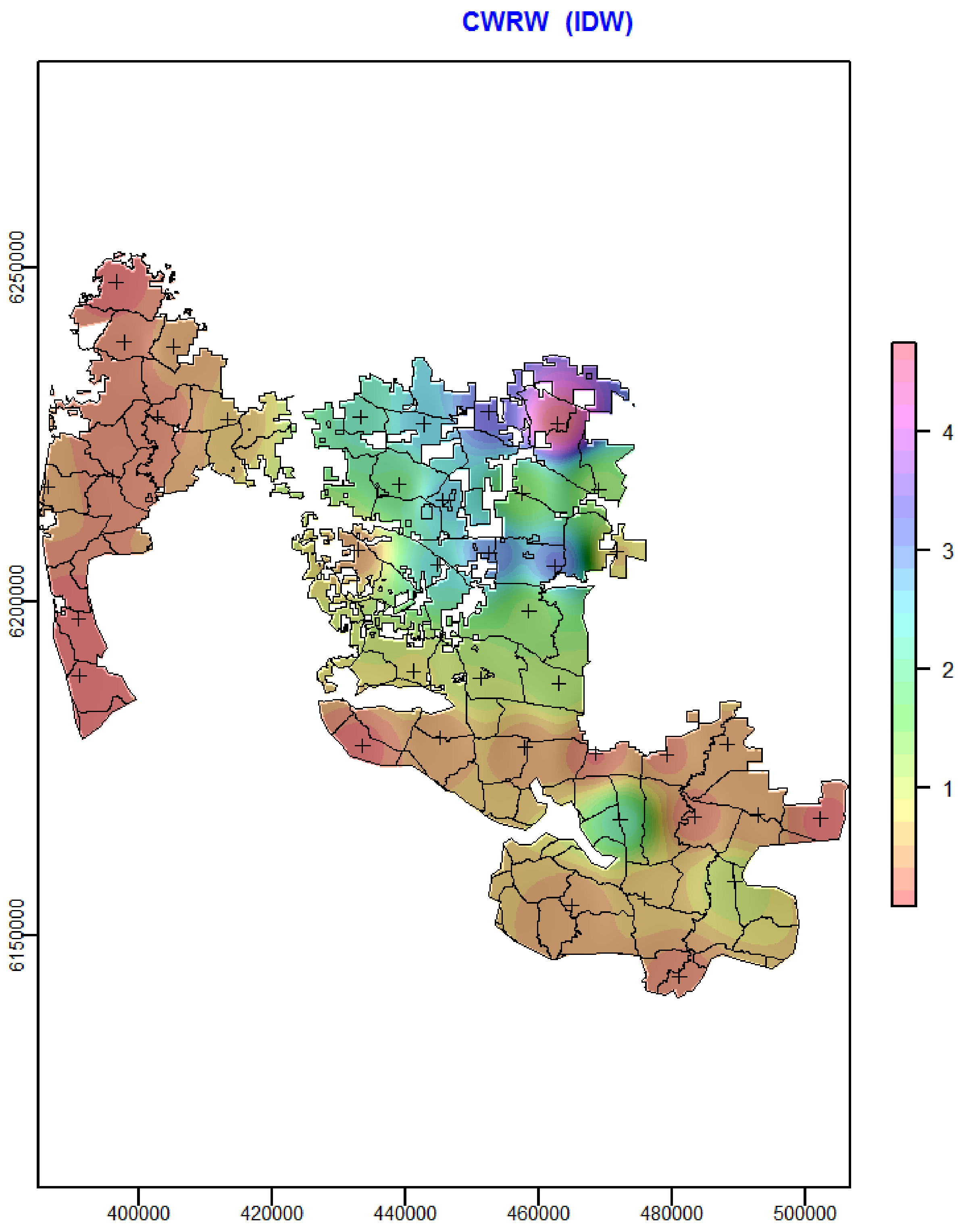

Figure 47. Relative activity of medium-sized native mammals (B. penicillata, D. geoffroii, I. fusciventer, M. fasciatus, N. eugenii , Ph. tapoatafa wambenger, Ps. occidentalis, S. brachyurus, Ta. aculeatus, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

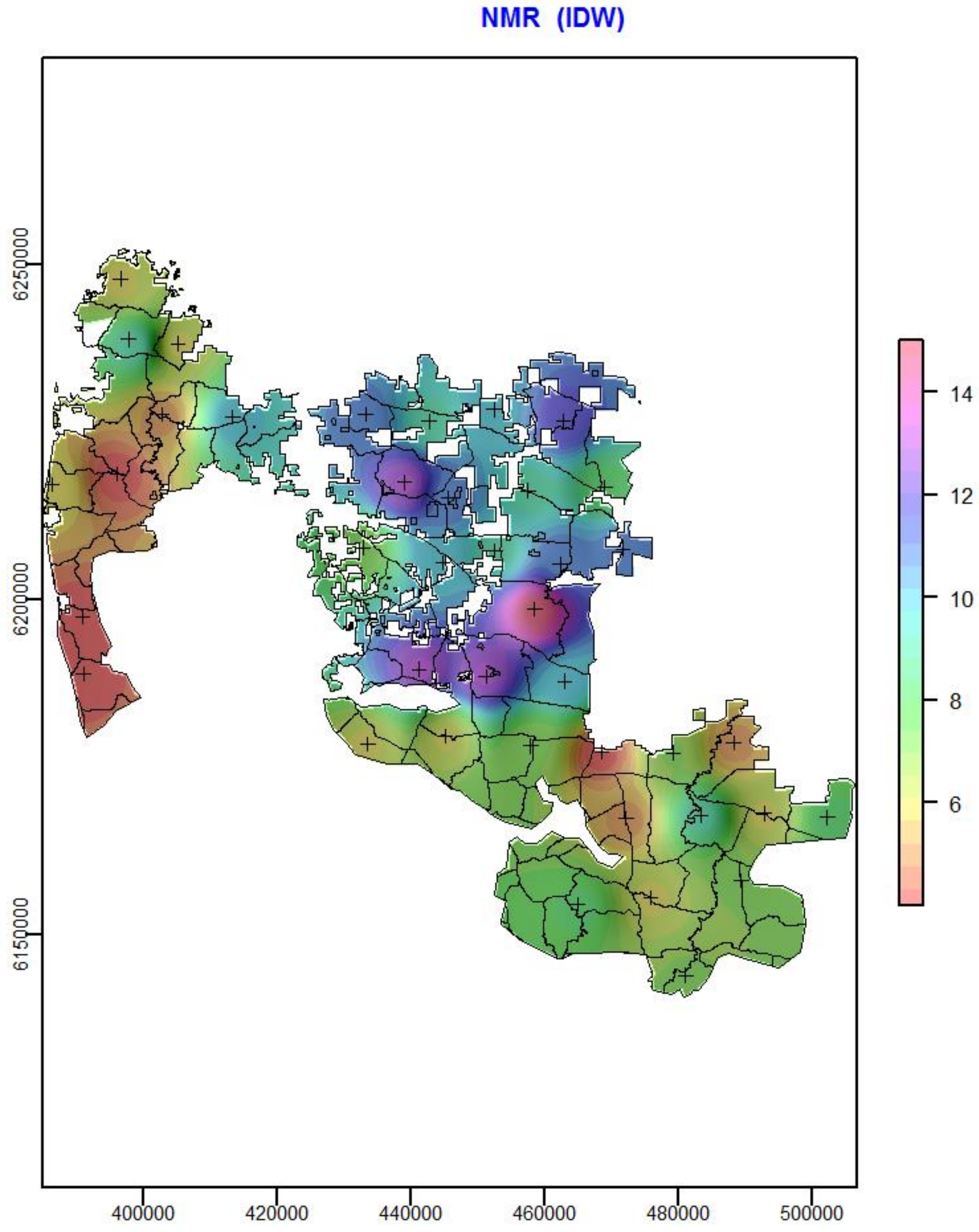

Figure 48. Species richness of native mammals (A. flavipes, B. penicillata, D. geoffroii, I. fusciventer, Ma. fuliginosus, My. fasciatus, N. irma, N. eugenii, Ph. tapoatafa wambenger, Ps. occidentalis, R. fuscipes, S. brachyurus, Sminthopsis spp., Ta. aculeatus, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

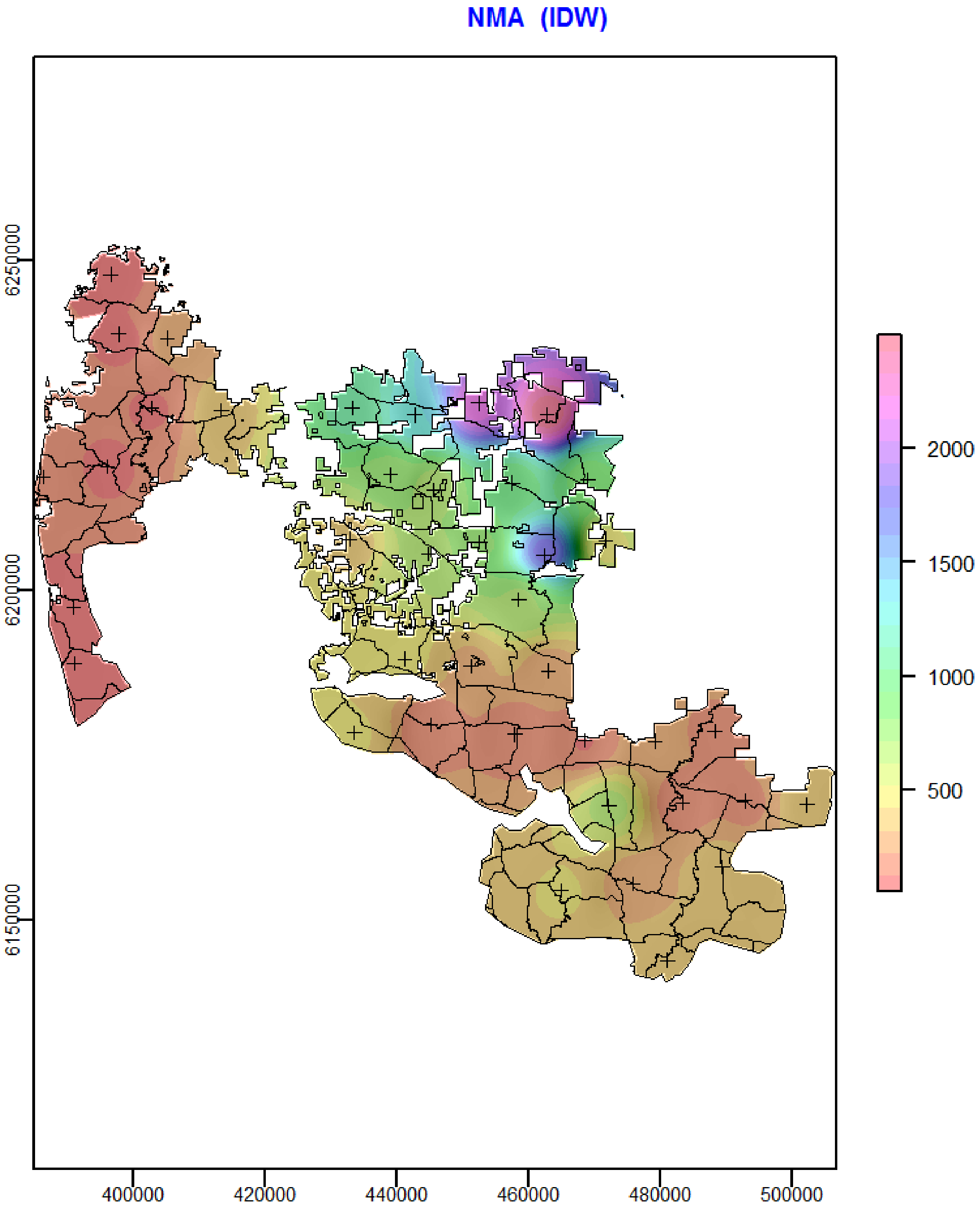

Figure 39. Combined activity of native mammals (A. flavipes, B. penicillata, D. geoffroii, I. fusciventer, Ma. fuliginosus, My. fasciatus, N. irma, N. eugenii, Ph. tapoatafa wambenger, Ps. occidentalis, R. fuscipes, S. brachyurus, Sminthopsis spp., Ta. aculeatus, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

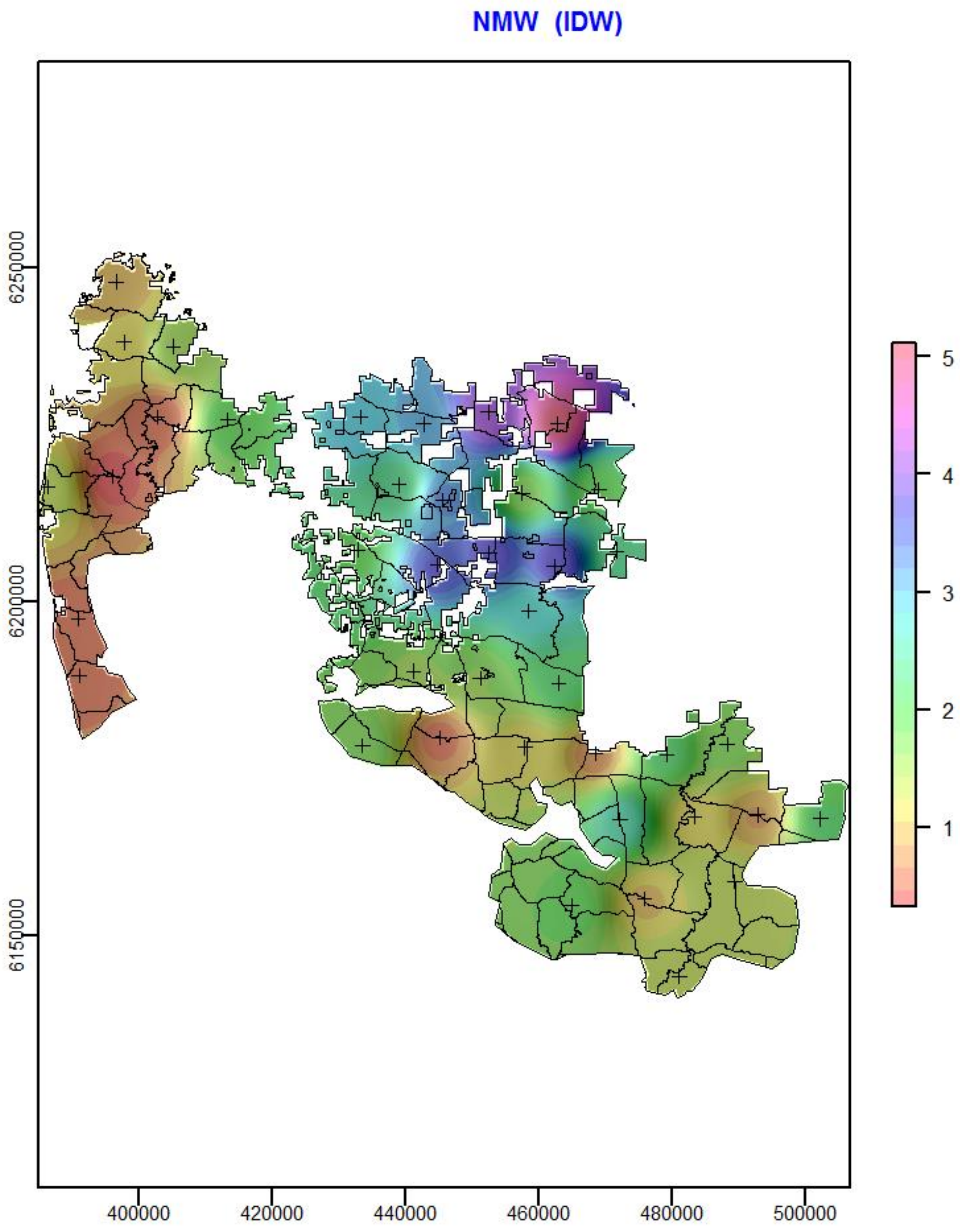

Figure 50. Relative activity of native mammals (A. flavipes, B. penicillata, D. geoffroii, I. fusciventer, Ma. fuliginosus, My. fasciatus, N. irma, N. eugenii, Ph. tapoatafa wambenger, Ps. occidentalis, R. fuscipes, S. brachyurus, Sminthopsis spp., Ta. aculeatus, Tr. vulpecula) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

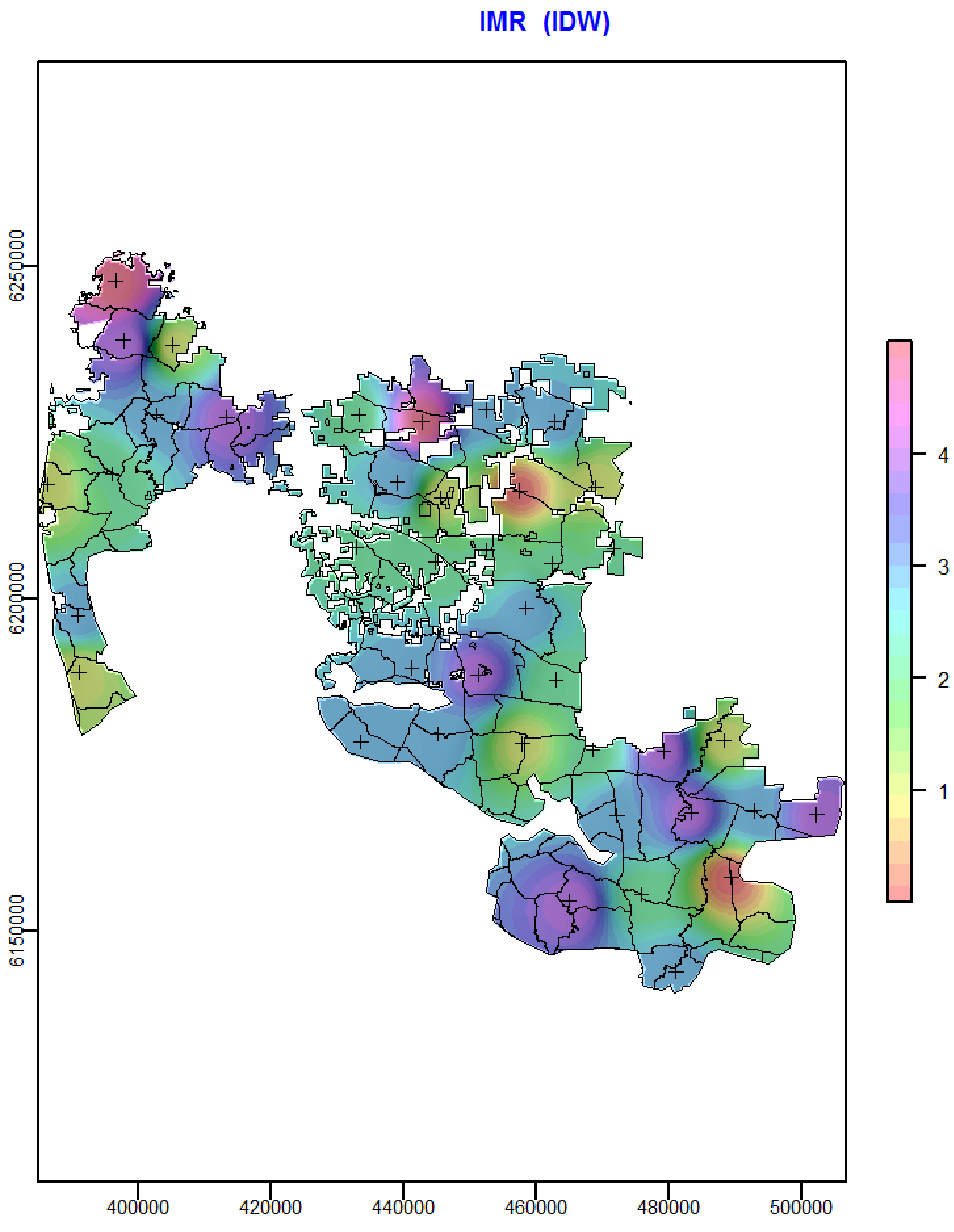

Figure 51. Species richness of commonly detected introduced mammals (F. catus, M. musculus, R. rattus, S. scrofa, V. vulpes) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

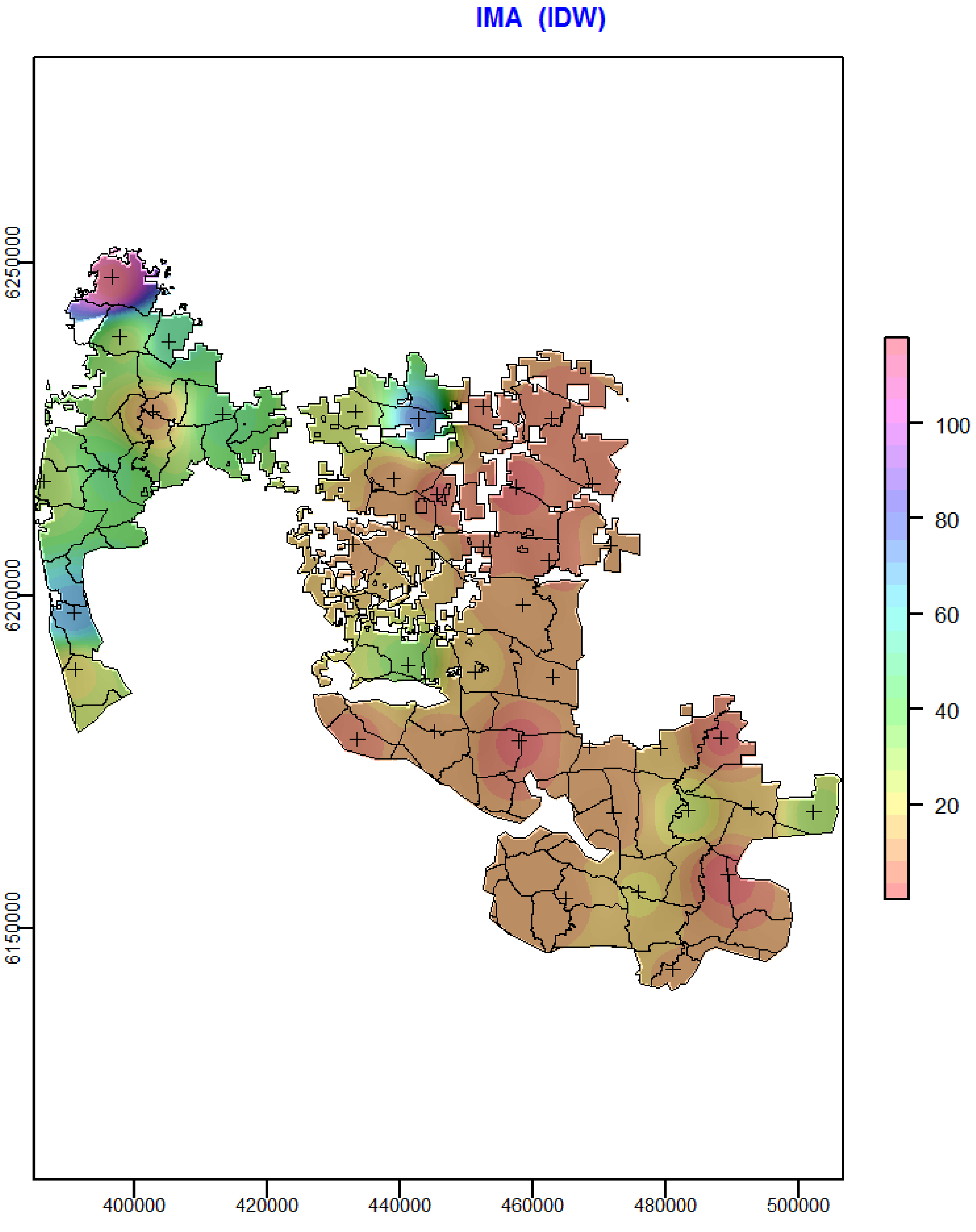

Figure 52. Combined activity of commonly detected introduced mammals (F. catus, M. musculus, R. rattus, S. scrofa, V. vulpes) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

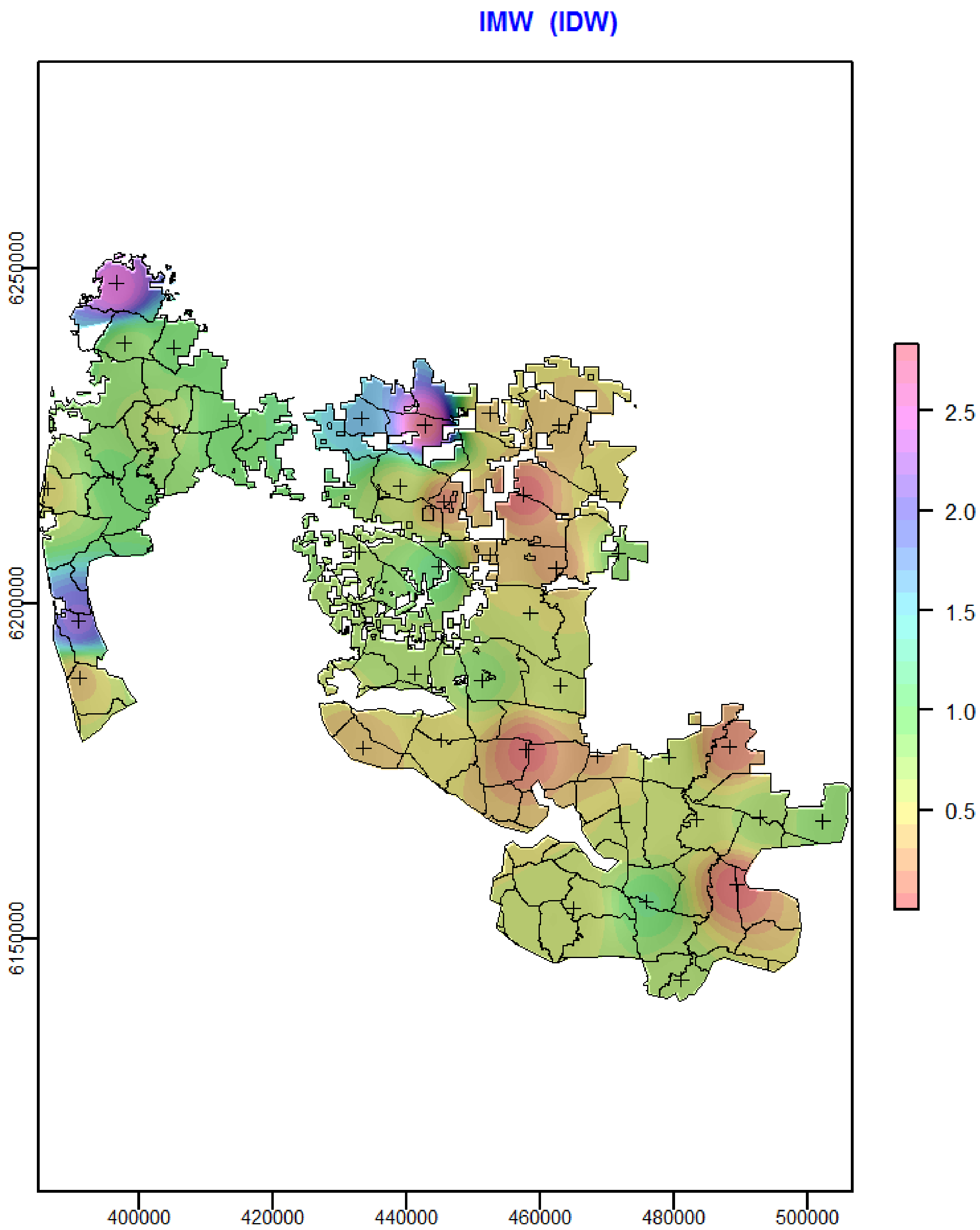

Figure 53. Relative activity of commonly detected introduced mammals (F. catus, M. musculus, R. rattus, S. scrofa, V. vulpes) across the southern jarrah forest (2016-2017) based on inverse distance weighted spatial interpolation.

3.5 Temporal activity patterns

Seasonal diel activity for selected species are provided in Figures 54-80. General seasonal activity patterns were clear for most species but was limited for those cases where sample sizes of the total number of independent detection events within particular seasons was less than about 100. Greater confidence and insight were possible in those cases where the seasonal sample sizes were in the high hundreds or thousands.

Most species were predominantly nocturnal, some strongly so (e.g. most small and medium-sized native mammals). Several species demonstrated a clear tendency to be more active an hour or two earlier in Autumn and Winter, than in Summer and Spring (e.g. *B. penicillata*, *D. geoffroii*, *Ma. fuliginosus*, *Mu. musculus*, *Ph. tapoatafa*, *R. fuscipes*, *R. rattus*, *S. brachyurus*, *Sminthopsis spp.* and *Tr. vulpecula*; Figures 55, 56, 59, 60, 64, 66, 67, 68, 69, 72, respectively). Some species had distinctly different temporal peaks in some seasons; such as *B. penicillata* during early evening in spring and autumn and *I. fusciventer* during early evening in autumn (Figures 55 and 58, respectively). Some species varied in the degree to which they were crepuscular or had two peaks of activity versus single peaks of activity, according to season; for example *Ps. occidentalis* and *R. rattus* tended to have two peaks in winter (early and late evening) and single peaks early-mid evening in the other seasons (Figures 65 and 67, respectively), *R. fuscipes* had similar double peaks of activity in autumn and winter and single peaks in spring and summer (Figure 66), *S. brachyurus* had strong double peaks in Autumn and Spring and a strong single peak in Summer (Figure 68).

Myrmecobius fasciatus were diurnal, with two or three peaks of activity in summer (early morning, mid-late morning and late afternoon), a single peak early-mid morning in spring and a single broader peak in the middle of the day in winter (Figure 61). *Tachyglossus aculeatus* were more strongly nocturnal in Summer and Autumn Figure 71). Some species had not clear seasonal patterns and were less strongly nocturnal in their activity (*F. catus*, *S. scrofa* and *V. vulpes*; Figures 57, 70 and 73, respectively).

When comparing the annualised diel activity between species some clear patterns emerged. For example, peak activity of *B. penicillata* was stronger and earlier than for other medium-sized mammals commonly trapped in wire cages (Figure 74). *Trichosurus vulpecula* and *Ph. tapoatafa* tend to be active 1-2 hours earlier than *Ps. occidentalis*, which had a stronger peak period of activity 20:00 – 03:00 hrs (Figure 75. The strongly nocturnal activity patterns of the small mammals were very similar, as were the crepuscular activity patterns of the larger macropods (Figures 76 and 77, respectively). *Myrmecobius fasciatus* and reptile had very similar strong diurnal activity patterns, while *Tac. aculeatus* were active at most times but were least active in the early morning and most active late-afternoon to midnight (Figure 78). *Corvus coronoides* (Australian raven) were strongly crepuscular whereas *Strepera versicolor* (grey currawong) were diurnal (Figure 79). *Felis catus* and *V. vulpes* activity patterns were similar having been active at almost any time but with peak activity in the early evening (Figure 80).

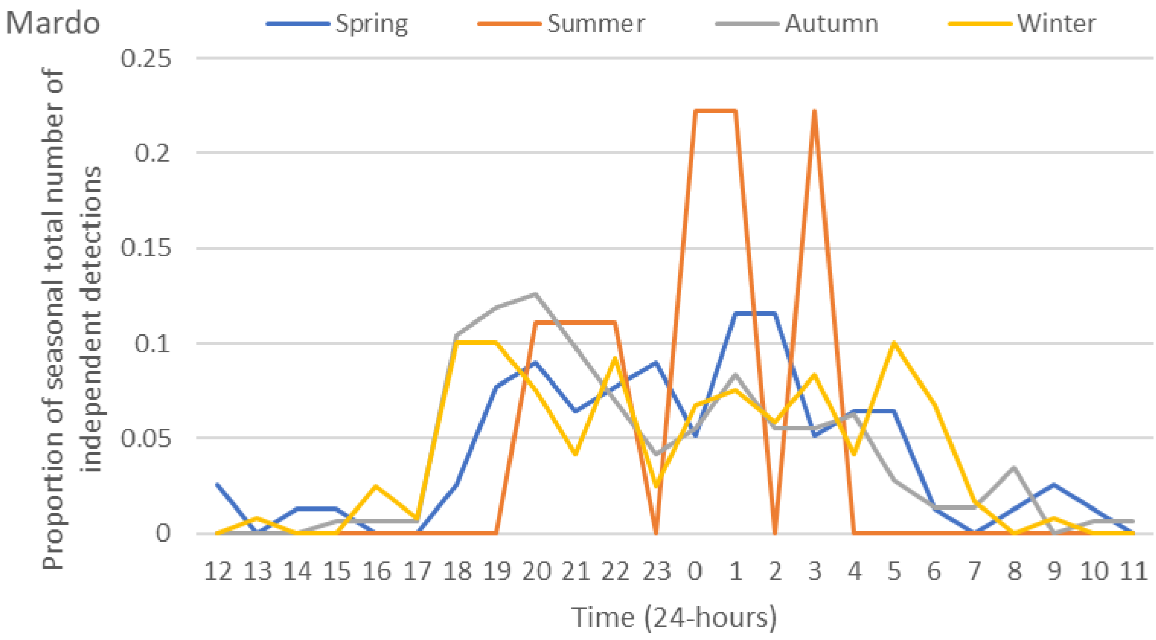

Figure 54. Antechinus flavipes diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 78, 9, 143, and 119, for spring, summer, autumn and winter, respectively).

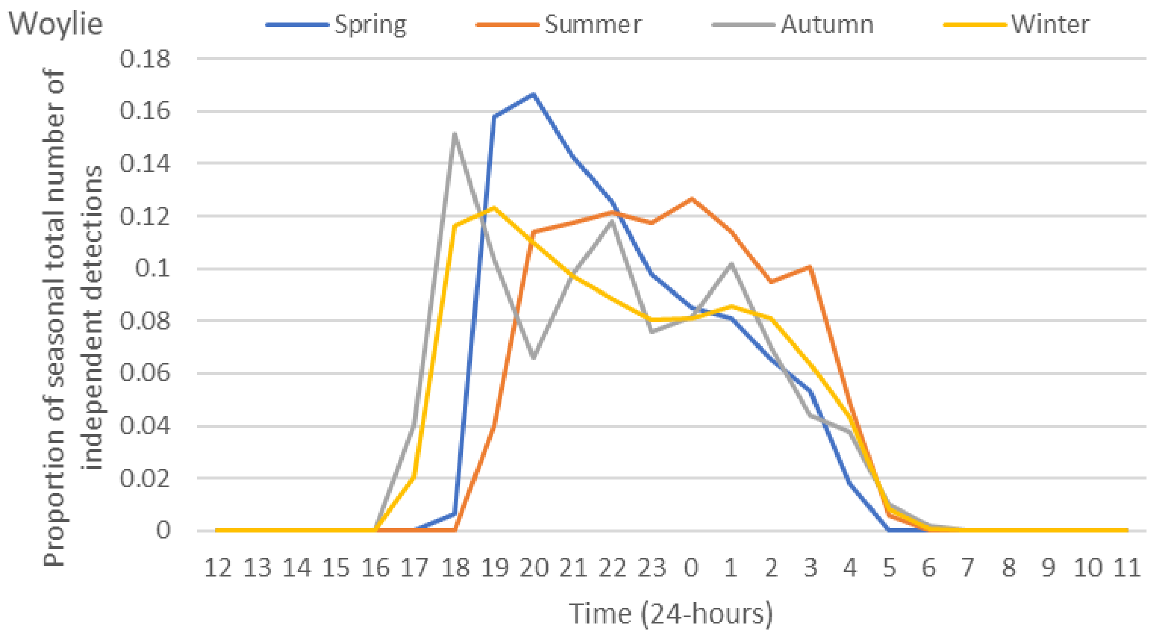

Figure 55. Bettongia penicillata diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 8148, 528, 501 and 6547, for spring, summer, autumn, and winter, respectively).

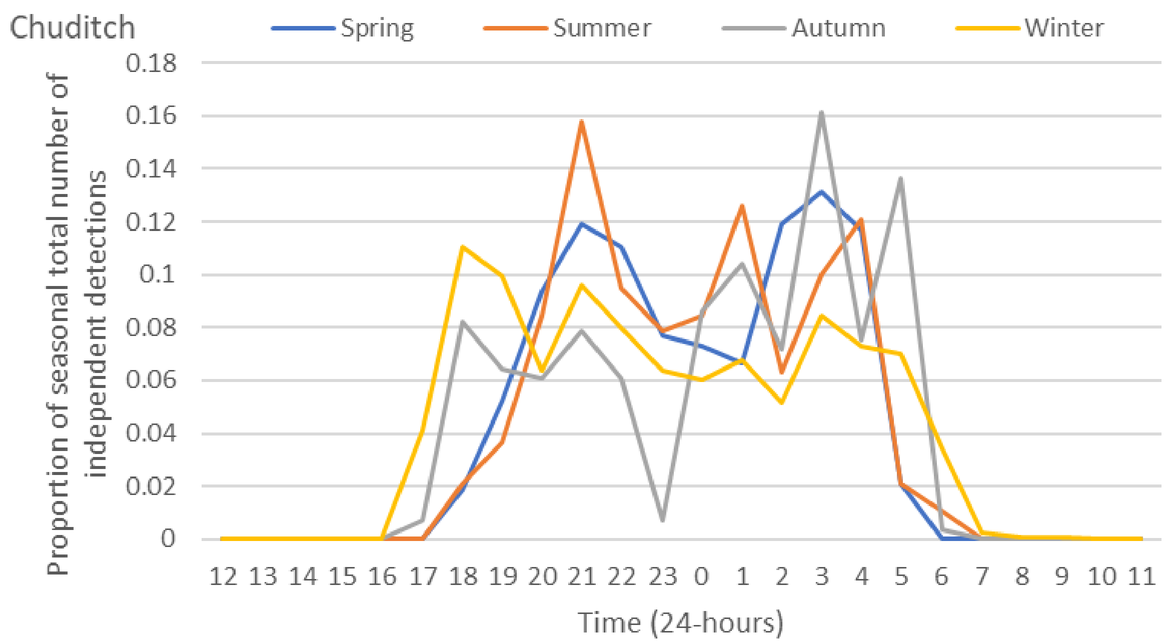

Figure 56. Dasyurus geoffroii diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 479, 190, 279 and 1457, for spring, summer, autumn, and winter, respectively).

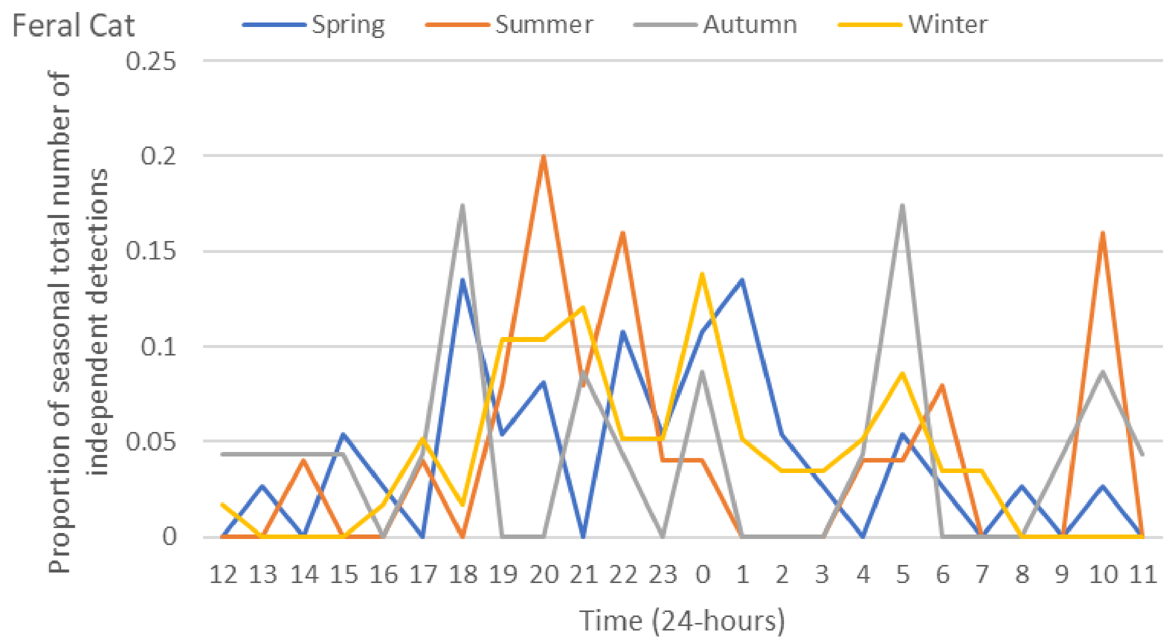

Figure 57. Felis catus diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 37, 25, 23, and 58, for spring, summer, autumn, and winter, respectively).

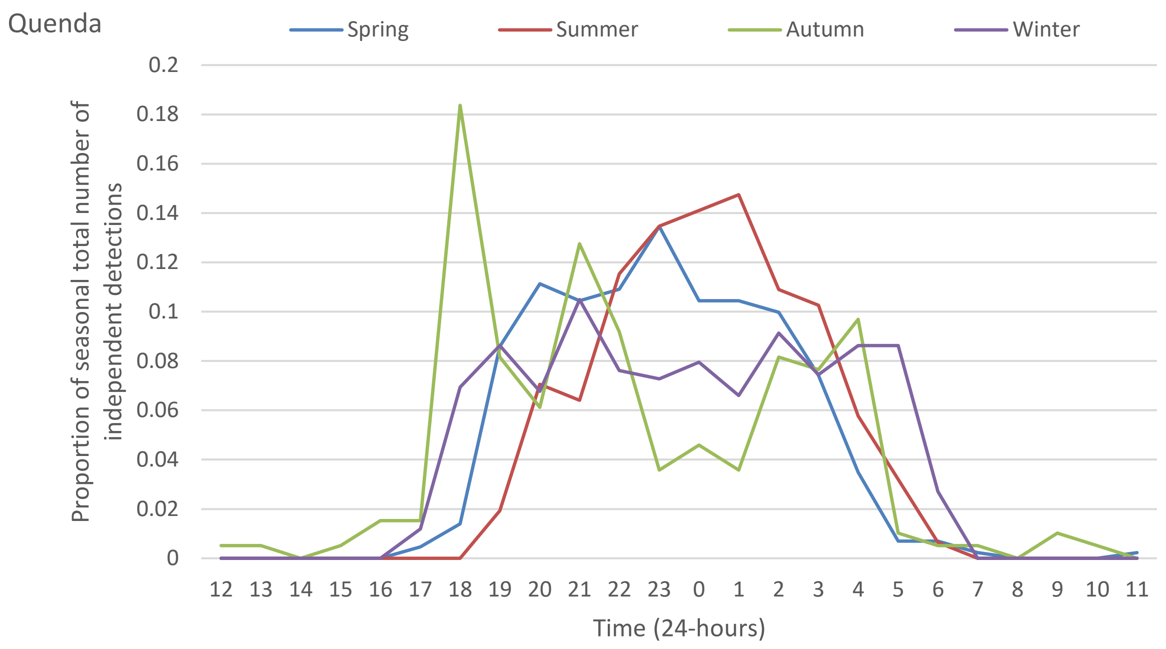

*Figure 58. Isoodon fuscivente*r *diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 431, 156, 196, and 591, for spring, summer, autumn, and winter, respectively).*

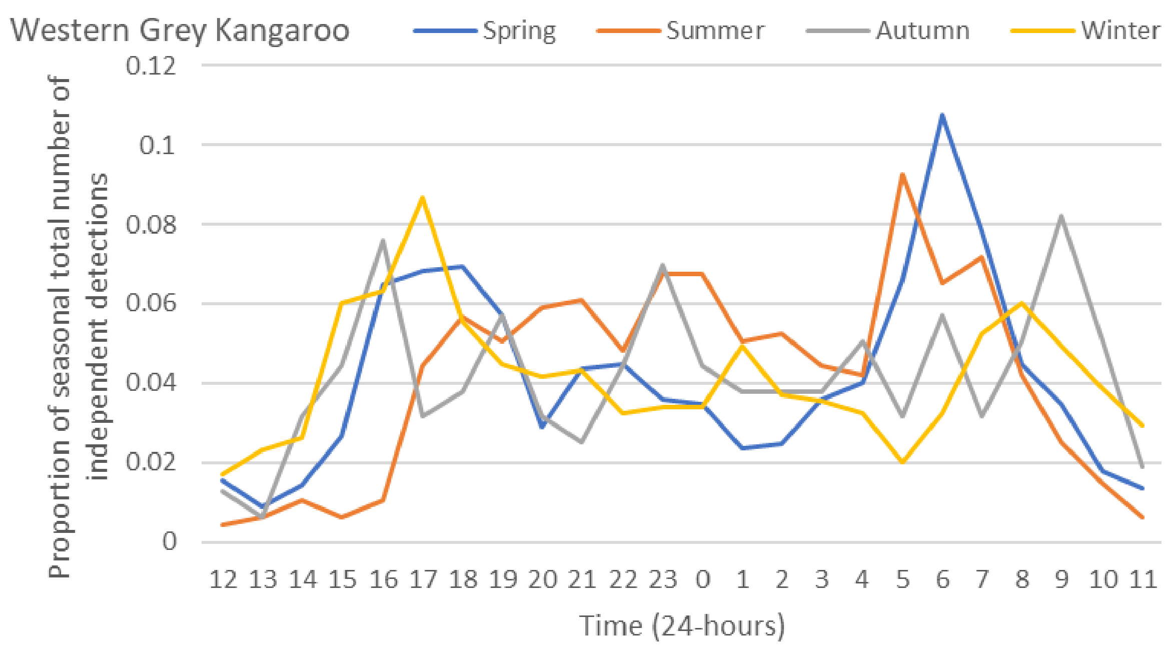

Figure 59. Macropus fuliginosus diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 894, 475, 158, and 647, for spring, summer, autumn, and winter, respectively).

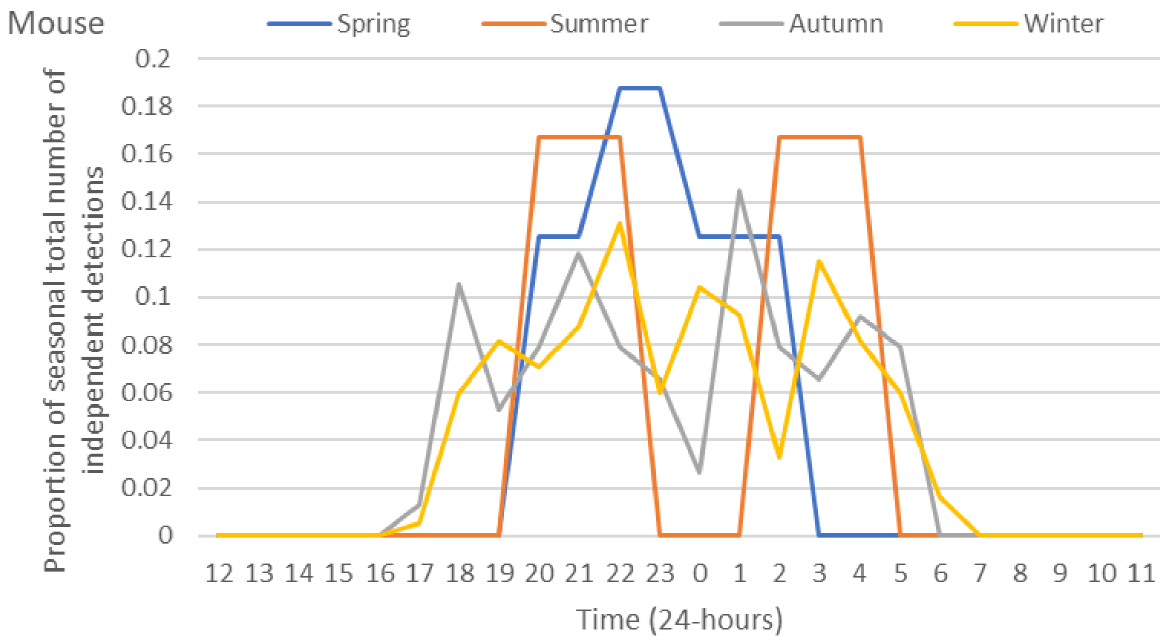

Figure 60. Mus musculus diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 16, 6, 76, and 183, for spring, summer, autumn, and winter, respectively).

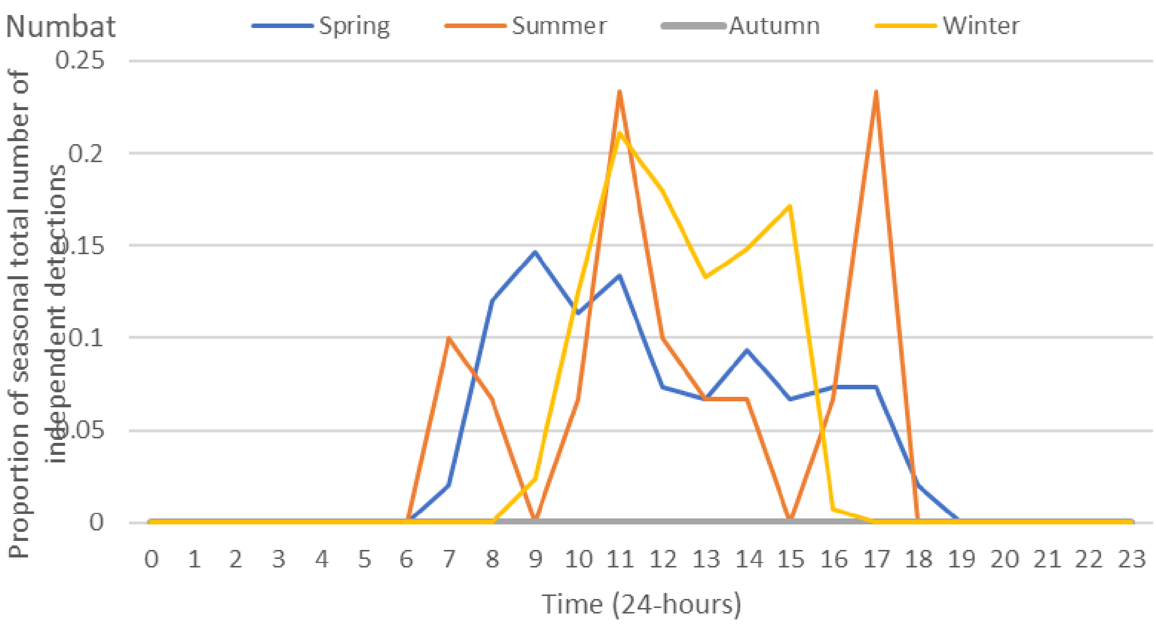

Figure 61. Myrmecobius fasciatus diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 150, 30, 0, and 128, for spring, summer, autumn, and winter, respectively)

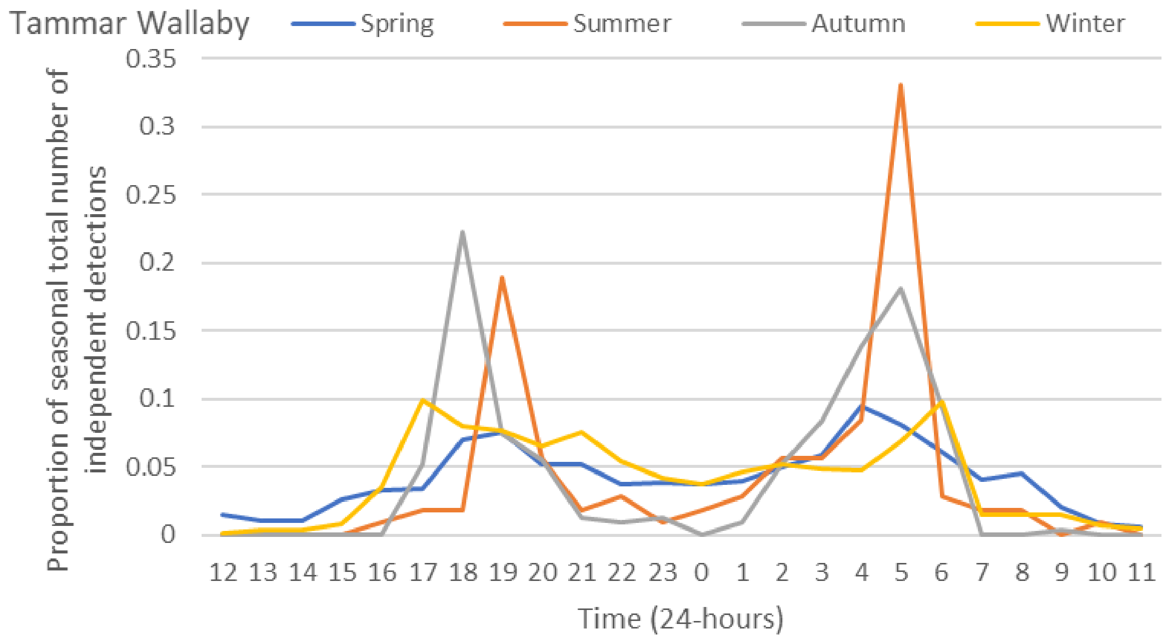

Figure 62. Notamacropus eugenii diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 780, 106, 310, and 1229, for spring, summer, autumn, and winter, respectively).

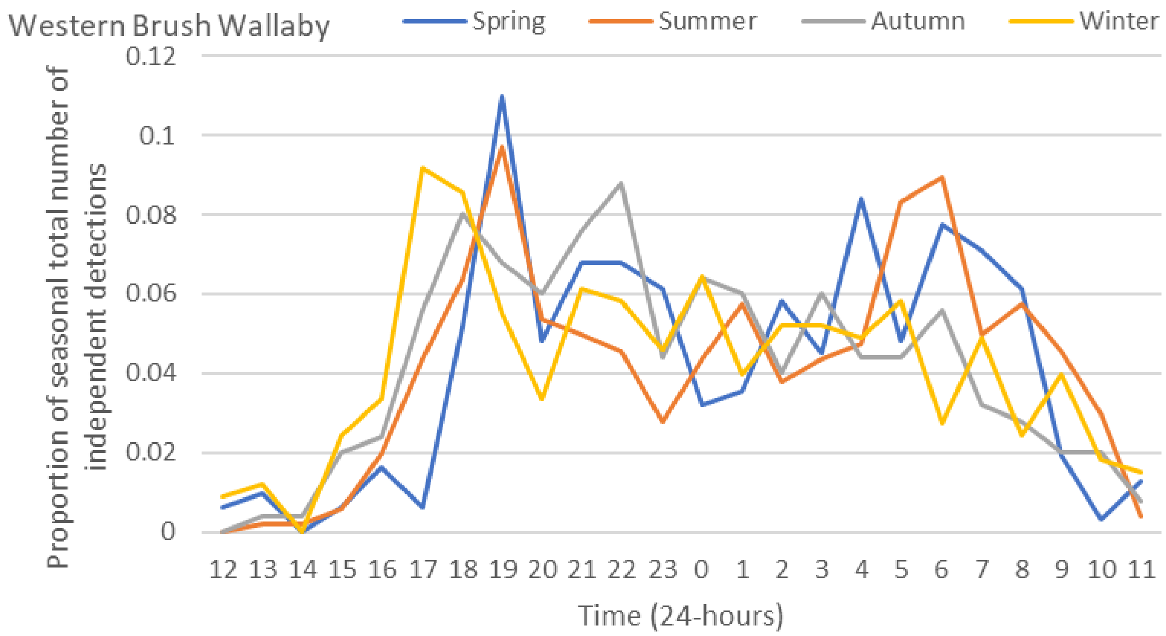

Figure 63. Notamacropus irma diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 310, 504, 250, and 327, for spring, summer, autumn, and winter, respectively).

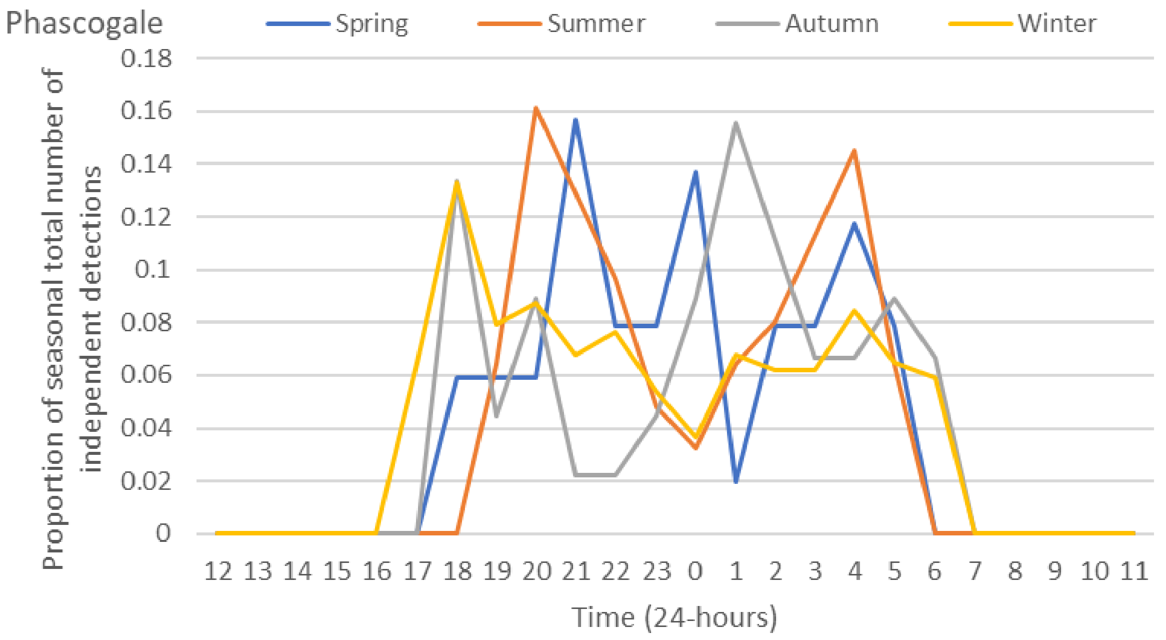

Figure 64. Phascogale tapoatafa diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 51, 62, 45, and 354, for spring, summer, autumn, and winter, respectively).

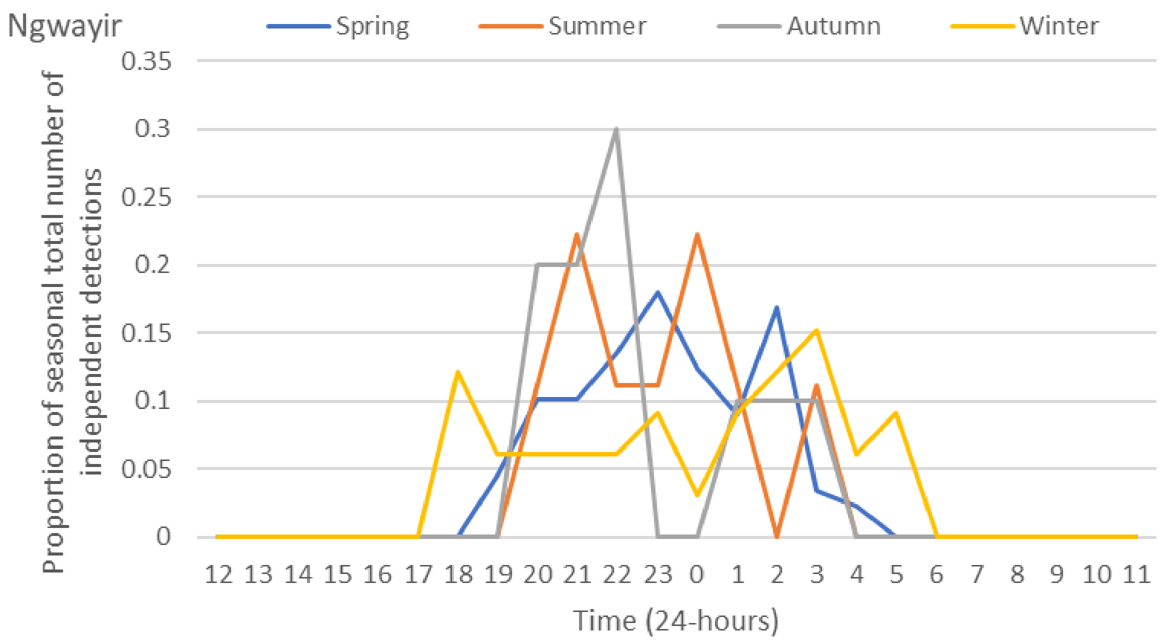

Figure 65. Pseudocheirus occidentalis diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 89, 9, 10, and 33, for spring, summer, autumn, and winter, respectively).

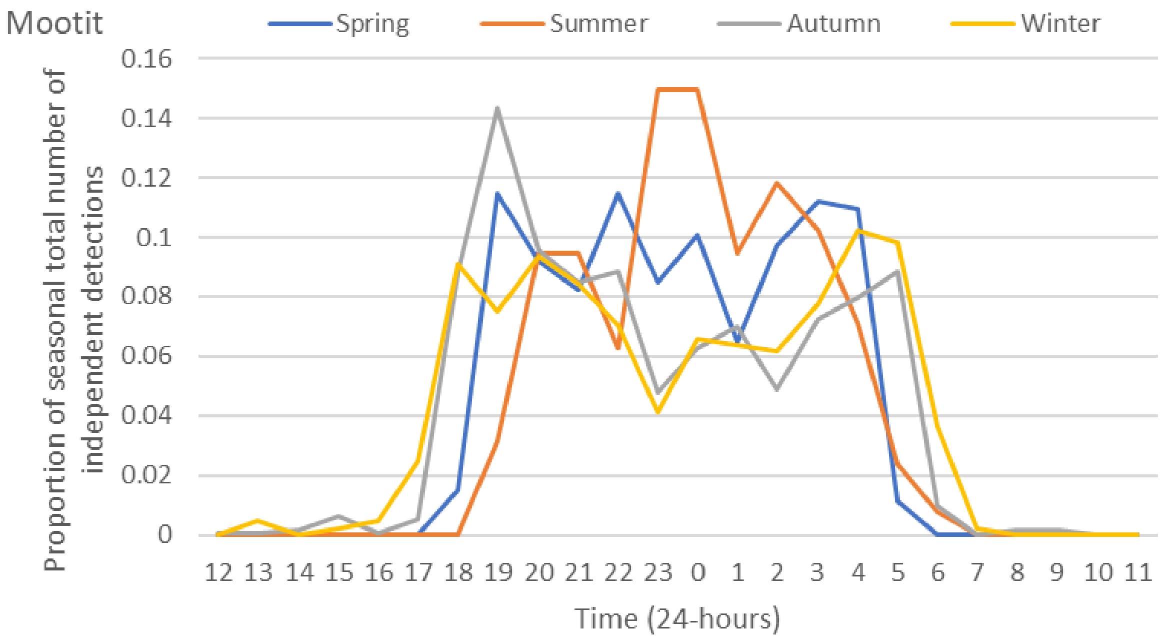

Figure 66. Rattus fuscipes diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 802, 127, 1129, and 439, for spring, summer, autumn, and winter, respectively).

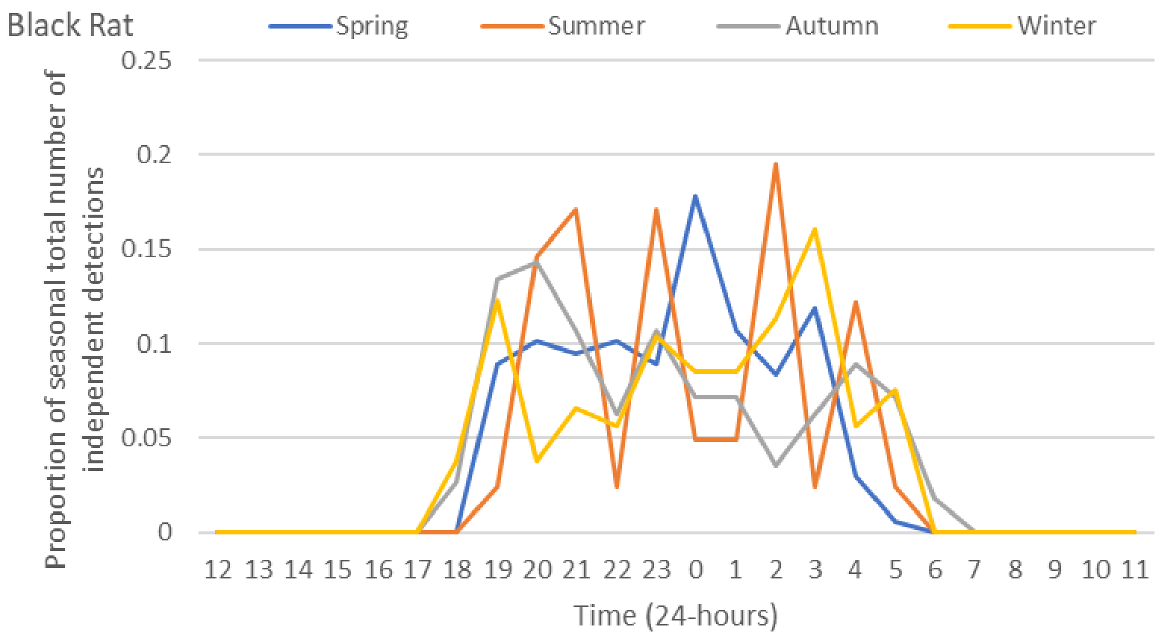

Figure 67. Rattus rattus diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 168, 41, 112, and 106, for spring, summer, autumn, and winter, respectively).

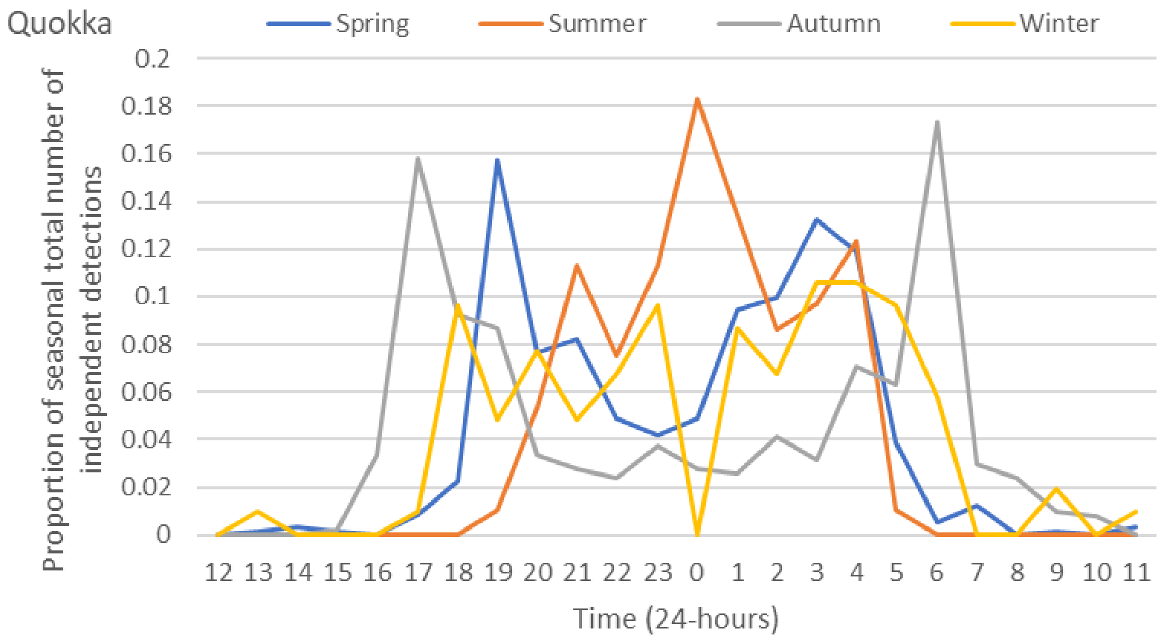

Figure 68. Setonix brachyurus diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 573, 186, 507, and 104, for spring, summer, autumn, and winter, respectively).

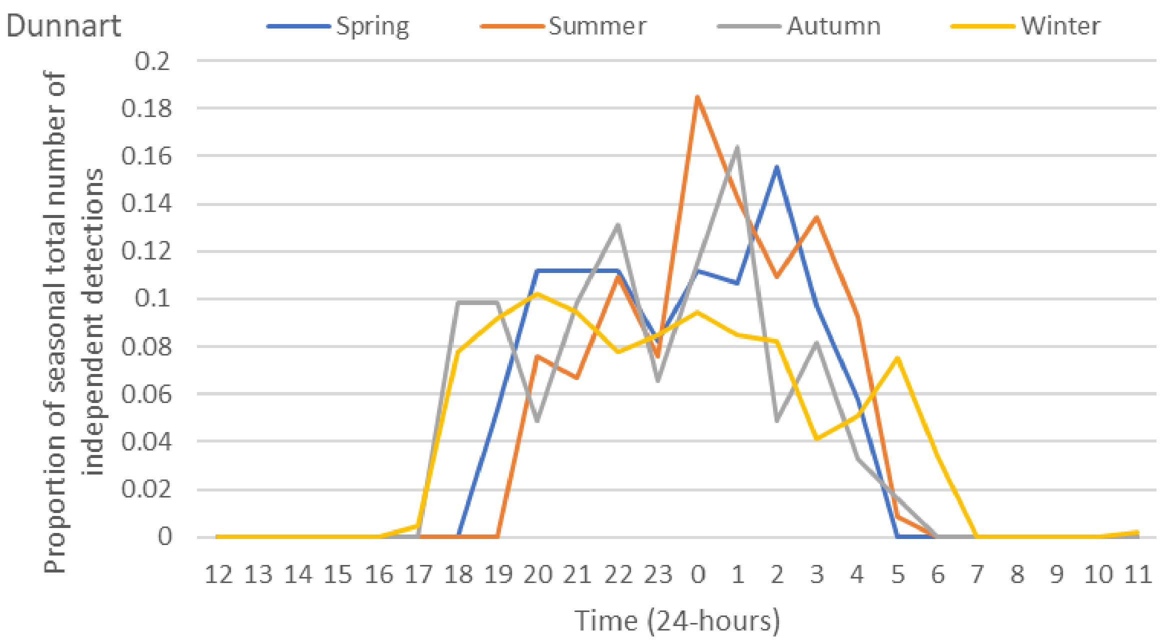

Figure 69. Sminthopsis sp. diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 206, 119, 61, and 412, for spring, summer, autumn, and winter, respectively).

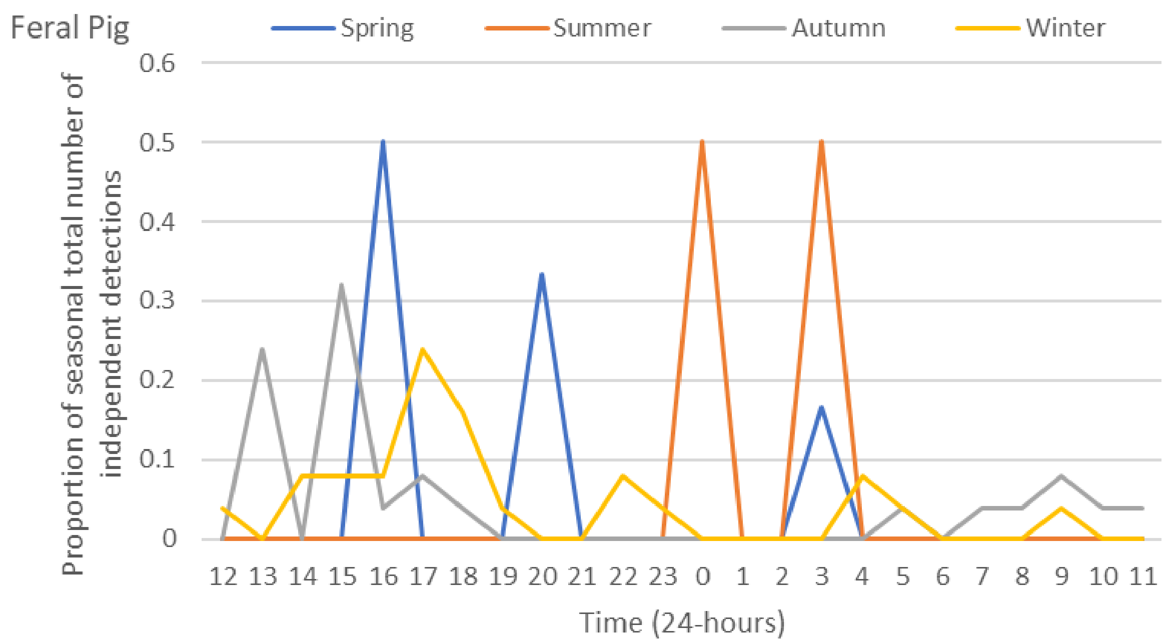

Figure 70. Sus scrofa diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 6, 2, 25, and 25, for spring, summer, autumn, and winter, respectively).

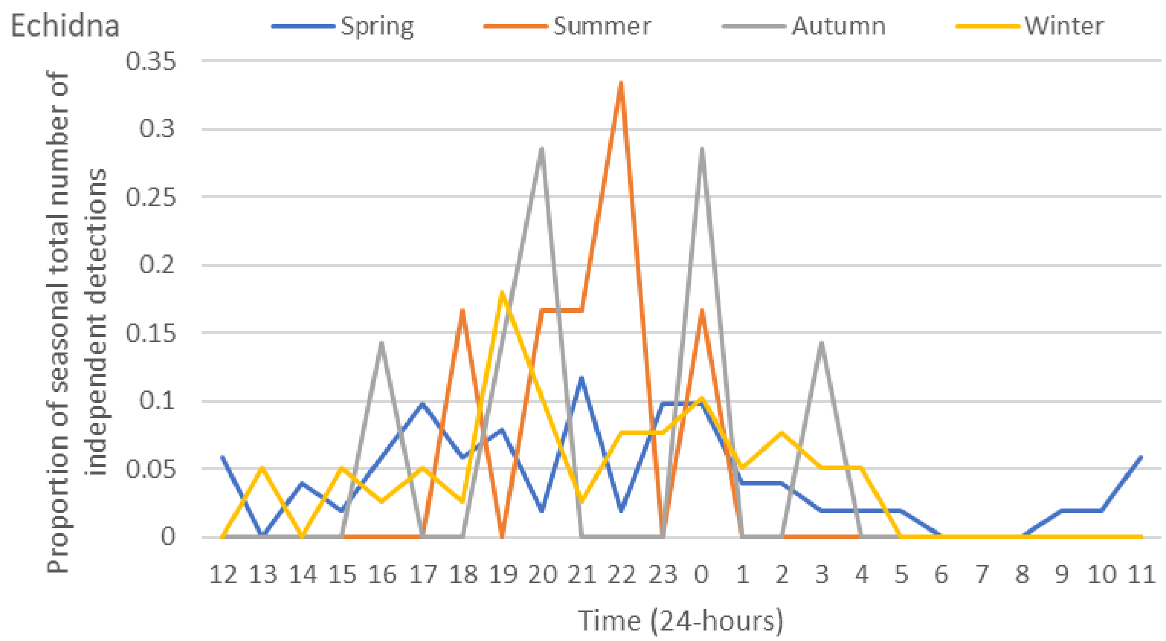

Figure 71. Tachyglossus aculeatus diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 51, 6, 7, and 39, for spring, summer, autumn, and winter, respectively).

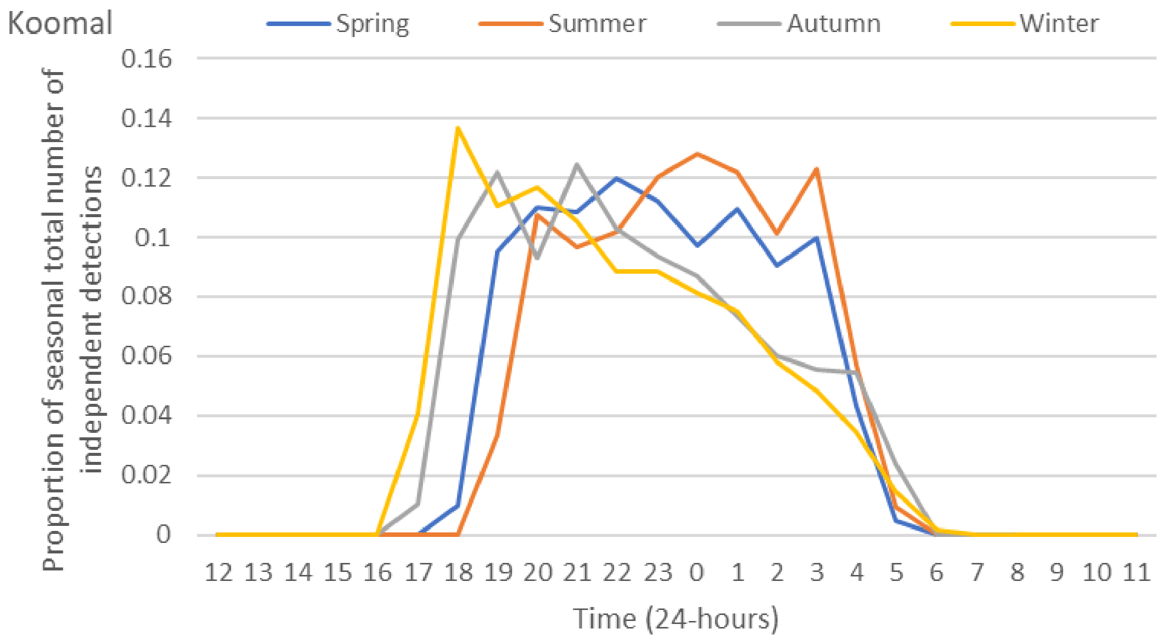

Figure 72. Trichosurus vulpecula diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 2679, 1157, 1633, and 4984, for spring, summer, autumn, and winter, respectively).

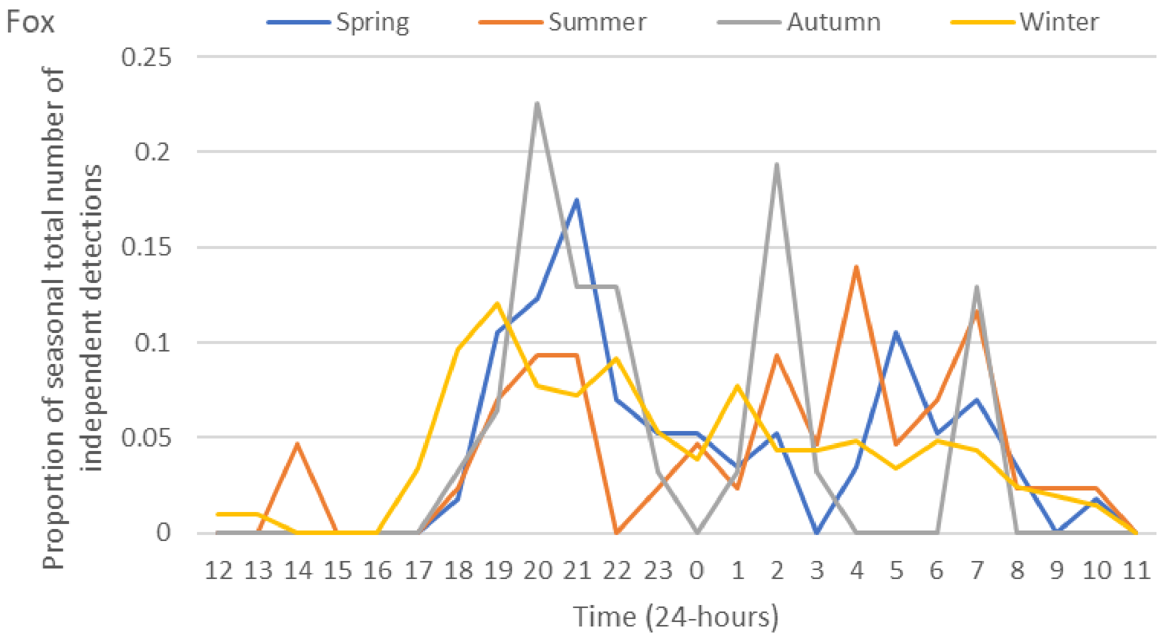

Figure 73. Vulpes vulpes diel activity by season, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 57, 43, 31, and 207, for spring, summer, autumn, and winter, respectively).

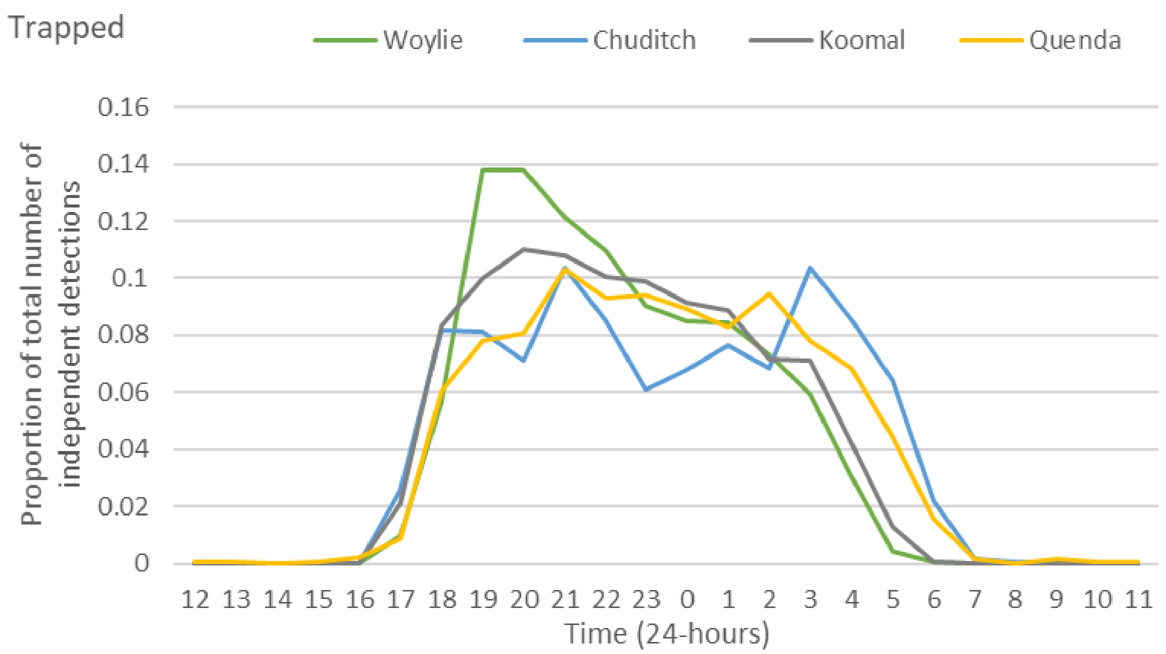

Figure 74. Diel activity of commonly trapped medium-sized native mammals, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 15724, 2405, 10453, and 1371, for B. penicillata, D. geoffroii, Tr. vulpecula and I. fusciventer, respectively).

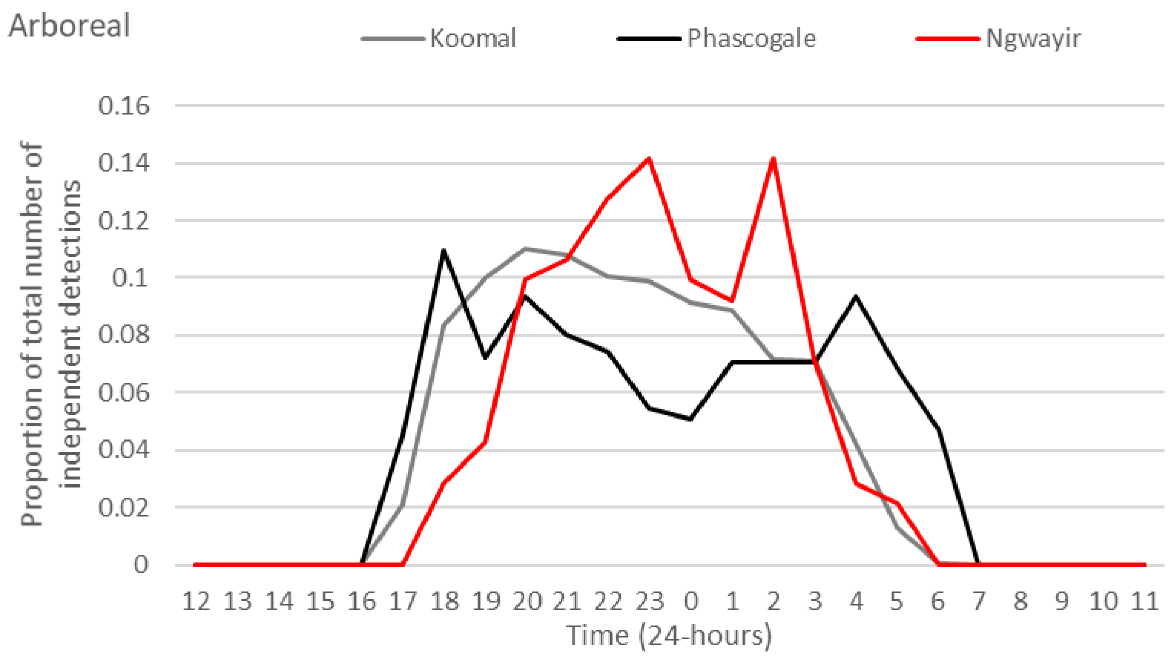

Figure 75. Diel activity of arboreal mammals, expressed as the hourly proportion of the total number of independent detection events within a given season (n= 10453, 512 and 141, for Tr. vulpecula, Ph. tapoatafa and Ps. occidentalis, respectively).

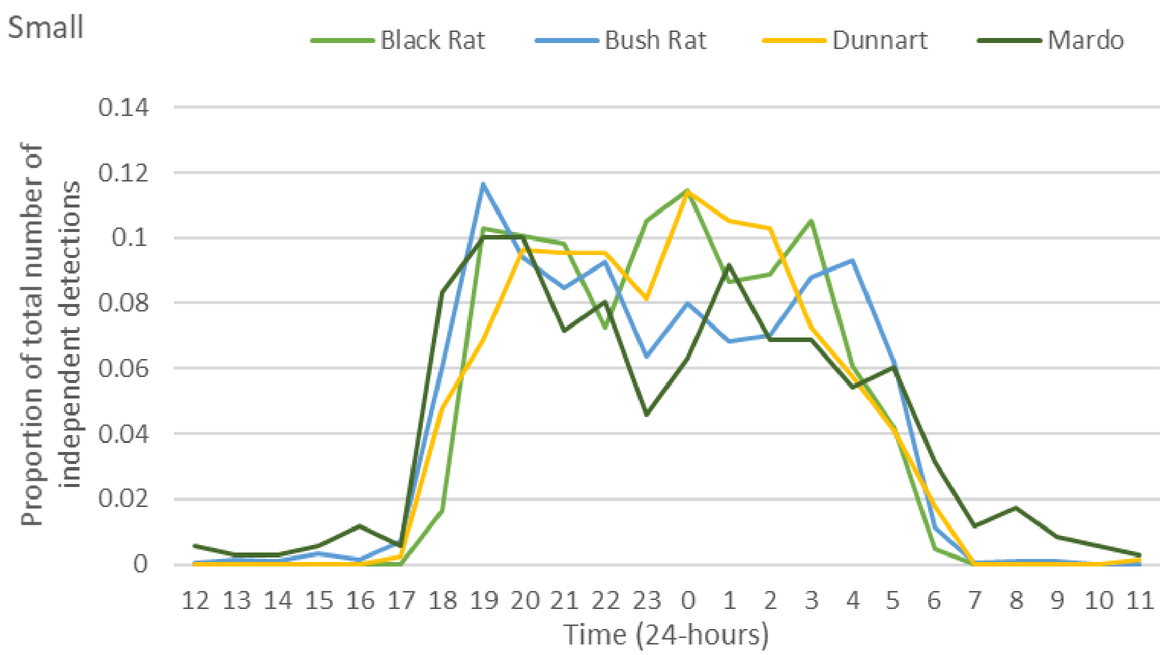

Figure 76. Diel activity of small native mammals, expressed as the hourly proportion of the total number of independent detection events (all seasons combined; n= 427, 2497, 798, and 349 for R. rattus, R. fuscipes, Sminthopsis spp. and A. flavipes, respectively).

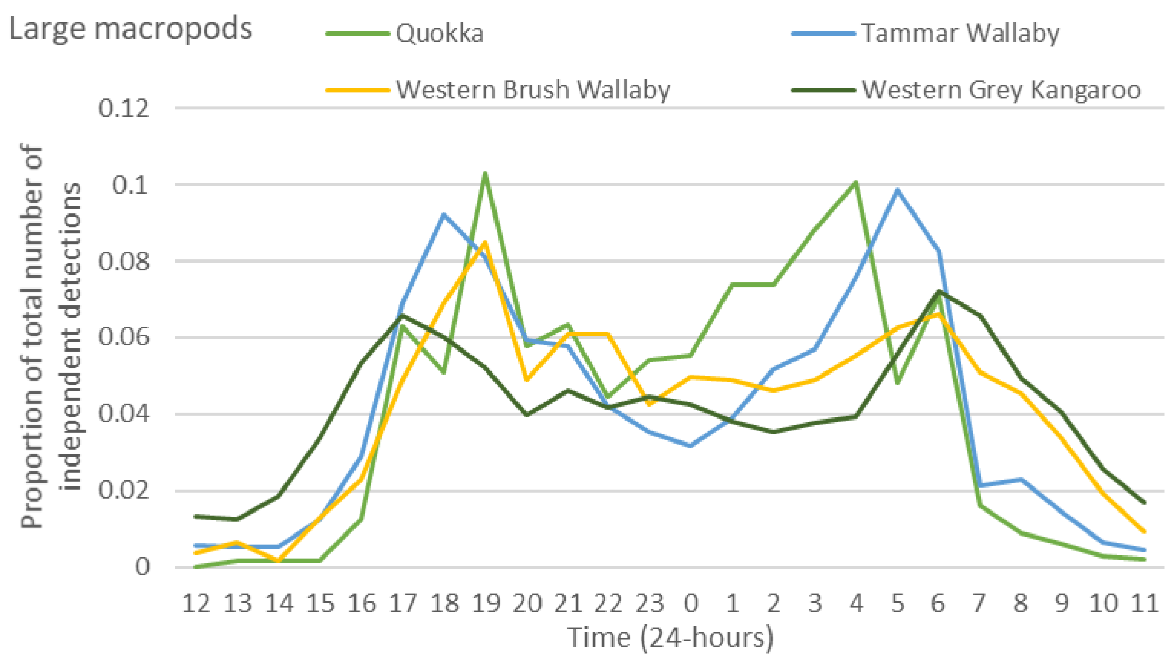

Figure 77. Diel activity of large macropods, expressed as the hourly proportion of the total number of independent detection events (all seasons combined; n= 1370, 2425, 1391 and 2174 for S. brachyurus, N. eugenii, N. irma, M. fuliginosus, respectively).

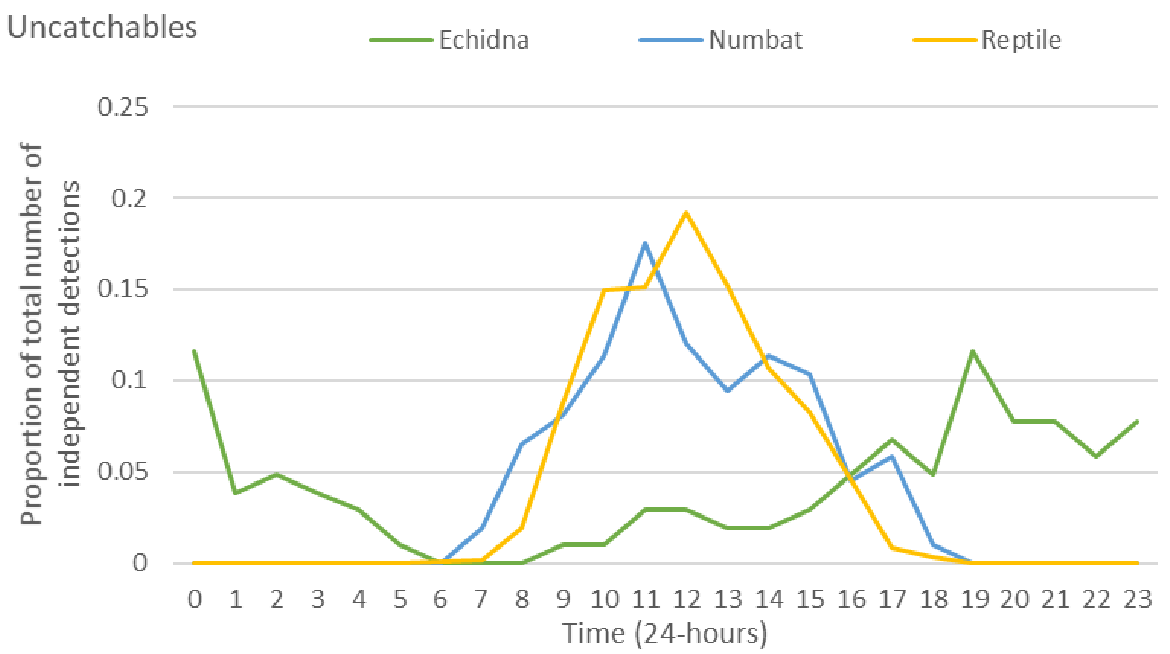

Figure 78. Diel activity of cage trap shy species, expressed as the hourly proportion of the total number of independent detection events (all seasons combined; n= 103, 308 and 1313, for Tac. aculeatus, M. fasciatus, and reptile species, respectively).

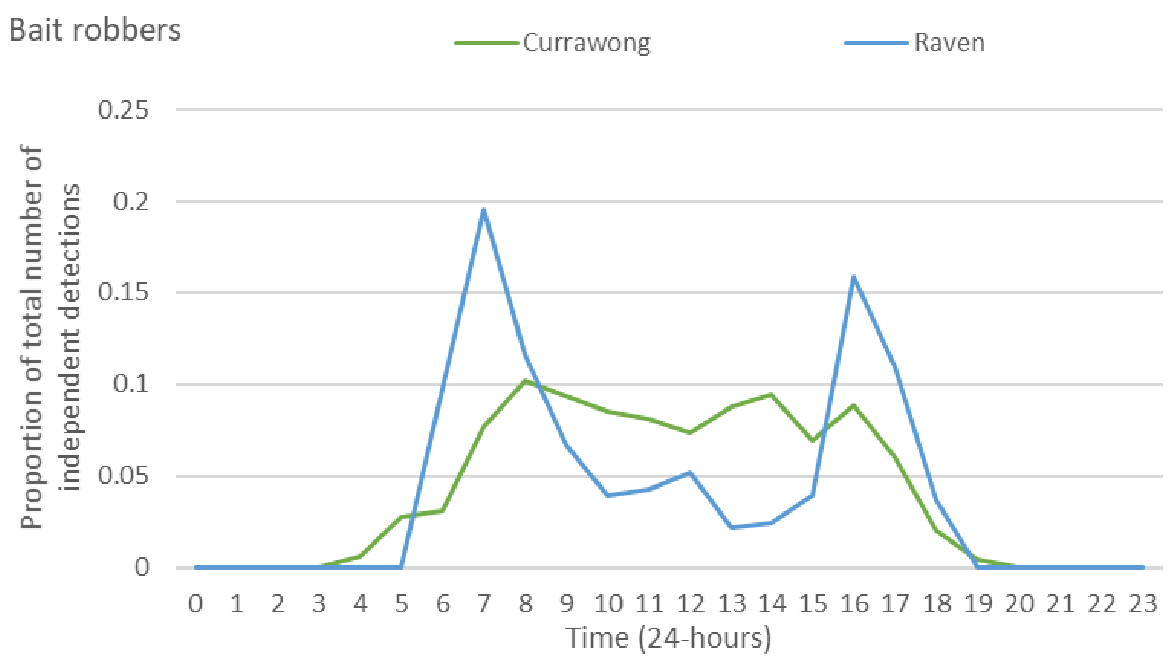

Figure 79. Diel activity of common avian non-target Eradicat® bait consumers, expressed as the hourly proportion of the total number of independent detection events (all seasons combined; n= 328 and 1394, for Corvus coronoides and Strepera versicolor, respectively).

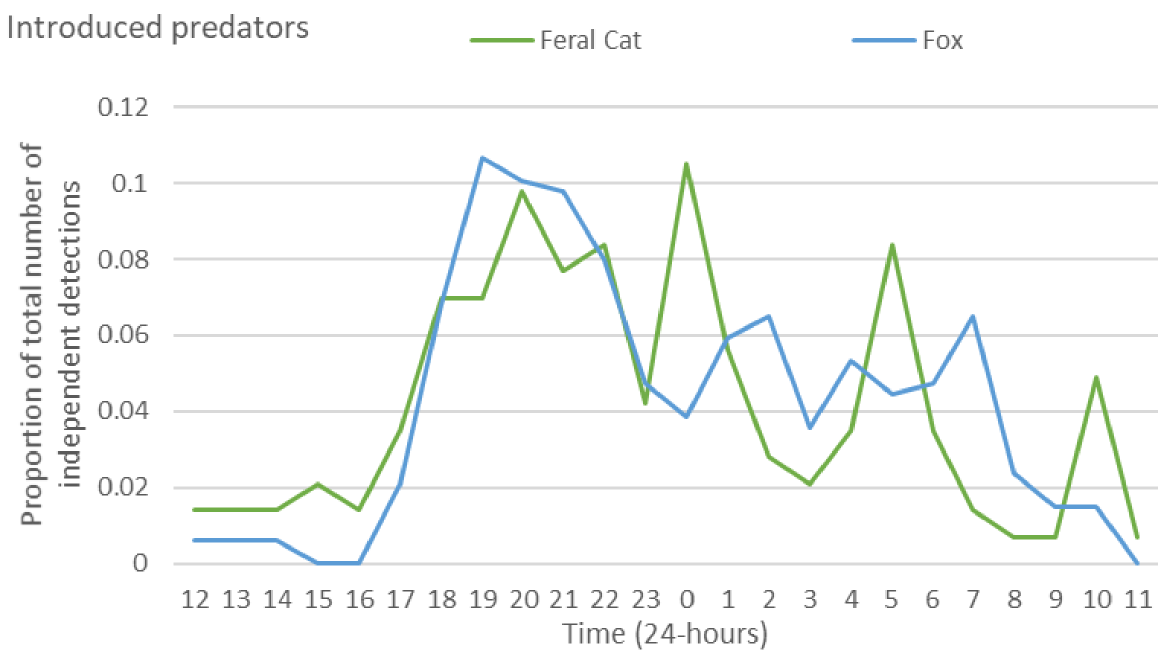

Figure 80. Diel activity of introduced predators, expressed as the hourly proportion of the total number of independent detection events (all seasons combined; n= 143 and 338, for Felis catus and Vulpes vulpes, respectively).

3.6 Fire responses

While appropriate statistical tests remain to be done, trend comparisons between burnt and unburnt sites of diel activity patterns were done for selected species using independent detection events from the autumn burn trials (May – July 2018; Figures 81 – 91). For most species investigated there were no clear differences in the diel activity patterns between burnt and unburnt sites. In some case the lack of clear difference may be in part a function of sample sizes being too small (e.g. *F. catus, N. irma, P. tapoatafa, Sminthopsis sp. and V. vulpes*; Figures 83, 87, 88, 89, and 91, respectively). In other cases, there is a higher level of confidence that the strikingly similar diel activity patterns in burnt and unburnt sites are real given the larger sample sizes (*D. geoffroii* and *Tr. vulpecula*; Figures 82 and 90 respectively). In other cases statistical tests are needed to determine whether there are significant differences, such as *I. fusciventer* whereby the peak activity in burnt areas was in the early evening but was in the last hours before dawn in the unburnt areas (Figure 84). The early evening peak activity of *N. eugenii* tended to be less pronounced and sustained longer in the burnt areas than unburnt areas (Figure 86). There was a small difference in the diel activity patterns for *B. penicillata* with a slightly more pronounced initial early evening peak and a conversely less pronounced pre-dawn peak in the burnt compared with unburnt areas (Figure 81).

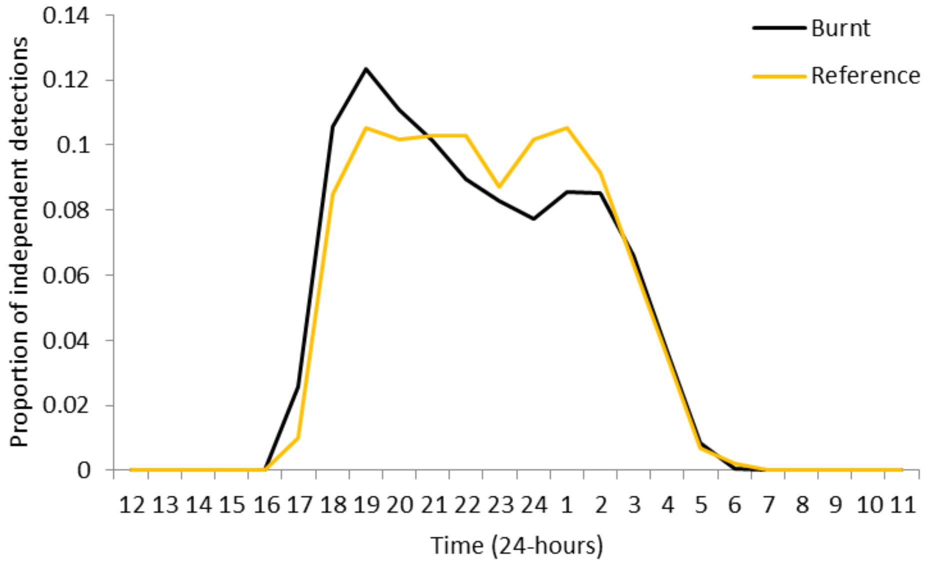

Figure 81. Bettongia penicillata diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 4169 and 885, for burnt and reference treatments, respectively).

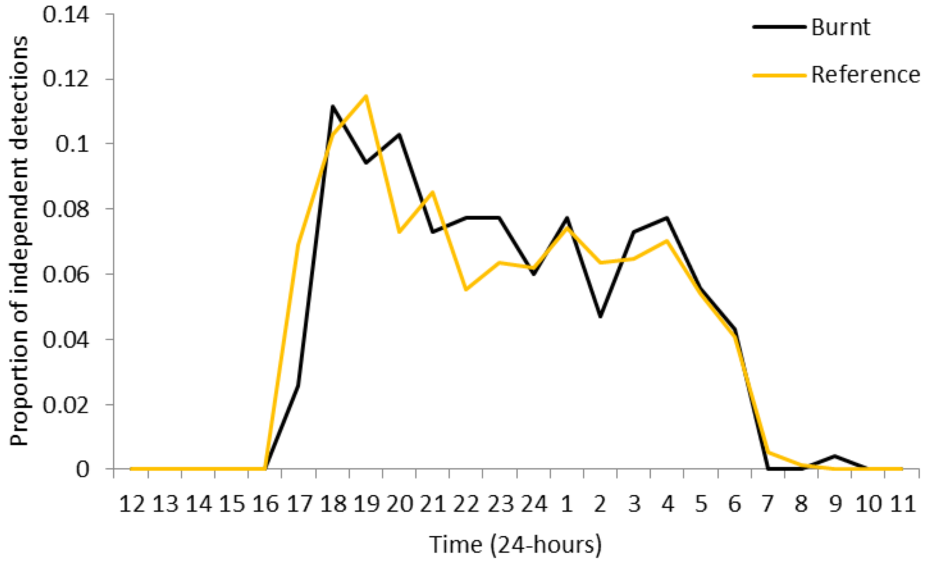

Figure 82. Dasyurus geoffroii diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 233 and 740, for burnt and reference treatments, respectively).

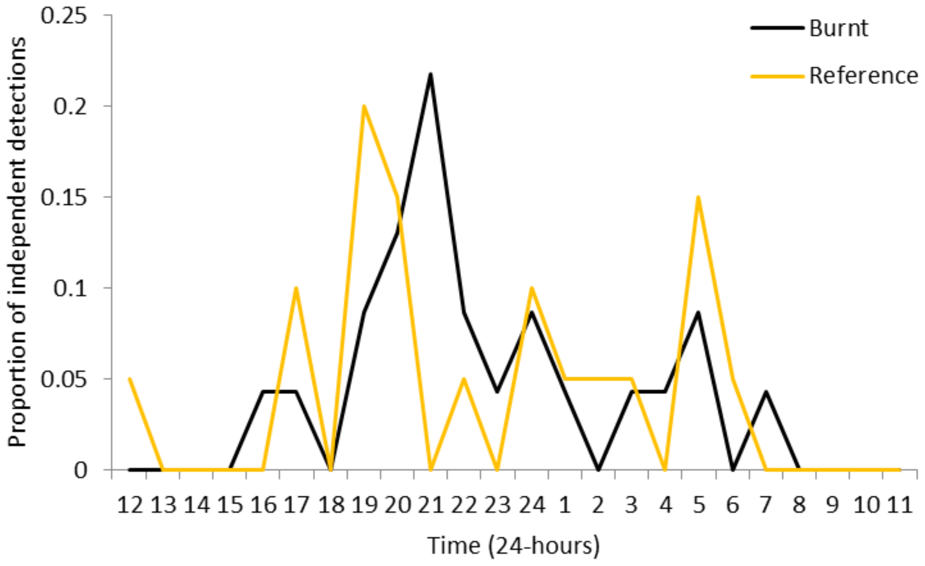

Figure 83. Felis catus diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 23 and 20, for burnt and reference treatments, respectively).

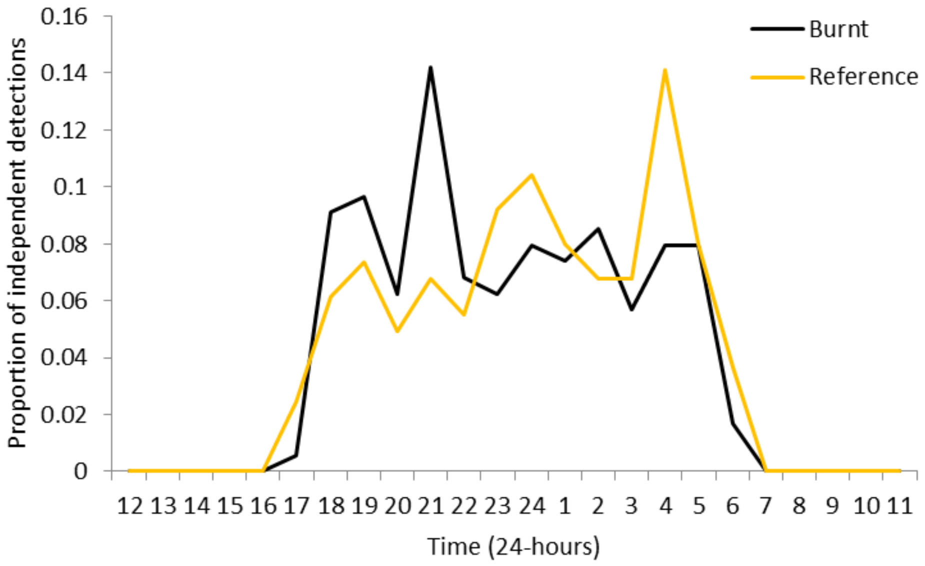

Figure 84. Isoodon fusciventer diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 176 and 163, for burnt and reference treatments, respectively).

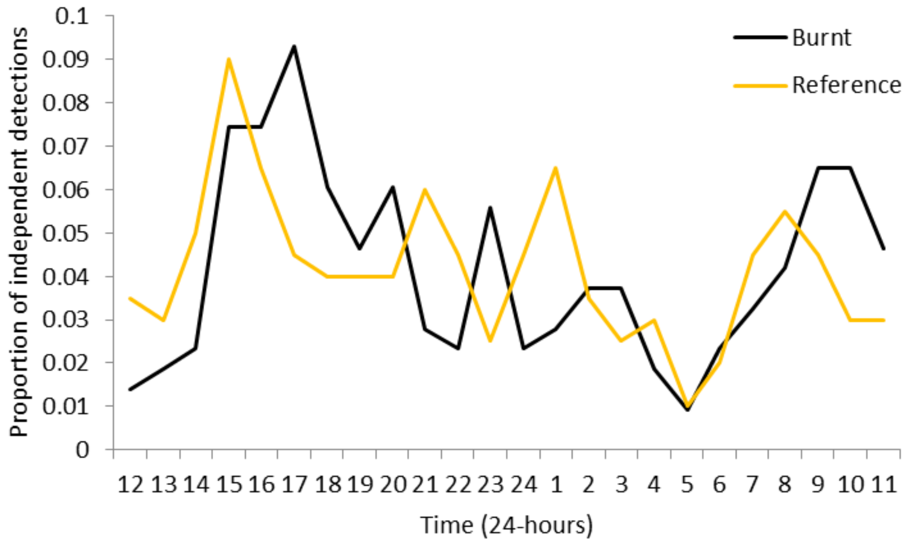

Figure 85. Macropus fuliginosus diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 215 and 200, for burnt and reference treatments, respectively).

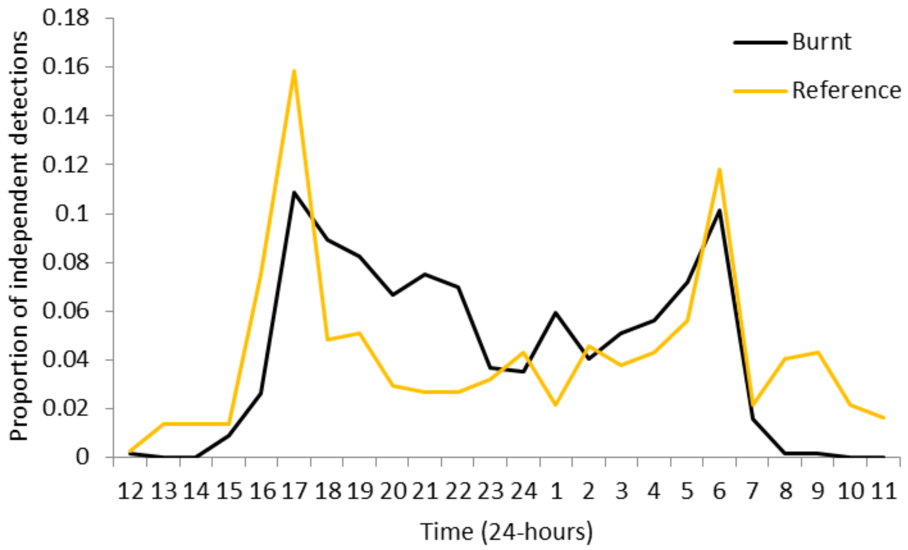

Figure 86. Notamacropus eugenii diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 571 and 372, for burnt and reference treatments, respectively).

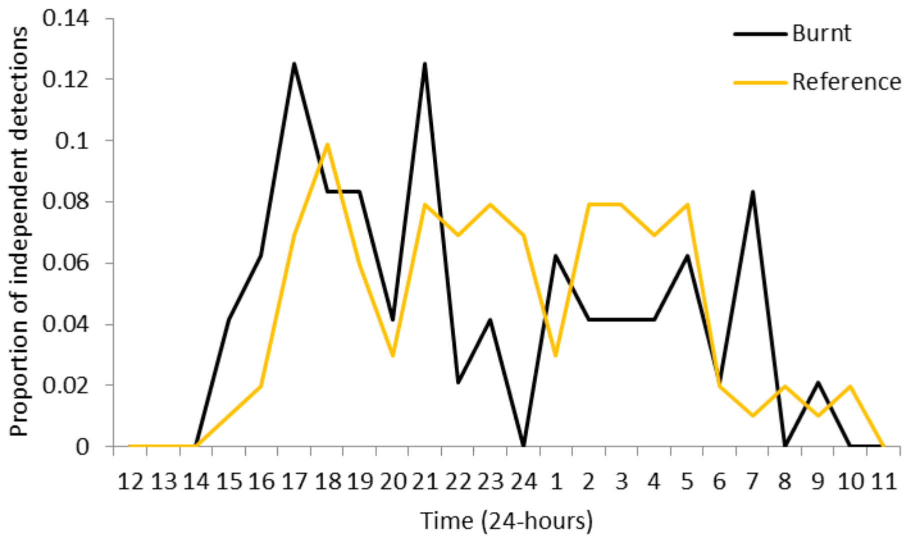

Figure 87. Notamacropus irma diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 48 and 101, for burnt and reference treatments, respectively).

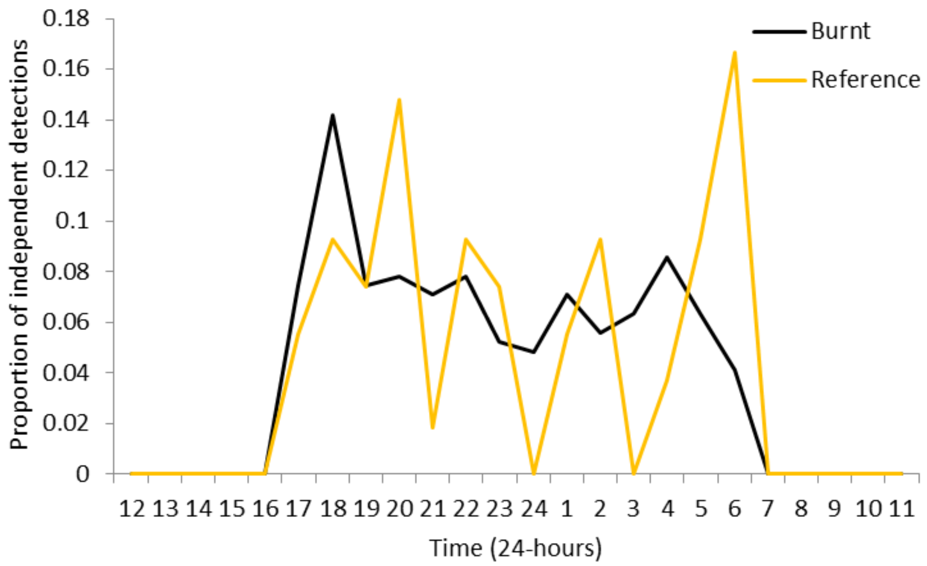

Figure 88. Phascogale tapoatafa wambenger diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 268 and 54, for burnt and reference treatments, respectively).

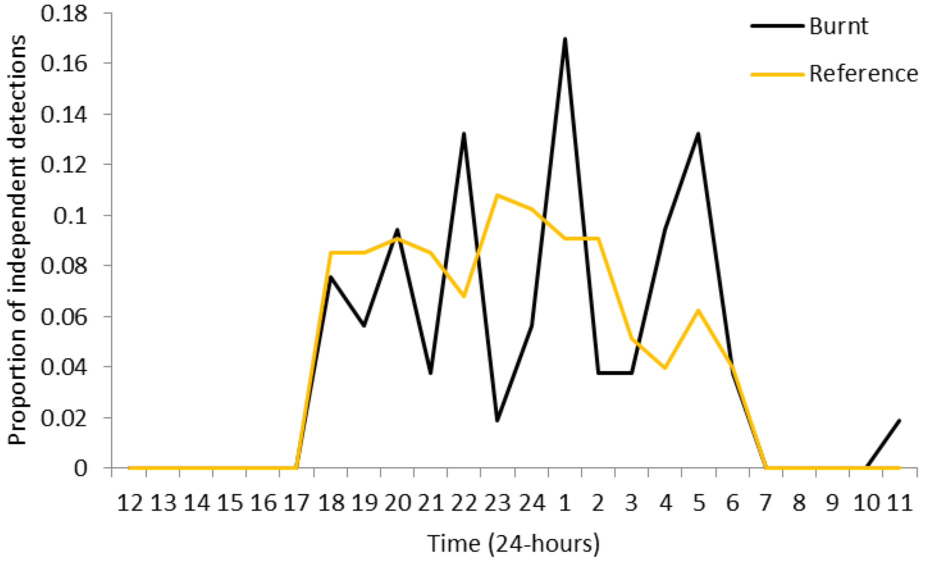

Figure 89. Sminthopsis spp. diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 53 and 176, for burnt and reference treatments, respectively).

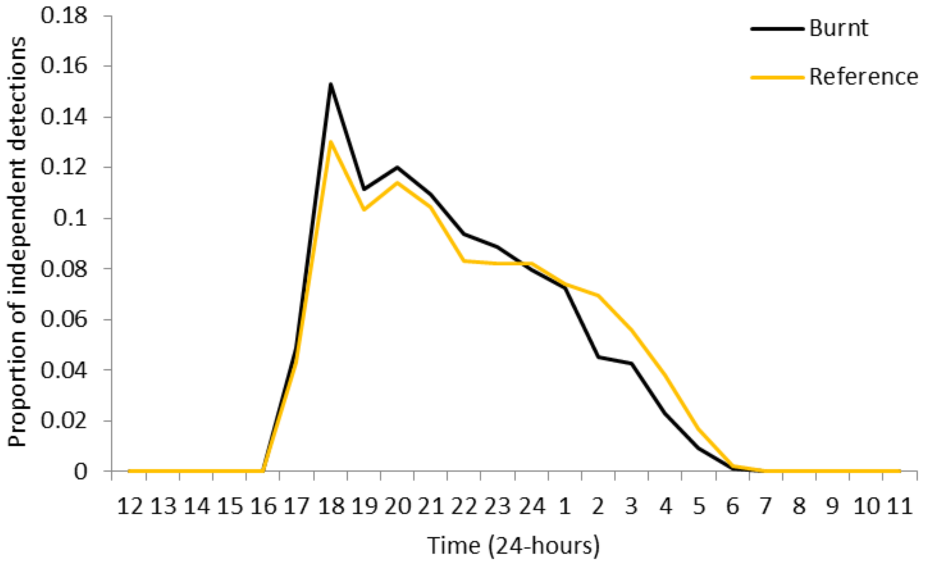

Figure 90. Trichosurus vulpecula diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 2734 and 1596, for burnt and reference treatments, respectively).

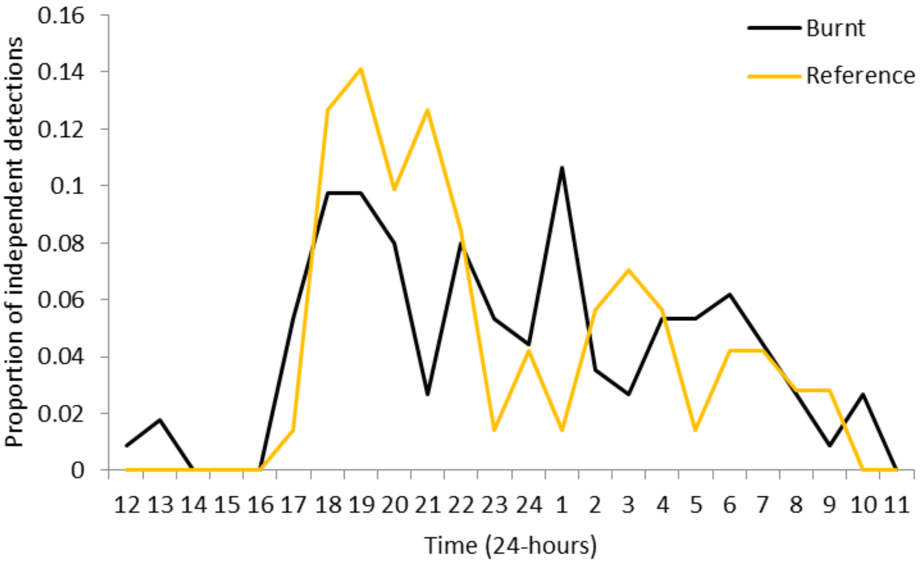

Figure 91. Vulpes vulpes diel activity by burn treatment, expressed as the hourly proportion of the total number of independent detection events (n= 113 and 71, for burnt and reference treatments, respectively).

4 Discussion

4.1 Management implications

Conservation and management in the southern jarrah forest (SJF) can be improved with the better understanding of the distribution, occupancy, species richness and spatial and temporal activity patterns of mammalian wildlife provided by this study. For example, this study has identified high-value areas for one or more priority species for conservation and priority areas for introduced species for management. Having greater clarity on high-conservation value areas can also help inform management decisions regarding other activities, such as prescribed burning and timber harvesting, to deliver improved conservation outcomes. For example, this information can assist in the identification of the threatened fauna values and risks associated with planned disturbance activities that need to be considered under the Western Australian *Biodiversity Conservation Act 2016* and Biodiversity Conservation Regulations 2018, including the taking of threatened animals.

While the Upper Warren Region (UWR) is clearly identified as particularly important for most threatened mammal species in the SJF, specific areas within the region are also clearly identified. For example, central and north-eastern UWR (i.e. the Perup and Yerraminup River catchments) had particularly high activity levels for all threatened mammals combined and for individual threatened species (e.g. *B. penicillata*, *Ps. occidentalis*, *D. geoffroii*, *My. fasciatus*, *Ph. tapoatafa* and *I. fusciventer*). The north-western and northern parts of UWR had the highest activity levels for the Priority 4 wallaby species (*N. eugenii* and *N. irma*) and *Tr. vulpecula*, while overall native mammal species richness was highest in southern parts of the UWR (e.g. Meribup, Tone and Kin Kin).

Threat mitigation and management of introduced predators and pests can also use this information to identify priorities. For example, the high levels of activity of the introduced *V. vulpes*, *F. catus* and *S. scrofa* in the western parts of the UWR were among and adjacent to high-value conservation areas for threatened mammals and may therefore, merit greater attention. Similarly, improved cat control and management in and around the highest *F. catus* activity areas in Peak forest block may provide greater, more efficient conservation outcomes for the *S. brachyurus* that had its highest activity centres in the adjacent forest blocks of Long and Crossing. Incidentally, areas of peak activity of *R. fuscipes* (O'Donnell and Collis forest blocks) were also adjacent to the high *F. catus* activity in Peak forest block. The high level of activity of introduced rodents in the western node of SJF is interesting and may be worth further investigation. The temporal activity patterns for introduced mammals may also assist in determining the most efficient and effective times for targeted control.

4.2 Ecological and behavioural insights

The dynamic nature of these ecosystems, species interactions and the changes occurring over space and time are important to consider. For example, the diversity, extent and frequency of disturbances occurring in the region, climatic and seasonal changes, significant changes in species abundances (e.g. Wayne et al. 2017), and even changes in land management practices adjacent to forest areas (e.g. livestock, cropping, plantations and introduced predator control activities) will mean that native fauna communities and species are in a constant state of flux. Therefore, the activity patterns observed in this study should be explicitly regarded as a ‘snap-shot in time’ that will continue to change.

Identifying what factors best explain the activity patterns observed in this study would substantially improve the value to conservation, management and ecology. For example, relating these fauna activity patterns to fire, timber-harvesting, introduced predator control and the management of the road network and jarrah dieback, would improve our understanding of how management activities may be influencing wildlife populations. Such insights are essential to best practice and ecologically sustainable resource and ecosystem management. Predictions of fauna responses and changes over time also become possible with an understanding of these relationships and their interactions (i.e. extending our insights beyond the ‘snapshot in time’).

Several interesting ecological insights have been gained from this study so far. These include the identification of the southern UWR (Meribup, Tone, Kin Kin forest blocks) as supporting relatively high native mammal species richness. This is best explained by the area being a transition or ecotonal zone between the mammal community most prevalent in the drier jarrah forests and woodlands (e.g. *B. penicillata*, *Ps. occidentalis*, *My. fasciatus*, *D. geoffroii*, *Ph. tapoatafa*, *N. eugenii* and *Tr. vulpecula*) overlapping with those species associated with the denser, more temperate jarrah forests to the south (e.g. *S. brachyurus*, *R. fuscipes* and *A. flavipes*).

An apparent area of comparatively low native mammal activity in the central parts of Perup Nature Reserve (Yackelup and Moopinup forest blocks; Figures 39 and 40) is somewhat intriguing and may be worth further investigation to verify whether this is real and, if so, what may account for this. Historically at least, cage trapping of medium-sized mammals has indicated this area to support comparatively high abundances of species such as *D. geoffroii*. *B. penicillata* and *Tr. vulpecula*.

Interesting temporal activity patterns include the similar crepuscular behaviour among the large macropods and the similarity between *My. fasciatus* and ectothermic reptiles. The seasonal differences in the temporal activity of many species is consistent with the time of darkness, ambient temperature and seasonal differences in food. For example, the earlier activity peak in autumn-winter by *B. penicillata* coincides with the fruiting season of their preferred food, hypogeal fungi. The relatively earlier and higher activity peak of *B. penicillata* compared with other medium-sized mammals commonly trapped in cages, may also indicate the potential for *B. penicillata* to be trapped earlier and therefore reduce the opportunity to trap other species. This has shown to be the case for *D. geoffroii* (Wayne et al. 2008) but may also be the case for other species such as *I. fusciventer* and *Tr. vulpecula*.

4.3 Values for survey and monitoring methods

While not specifically designed to survey fauna, this study demonstrates several of the benefits and values of remote sensor cameras (RSCs) for survey and monitoring. These include detecting a much broader range of species than most other survey methods used in the region such as cage trapping, spotlighting and sand pads. For some species, such as introduced predators, remote sensor cameras currently represent the best practical approach to surveying and monitoring. RSCs also generally have less animal welfare risks and ethical challenges compared with many other popular methods such as cage trapping, active searches and spotlighting. Furthermore, RSCs obtain additional types of data (e.g. behavioural and temporal activity data), not readily available from other commonly used methods. The data from RSCs can also be used to help improve other survey methods. For example, temporal activity data can be used to optimise when (season and time of day) may be best time to survey particular species, such as the *My. fasciatus* (sighting), *Ps. occidentalis* (spotlighting) and trapping (*D. geoffroii*).

There were several insights from comparisons of the detection records of selected species between this study and existing local DBCA records accumulated over several decades. They generally confirmed our current understanding of the distribution of species and demonstrated that the use RSCs in the Eradicat® study was generally effective in detecting species previously recorded in the vicinity. This study was also able to confirm the presence of some species in areas that had not otherwise been recorded by other means for some time. This study also extended the known ranges and/or substantially increased the number of records of several mammal species, including animals as small as *Tar. rostratus* and *Ce. concinnus*.

While there are many advantages to the use of RSCs, their limitations need to be carefully considered. The pilot trials that preceded this study (Baraud 2016, A. Wayne unpublished data) highlight the importance for the need for extreme care when it comes to setting up RSCs in the field. While many users of RSCs simplistically believe their equipment is working adequately because 'lots of fauna' are detected, it is often underappreciated what is *not* detected and therefore how ineffective the equipment may be. For example, our pilot trials showed that small and simple differences in the camera set up improved our detection of Eradicat® bait removal events from 12% (Baraud 2016, A. Wayne unpublished data) to 80% in the first trials and 99% in the second, autumn burn trials (Wayne et al. in prep). The differences in the effective detection rates between the first and second bait up take trials are thought to be a function of temperature and season, with small reptiles removing many of the baits in warm ambient conditions in Spring and Summer. Other factors that can affect whether an animal is detected or not include its size, distance from and angle of approach to the RSC, thickness of their coat (mammals), the temperature differentials between the animal and the ambient conditions, whether the animal has a wet coat and whether the relatively warmer parts of the body (e.g. face and anus) are oriented toward the camera's infrared sensors (Paul Meek pers. com.).

There are also substantial differences between and within models, and even within the same camera with different settings, over time and as a result of servicing (Baraud 2016, Meek et al 2015, A. Wayne unpublished data). The location of RSC in relation to specific habitats may also change the detection of those species with more specific habitat associations (e.g. *Ta. rostratus*).

The time and resources required for the effective use of RSCs as a tool for survey and monitoring is also often grossly underestimated. Simplistically, RSCs can be considered comparatively quicker and easier than other methods such as cage trapping. But comparisons are often poorly made. For example, the time taken to manage the image data from RSCs is frequently grossly underestimated. In this study, image processing times and the quality of data management varied greatly between individuals and the additional time for data validation was considerable. Appropriate comparisons also need to explicitly consider the type of data that can and cannot be collected using different methods, and their suitability for addressing the specific needs and questions being addressed. Sensible comparisons also carefully consider having an appropriate design and adequate sampling effort (number of sites and RSCs and survey duration), which remains critically important to determining the quality of the data, the confidence in the results, and therefore, the value of the study. The risks of RSC theft and damage, also needs to be considered in terms of cost and the extent to which it may compromise the study.

4.4 Future work

The data from this study is suitable for further development. More detailed modelling that relates species occupancy and activity patterns to habitat and management would be valuable and relatively straight forward. It could include habitat data collected at these sites during the study and pre-existing data relating to timber harvesting, fire, fox-baiting, climate, jarrah dieback, forest fragmentation and other landscape attributes (e.g. proximity to agriculture and hydrographic features, landscape position, road network density, etc.). The autumn burn trials also provide meaningful opportunities to investigate animal responses to fire. For instance, occupancy modelling of the seven sites involved in these trials could include the autumn burn treatment as a covariate. Investigating differences between fauna responses at the edge and core of burns also remains to be done.

Using the results from these multivariate analyses to improve the spatial interpolation and prediction of fauna responses to different management and disturbance regimes would be particularly helpful for biodiversity conservation and forest management. By further extension this would help to identify and develop optimal management regimes required for specific outcomes. These developments would be particularly helpful to DBCA's *Western Shield* program (focussing on introduced predator management, and native fauna recoveries and translocations) and the Fauna Distribution Information System (FDIS) used to inform the planning of timber-harvesting and prescribed burning activities. In the meantime, the current results also present an opportunity to review and validate the DBCA's existing (FDIS) by comparing the species-habitat associations between these two sources.

Temporal activity patterns of priority species could also be investigated using appropriate analysis methods that include covariates (e.g. season, fire history, weather and climatic factors, and interactions between species). Investigating spatio-temporal interactions between species (e.g. predator-prey relationships and competitors) may also be insightful.

Future surveys and monitoring can also be informed by this study to help improve their efficiency and effectiveness. For instance, monitoring of threatened and priority mammals in the SJF can focus on the UWR where species richness and activity was greatest. A consistent spatial and temporal sampling design, higher spatial resolution (e.g. 3-5 km distances between sites) and longer survey duration per site are obvious improvements that could be made for a dedicated monitoring program. The collection of covariate data at all sites that may help to explain spatio-temporal variations in mammal species would also substantially improve the value of the monitoring program (e.g. Legge et al. 2018). Designing the survey and monitoring to reliably infer abundance or density (e.g. spatially explicit capture-recapture) of priority species (e.g. threatened species and introduced predators) would also be a substantial improvement if it can be shown to be reliable and practical to do so.

There would also be considerable benefits from improving the management of and access to existing species data collected across a range of methods, by a range of groups over many years. It is worth noting that currently there is no straightforward, consistent, reliable or timely way to comprehensively access all corporate records of mammalian wildlife within any of the forest biomes in south-western Australia. While some platforms exist (e.g. Fauna File, Nature Map and BioSys), they all currently have their limitations that reduce their utility. Better data validation and quality control, the centralisation of all relevant corporate datasets and maintaining currency would substantially increase the value of this data for management and conservation.

In conclusion, this study demonstrates the value of RSC in the survey and monitoring of a broad suite of species, many of which are otherwise difficult to adequately detect by other methods (e.g. *F. catus, Ce. concinnus, Tac. aculeatus, Tar. rostratus* and *V. vulpes*). Data from a well-designed programme using RSC can complement other methods (e.g. trapping, spotlighting, sign surveys) to understand population dynamics of priority species for conservation and management. It also provides an indication of the substantial benefits of having a regional-scale survey and monitoring program that is appropriately designed to demonstrate fauna responses to management and conservation activities and spatio-temporal, environmental and population changes at the landscape and biome scale. Developing such a programme is a fundamentally important in the department’s ability to more effectively and efficiently deliver better biodiversity conservation and management outcomes, and is therefore highly recommended.

Appendices

Appendix 1 Adjusted detection rates of mammals from remote sensor cameras in the first bait uptake trials in the southern jarrah forest (September 2016 – November 2017).

SiteNo	Site	*Antechinus flavipes*	*Bettongia penicillata*	*Dasyurus geoffroii*	*Felis catus*	*Isoodon fusciventer*	*Macropus fuliginosus*	*Mus musculus*	*Myrmecobius fasciatus*	*Notamacropus eugenii*	*Notamacropus irma*	*Phascogale tapoatafa*	*Pseudocheirus occidentalis*	*Rattus fuscipes*	*Rattus rattus*	*Setonix brachyurus*	*Sminthopsis spp.*	*Sus scrofa*	*Tachyglossus aculeatus*	*Trichosurus vulpecula*	*Vulpes vulpes*
1	Dalgarup	9	0	0	0	70	49	0	0	0	0	0	0	71	50	0	23	0	0	11	0
2	Gregory	43	0	0	0	4	17	1	0	0	1	1	0	1	25	14	1	3	0	1	2
3	Ellis Creek	29	0	0	4	0	20	74	0	0	0	0	0	11	31	13	3	5	0	1	4
4	Netic	5	0	0	7	0	21	0	0	0	2	0	0	0	1	28	0	0	0	39	3
5	Carter	48	0	0	4	3	14	29	0	0	35	1	2	4	9	5	1	0	0	255	3
6	Dudijup	0	412	6	11	27	94	0	8	242	19	0	1	0	0	0	2	0	4	224	13
7	Kingston	0	386	62	5	14	24	38	0	234	11	0	6	0	4	0	11	14	0	578	13
8	Dwalgan	0	1751	25	2	35	62	0	22	0	39	2	58	0	0	0	7	2	0	182	2
9	Balban	0	1639	55	1	33	31	0	26	208	1	6	2	0	0	0	7	2	89	399	2
10	Easter	0	0	0	0	3	6	0	0	0	127	8	0	0	28	1	0	0	0	1	0
11	Lewin	0	0	0	3	5	10	0	0	0	0	0	0	18	40	58	0	0	0	0	0
12	Warrup	0	202	21	5	30	30	1	5	72	7	4	5	3	0	0	5	0	15	375	4
13	Yerramin	0	216	69	0	18	36	0	37	19	14	13	5	0	0	0	18	0	0	211	2
14	Yackelup	0	658	62	0	21	13	0	7	68	0	0	0	0	0	0	5	0	9	103	0
15	Moopinup	0	436	82	0	8	43	0	0	0	0	4	0	0	0	0	10	0	14	279	6
16	Cardac	0	0	30	2	2	135	0	0	0	66	1	0	0	0	0	2	0	0	102	9
17	Yeticup	0	182	31	1	49	70	0	17	0	54	25	1	0	0	0	19	0	0	178	14
18	Weinup	0	198	265	0	166	23	1	9	0	38	14	0	0	0	0	12	0	0	79	4

SiteNo	Site	*Antechinus flavipes*	*Bettongia penicillata*	*Dasyurus geoffroii*	*Felis catus*	*Isoodon fusciventer*	*Macropus fuliginosus*	*Mus musculus*	*Myrmecobius fasciatus*	*Notamacropus eugenii*	*Notamacropus irma*	*Phascogale tapoatafa*	*Pseudocheirus occidentalis*	*Rattus fuscipes*	*Rattus rattus*	*Setonix brachyurus*	*Sminthopsis spp.*	*Sus scrofa*	*Tachyglossus aculeatus*	*Trichosurus vulpecula*	*Vulpes vulpes*
19	Boyicup	0	1160	36	2	76	60	0	9	6	16	0	2	0	0	0	6	0	101	302	2
20	Chariup	0	0	30	1	7	128	0	0	5	44	1	1	2	0	0	16	0	1	237	10
21	Carey	8	0	0	0	0	41	0	0	0	0	0	0	0	54	4	1	11	0	0	5
22	Meribup	3	199	1	2	2	61	0	8	70	5	4	3	6	4	22	37	0	2	272	4
23	Flybrook	1	0	0	0	0	24	0	0	0	28	0	0	0	20	0	6	0	0	0	0
24	Kin Kin	12	7	14	0	6	21	15	0	2	26	6	0	28	19	1	2	0	2	300	3
25	Tone	6	0	3	2	2	13	2	3	41	11	11	0	1	0	6	12	3	4	172	6
26	Stoate	0	5	57	2	0	4	0	0	11	73	21	0	1	0	0	16	0	3	56	7
27	Poole	33	7	0	4	0	3	0	0	0	0	0	0	369	1	3	0	1	2	0	0
28	Curtin	6	0	0	4	0	12	0	0	65	0	0	0	2	6	21	0	2	0	2	0
29	Mindanup	1	0	0	0	0	4	0	0	0	34	5	0	0	1	50	22	0	0	1	0
30	Poorginup	0	0	0	0	0	41	6	0	0	27	0	0	0	0	28	6	0	0	0	3
31	Chitelup	0	0	17	3	0	92	4	0	0	90	4	0	0	0	6	25	3	0	4	3
32	Hiker	0	0	51	2	0	14	0	0	0	83	7	0	0	0	0	23	0	0	0	0
33	Long	0	0	96	4	104	0	2	0	0	0	0	0	110	0	323	15	0	0	0	4
34	Karara	1	0	0	4	3	35	11	0	0	8	1	0	15	9	36	29	0	0	4	1
35	Northumberland	5	0	0	5	15	2	0	0	0	0	0	0	57	3	96	8	0	0	0	5
36	Table Hill	2	0	0	3	8	9	9	0	0	13	0	0	289	13	4	53	0	0	2	4
37	O'Donnell	23	0	4	2	7	4	4	0	0	30	4	0	304	1	40	0	6	0	0	0
38	Peak	3	0	44	17	27	0	0	0	0	18	0	0	96	1	64	0	0	0	0	0
39	Crossing	0	0	49	0	9	8	0	0	0	0	0	0	6	0	262	9	0	0	11	0
40	Collis	6	0	0	8	15	10	0	0	0	0	2	0	348	1	13	2	4	0	0	0

Glossary

DBCA	Department of Biodiversity, Conservation and Attractions
FDIS	Fauna Distribution Information System
IDW	Inverse Distance Weighting (spatial interpolation modelling)
LCU	Landscape Conservation Unit
RSC	Remote sensor camera
SJF	Southern jarrah forest
SWTFRP	South West Threatened Fauna Recovery Project
UWR	Upper Warren Region

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