Invasive mesopredator release

Supplementary material

MW Rees

2021-07-30

Contents

1 Survey methods

1.1 Timeline

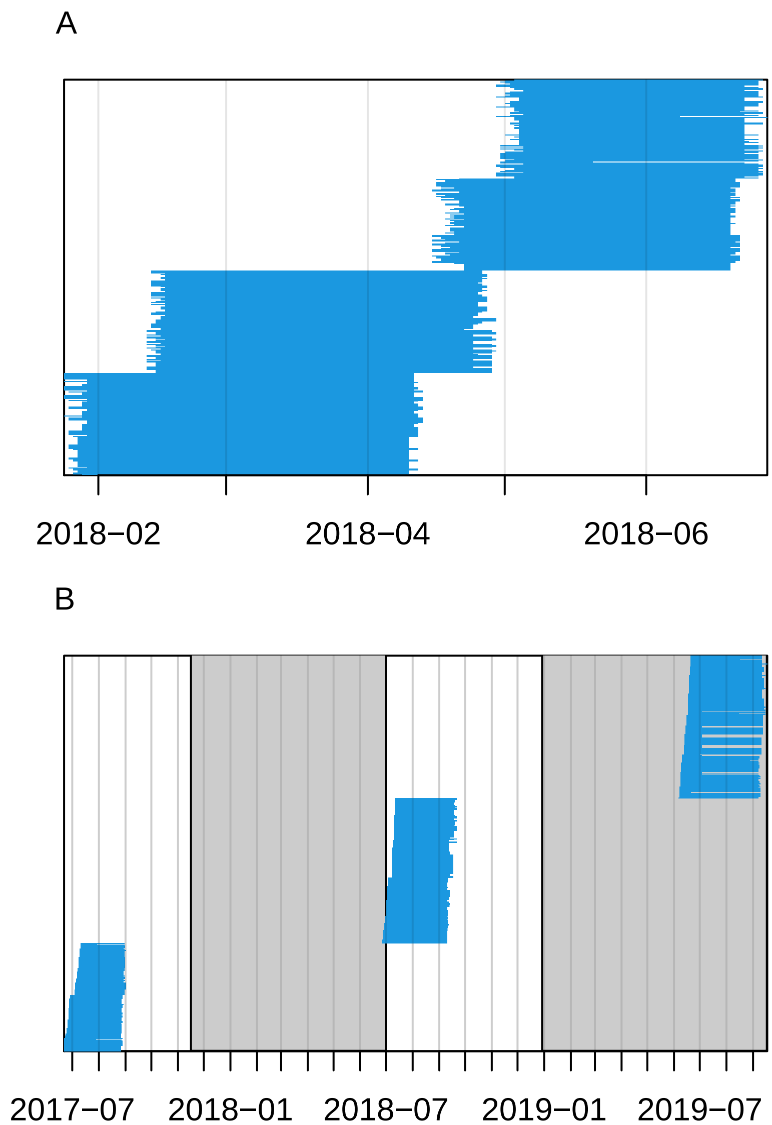

Figure 1: Camera-trap operation times in the Glenelg region (A) and Otway Ranges (B). Each blue, horizontal line represents one camera-trap. Grey shading indicates periods of fox control in the Otway Ranges.

1.2 Camera-trap deployment

In the Glenelg region, we deployed camera sites once, whereas in the Otways, we redeployed cameras three times annually. All 2017 camera-sites were resurveyed each year, except for four logistically challenging sites in the southern grid. In 2018, we added 16 additional sites in the southern grid, as well as 36 additional sites in the northern grid. These additional sites were resurveyed in 2019. Camera-trap grids ranged from 3442 - 7819 camera-trap nights across both regions (Table 1).

At each site, we deployed a singular remote trail camera with infrared flash and temperature-in-motion detector. The vast majority of cameras were Reconyx Hyperfire HC600, but a small proportion were PC900's HF2X's, infrared camera-traps (Reconyx, Holmen, Wisconsin). We programmed camera's to their highest sensitivity and to take five consecutive photographs when triggered (no quiet period). We attached each camera to a tree, approximately 30 cm above the ground, and facing toward a lure 2 - 2.5 metres away. The lure comprised an oil-absorbing cloth doused in tuna oil and placed inside a PVC pipe container with a mesh top. We secured each lure to the top of a 1 metre wooden stake and attached a handful of small white feathers to the outside of the PVC pipe container. We cleared vegetation in the camera's line-of-sight to reduce false triggers and avoid obscuring cat coat markings in images. While these cameras were aimed to target predators, they were also effective at detecting mammalian prey species.

Figure 2: Example of a camera-trap set-up

2 Individual cat identification

We first labelled every camera-trap image with a species metadata tag using DigiKam software www.digikam.org. We also tagged cats based on their coat type: black, mackerel tabby, classic tabby, ginger and other: coats with multiple colour blends (Fig. 3). This allowed us to summarise species detections and extract cat images using the "camtrapR" R package (Niedballa et al., 2016).

We considered all black cats to be of the 'unmarked' category in spatial mark-resight models - even the few with white splotches on their underside (these couldn't always be seen as cats move with their head down).

In the remaining coat categories, we identified individual cats based on their unique coat markings. The ability to identify individuals substantially increased as the image library for each cat increased. Therefore we made the easiest identifications first to build up these libraries, before making decisions on the less obvious detections. We examined and matched all coats markings seen between two particular defections. Markings on the front legs were most often seen and particularly useful for ID's as the patterns do not skew as much with different body positions. On the whole, unidentifiable detections were mainly due to only part of a cat appearing in the frame, or because photos were blurry (fast moving cats or a fogged up camera lens).

However, we were left with a small number of instances (less than ten) where only left or right flanks could be seen. In this case, the side with the most repeat detections was labelled as an individual, whereas the side with the least number of detections was considered unidentifiable.

Additionally, an extremely small portion of cats in the Otways had ginger coats. When ginger coats are photographed with an infrared flash, they become overexposed and appear consistently white (bottom-right corner in Fig. 3). We only had one detection of a ginger cat without an infrared coat. Therefore, if there were multiple ginger cat detections in a single grid, we treated them in the same way as one-sided flank detections.

One observer identified the feral cats in the Glenelg region (MR). In the 2017 and 2018 Otway datasets, where there were substantially more cat detections and fewer distinct coat patterns, two independent observers identified individual cats and discrepancies between observers were reviewed together until consensus was reached (MR, MLP, BH). If no consensus could be reached, the cat was considered unidentifiable. In the 2019 Otway dataset, many of the identified cats were sighted in the previous surveys – these larger individual libraries meant that cats could be identified more easily so only one observer was necessary (MR). We also made use of additional cat images taken within the Otway grids (just before each of our surveys) by white flash camera-traps from a complementary study (Z. Banikos, unpublished data). This provided additional and higher quality images (due to the white flash) of individuals.

We were therefore left with three groups of cats: unmarked (black cats), marked (cats which could be identified to the individual-level with complete certainty) and mark status unknown (cats which were not black, but couldn't be identified to the individual level with complete certainty).

We discarded detections of cats which were obviously young enough to be dependent on a parent, as these kittens do not have independent activity centres or movements and not yet recruited into the adult population.

Figure 3: Feral cat coat categories.

3 Summary statistics

Table 1: Camera-trap surveys and feral cat spatial capture-recapture summary statistics.

Landscape	Fox control?	Camera-traps	Trap nights	Identified cats	Identified detections	Unidentified detections	Unmarked detections
Annya	no	110	8000	9	23	3	20
Cobbob	yes	110	7752	13	35	9	37
Hotspur	no	99	6085	8	22	3	13
Mt Clay	yes	106	5451	10	33	5	0
North 2017	no	67	3565	26	60	8	46
South 2017	no	73	7099	20	62	4	48
North 2018	yes	103	7838	30	90	12	62
South 2018	no	85	4543	24	75	17	59
North 2019	yes	99	6077	27	90	22	101
South 2019	no	86	7150	25	133	23	58

Note: There is a maximum of one detection per each 24-hour occasion.

4 Feral cat detection plots

4.1 Glenelg

4.1.1 Pair 1

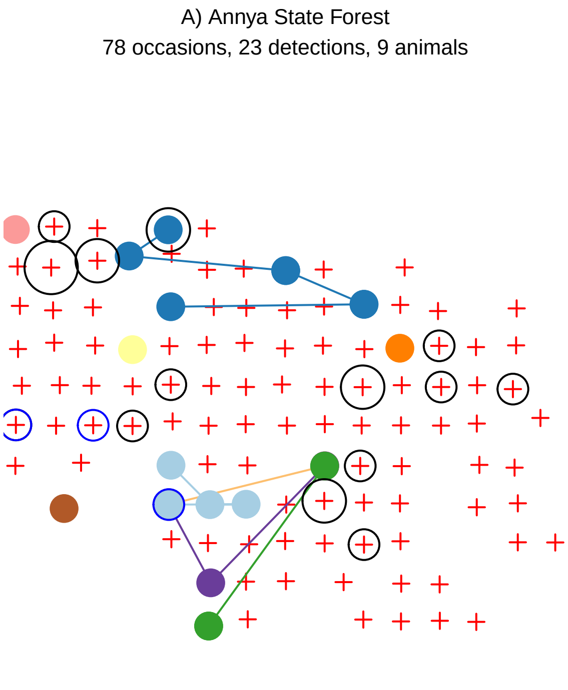

Figure 4: Feral cat detections in the first grid pair of the Glenelg region. Camera-traps are indicated by red crosses. Circles with coloured fills represent individual cats and lines denote thier observed movements. Black circles represent black cats, blue circles unidentifiable detections (the circle radius scales positively with the number daily detections). Fox control does not occur in Annya (A) but has since 2005 in Cobboboonee (B).

4.1.2 Pair 2

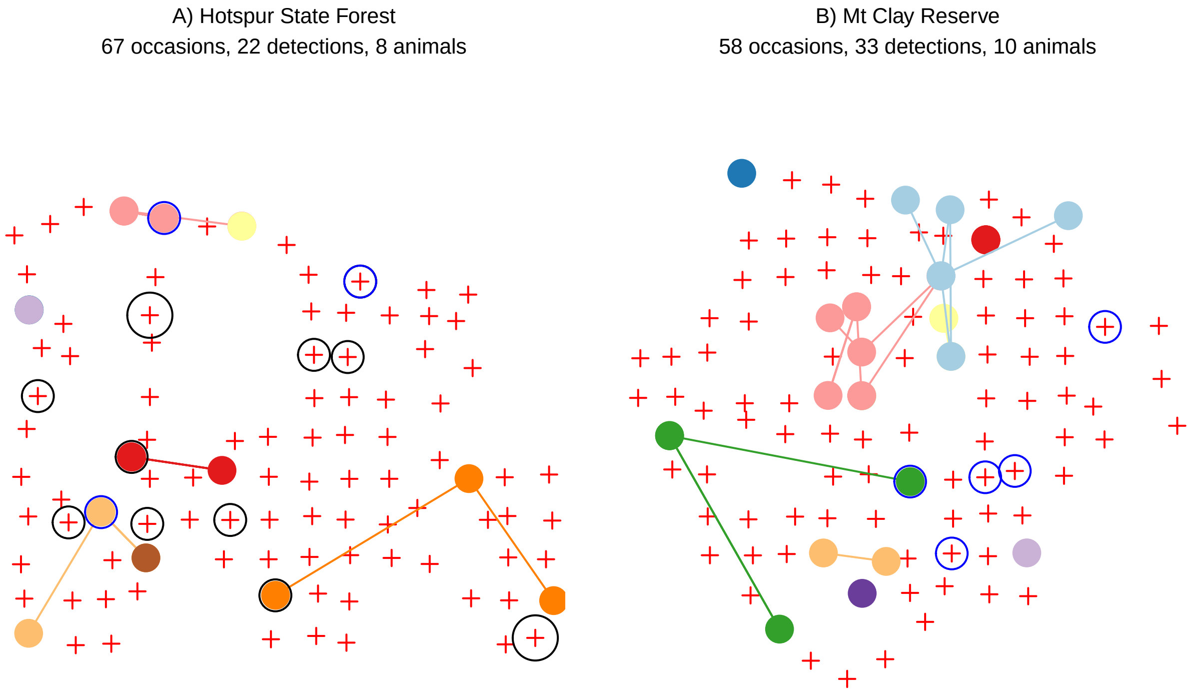

Figure 5: Feral cat detections in the second grid pair of the Glenelg region. Camera-traps are indicated by red crosses. Circles with coloured fills represent individual cats and lines denote thier observed movements. Black circles represent black cats, blue circles unidentifiable detections (the circle radius scales positively with the number daily detections). Fox control does not occur in Hotspur (A) but has since 2005 in Mt Clay (B).

4.2 Otway Ranges

4.2.1 2017

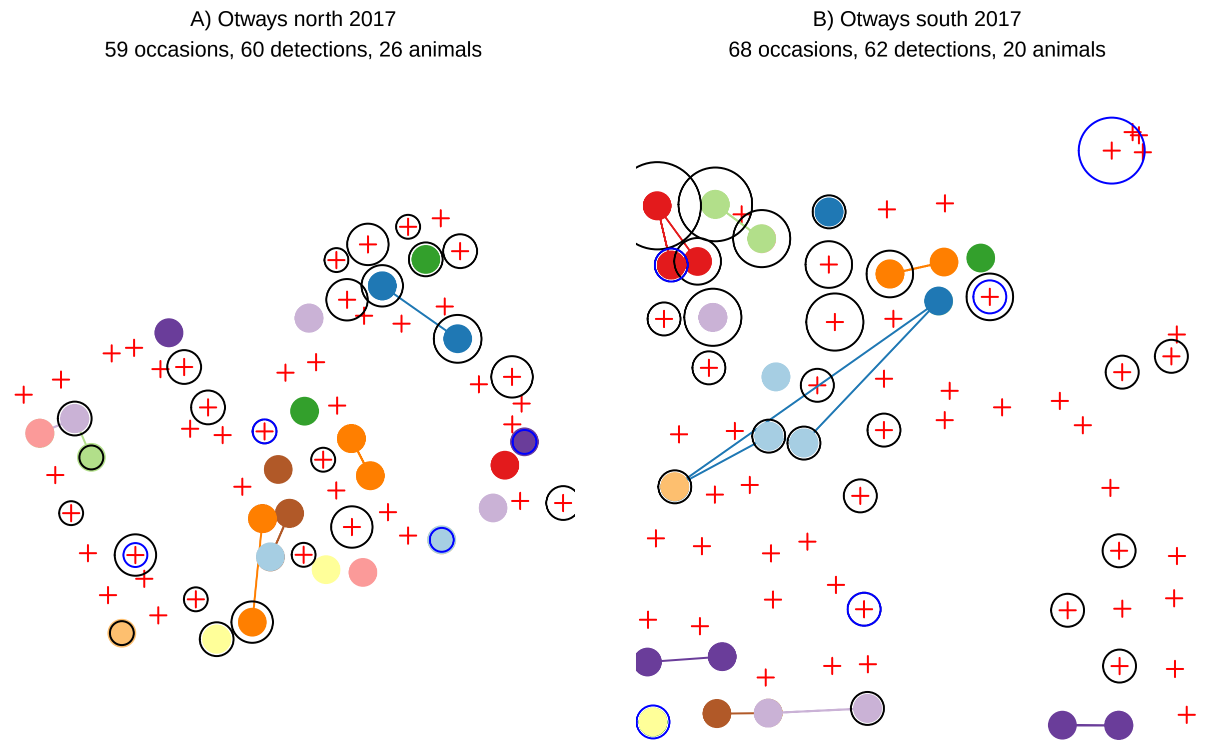

Figure 6: Feral cat detections in the Otway Ranges 2017. Camera-traps are indicated by red crosses. Circles with coloured fills represent individual cats and lines denote thier observed movements. Black circles represent black cats, blue circles unidentifiable detections (the circle radius scales positively with the number daily detections). Fox control did not occur in either of the grids during this time.

4.2.2 2018

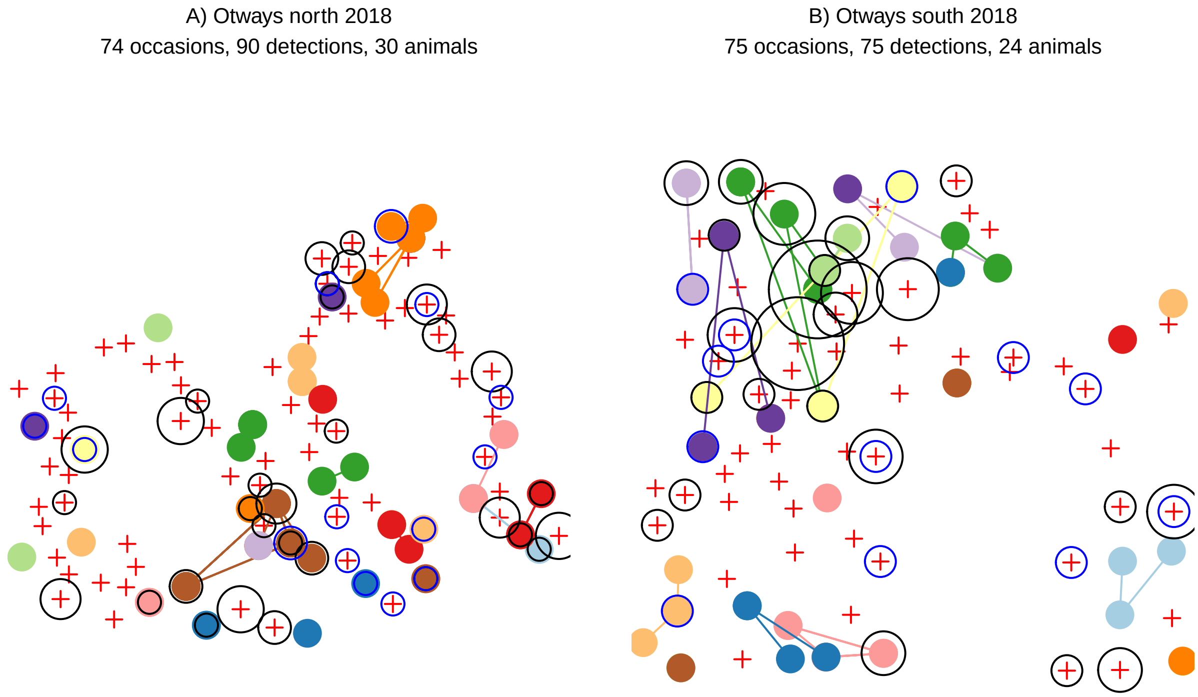

Figure 7: Feral cat detections in the Otway Ranges 2018. Camera-traps are indicated by red crosses. Circles with coloured fills represent individual cats and lines denote thier observed movements. Black circles represent black cats, blue circles unidentifiable detections (the circle radius scales positively with the number daily detections).

4.2.3 2019

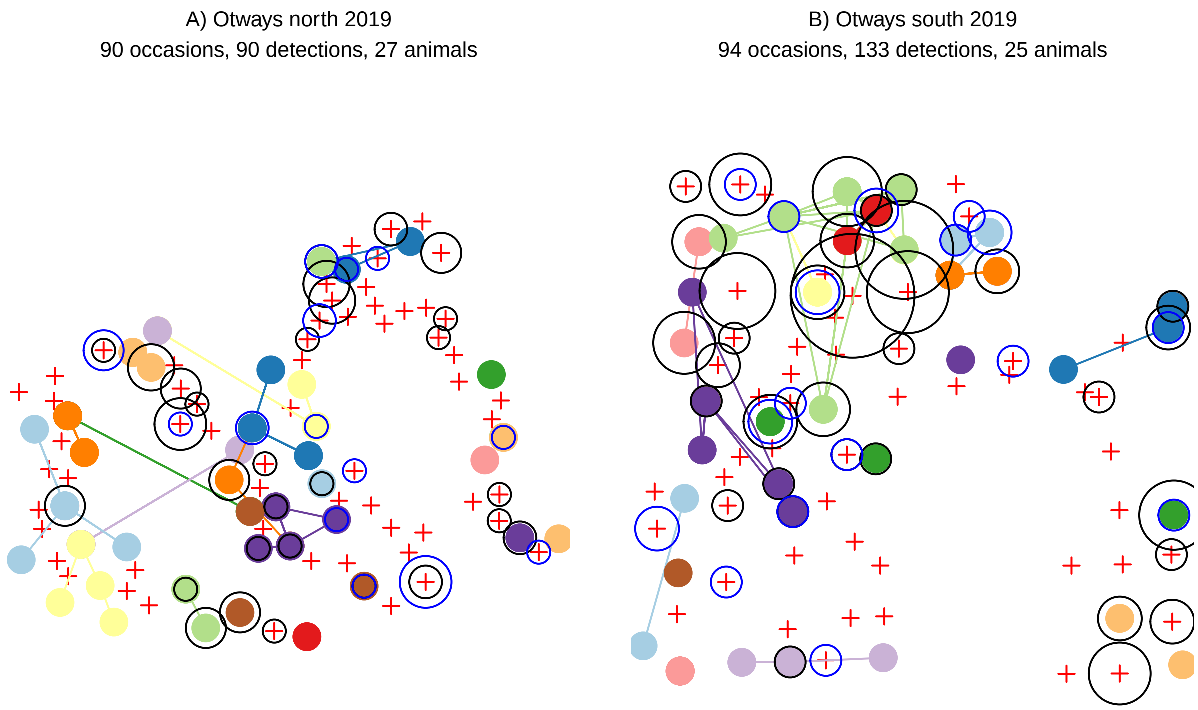

Figure 8: Feral cat detections in the Otway Ranges 2019. Camera-traps are indicated by red crosses. Circles with coloured fills represent individual cats and lines denote thier observed movements. Black circles represent black cats, blue circles unidentifiable detections (the circle radius scales positively with the number daily detections).

5 Fox spatial occupancy

5.1 Glenelg

```
##
## Family: binomial
## Link function: logit
##
## Formula:
## fox ~ s(x, y, bs = "ds", m = c(1, 0.5), k = 200) + offset(log(survey_duration))
##
## Parametric coefficients:
##             Estimate Std. Error z value            Pr(>|z|)
## (Intercept)  -4.5577     0.1039  -43.84 <0.0000000000000002 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##          edf Ref.df Chi.sq    p-value
## s(x,y) 24.29    199  54.76 0.00000614 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.142   Deviance explained = 14.8%
## fREML = 670.38  Scale est. = 1         n = 425
```

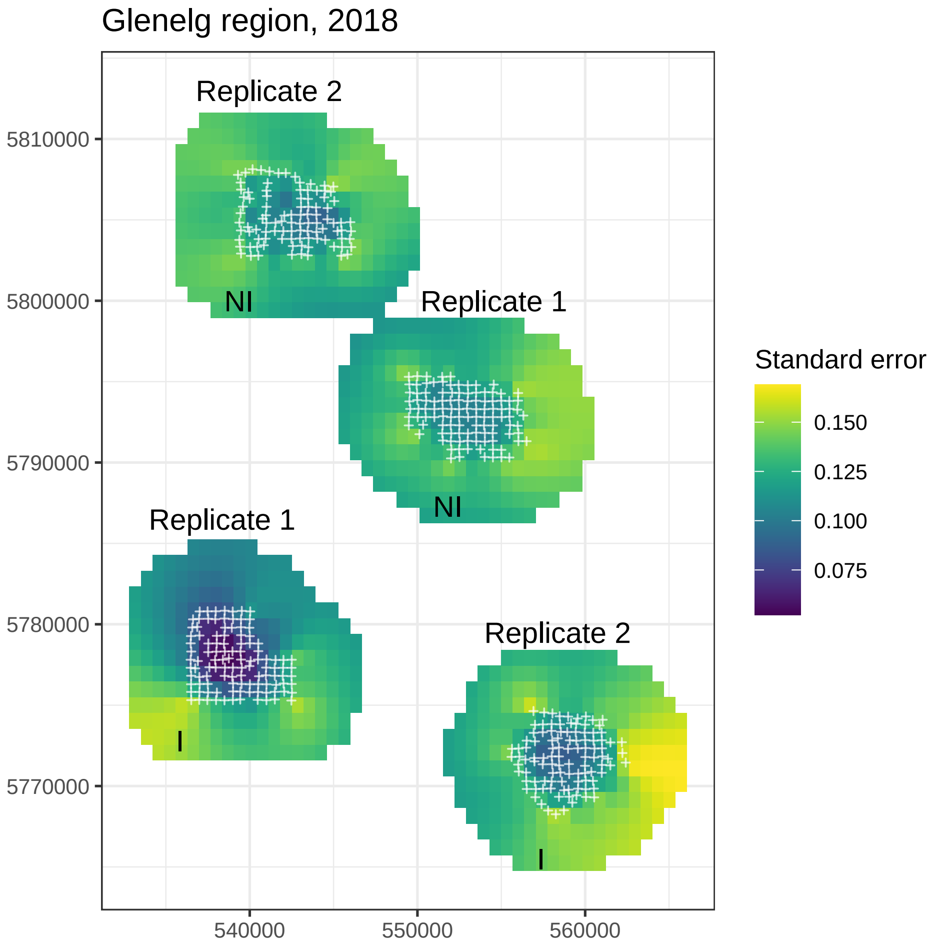

Figure 9: Standard error of fox occupancy probability derived from generalised additive models within each impact (I) and associated non-impact (NI) landscape in the Glenelg region.

5.2 Otway Region

```
##
## Family: binomial
## Link function: logit
##
## Formula:
## fox ~ year + s(x, y, by = year, bs = "ds", m = c(1, 0.5), k = 100) +
##     s(station, bs = "re") + offset(log(survey_duration))
##
## Parametric coefficients:
##              Estimate Std. Error z value            Pr(>|z|)
## (Intercept) -5.283154   0.230023 -22.968 <0.0000000000000002 ***
## year2018     0.004643   0.277696   0.017               0.987
## year2019     0.037119   0.282270   0.132               0.895
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                        edf Ref.df Chi.sq  p-value
## s(x,y):year2017  2.68844090     99  8.096 0.010597 *
## s(x,y):year2018  0.00002494     99  0.000 0.506341
## s(x,y):year2019  6.14777668     99 22.262 0.000380 ***
## s(station)      53.65519870    194 75.723 0.000116 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =   0.24   Deviance explained = 27.8%
## fREML = 763.36  Scale est. = 1         n = 513
```

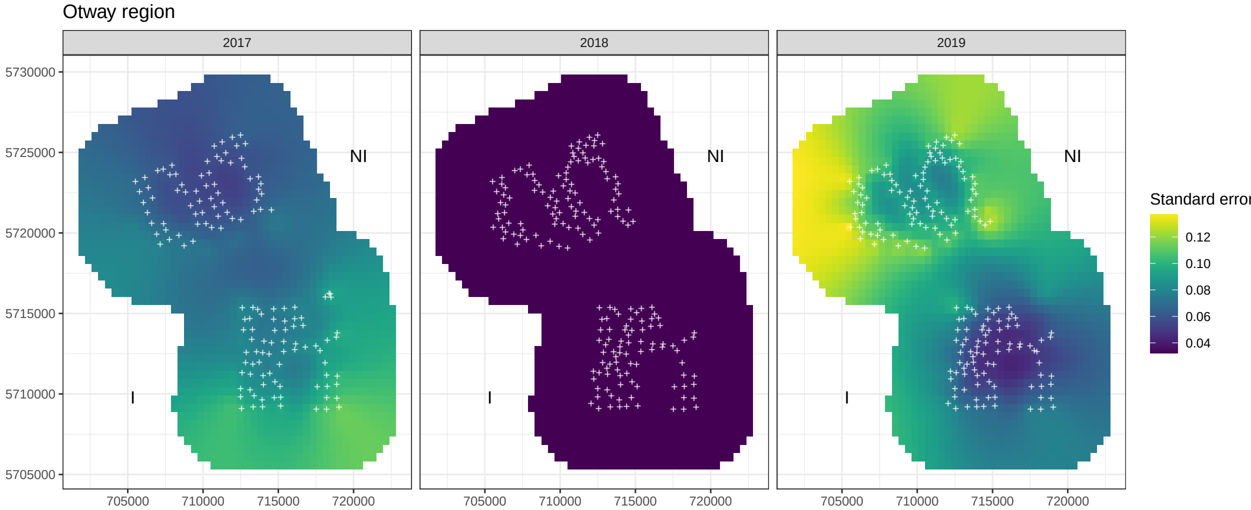

Figure 10: Standard error of fox occupancy probability derived from generalised additive models within each impact (I) and associated non-impact (NI) landscape in the Otway region.

6 Vegetation categories

We condensed the main Ecological Vegetation Class groupings (DELWP, 2020) present into three categories for each region: Cleared Land, Heathy Woodlands, Lowland Forests (Glenelg region only) and Wet Forests (Otways region only). We merged similar groups to reduce the number of categories for each region. In the Glenelg region, we merged Dry Forests with Lowland Forests. In the Otway Ranges, we merged Rainforests with Wet Forests, as well as merged Dry Forests and Heathy Woodlands.

A very small proportion of other Ecological Vegetation Class groupings were present in the habitat masks: Riparian Scrubs or Swampy Scrubs and Woodlands, Coastal Scrubs Grasslands and Woodlands, Wetlands, Riverine Grassy Woodlands or Forests, Plains Woodlands or Forests, Herb-rich Woodlands. We removed these groups, and interpolated cell values from the nearest of the three vegetation categories.

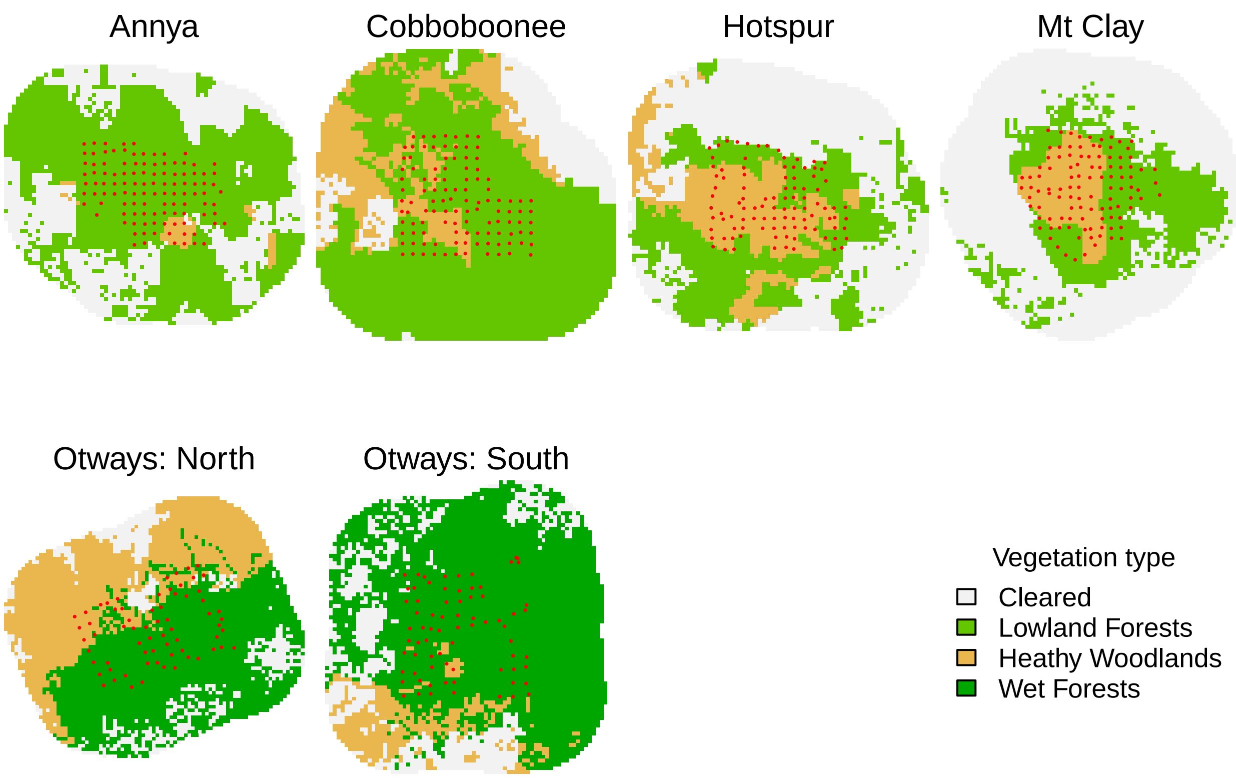

Figure 11: Condensed Ecological Vegetation Class groups used as habitat mask covariates in spatial mark-resight models.

7 Spatial mark-resight models

7.1 Glenelg region

7.1.1 Detector function fits

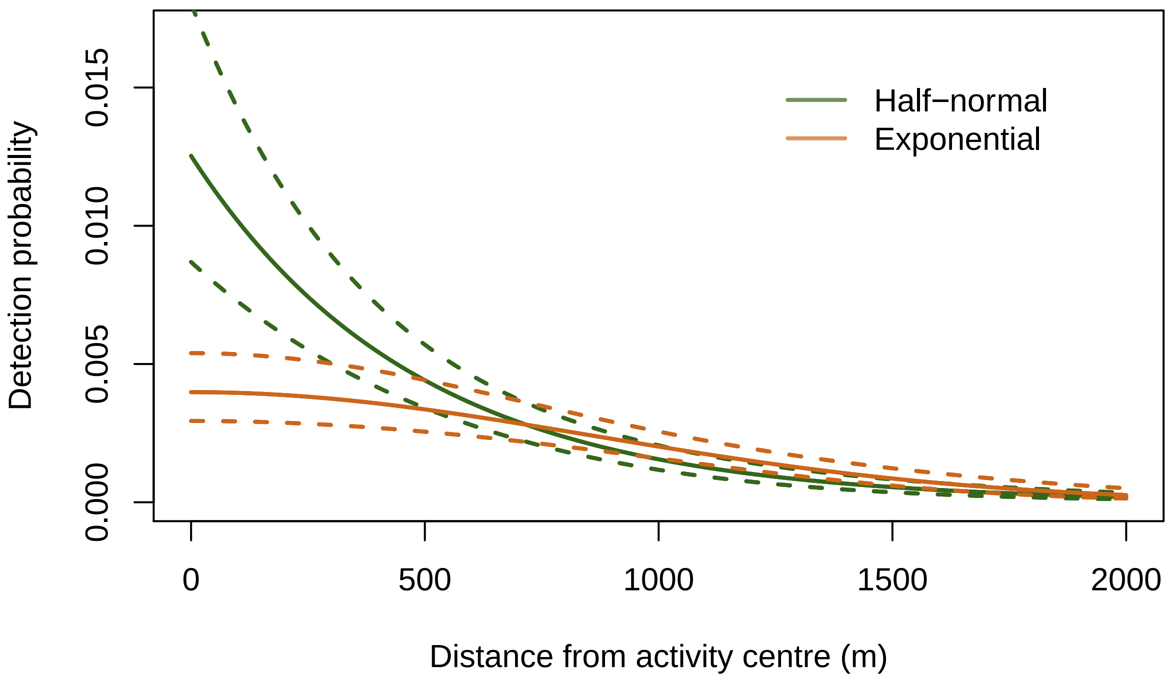

Figure 12: Detector function shapes (solid line) and 95% confidence intervals (dashed lines) tested for the Glenelg region.

Table 2: Akaike's Information Criterion values for detector functions in the Glenelg region.

Detector function	Parameters	logLik	AIC	AICc	dAICc	AICcwt
exponential	3	-1441	2887	2888	0	1
half-normal	3	-1453	2911	2912	23.92	0

7.1.2 Candidate model fits

Table 3: Akaike's Information Criterion values adjusted for small sample size for feral cat density models in the Glenelg region; model set 1 (ordered in decreasing AICc scores).

Density	Detectability	Parameters	logLik	AICc	dAICc
1	1	3	-990.862	1988.39	0
1	T	4	-990.181	1989.51	1.115
vegetation	1	5	-989.632	1991.03	2.638

Table 4: Akaike's Information Criterion values adjusted for small sample size for feral cat density models in the Glenelg region; model set 2 (ordered in decreasing AICc scores).

Density	Detectability	Parameters	logLik	AICc	dAICc
fox_occ	1	4	-988.246	1985.63	0
s(fox_occ, k = 3)	1	5	-988.226	1988.22	2.582
1	1	3	-990.862	1988.39	2.756
fox_occ	fox_occ	6	-987.976	1990.5	4.864
1	fox_occ	5	-990.314	1992.39	6.759
1	s(fox_occ, k = 3)	7	-988.343	1994.19	8.552
s(fox_occ, k = 3)	s(fox_occ, k = 3)	9	-986.311	1996.62	10.989

Table 5: Akaike's Information Criterion values adjusted for small sample size for feral cat density models in the Glenelg region; model set 3 (ordered in decreasing AICc scores).

Density	Detectability	Parameters	logLik	AICc	dAICc
session	1	6	-984.97	1984.48	0
session	pair	8	-983.089	1986.82	2.338
session	foxbaiting_012	10	-982.528	1992.64	8.157
session	pair + foxbaiting_012	12	-981.298	1998.15	13.667

session - *landscape (n = 4)*

1 - *constant*

T - *linear time trend (g0 only)*

vegetation - *vegetation type (lowland forest, heathy woodland or cleared native vegetation)*

fox_occ - *spatial occupancy probability of foxes derived from generalised additive models*

s(fox_occ, k = 3) - *non-linear smooth of fox_occ with three knots*

foxbaiting_012 - *fox-baited or not, but with seperate effects of foxbaiting for the two baited landscapes*

7.2 Otway region

7.2.1 Detector function fits

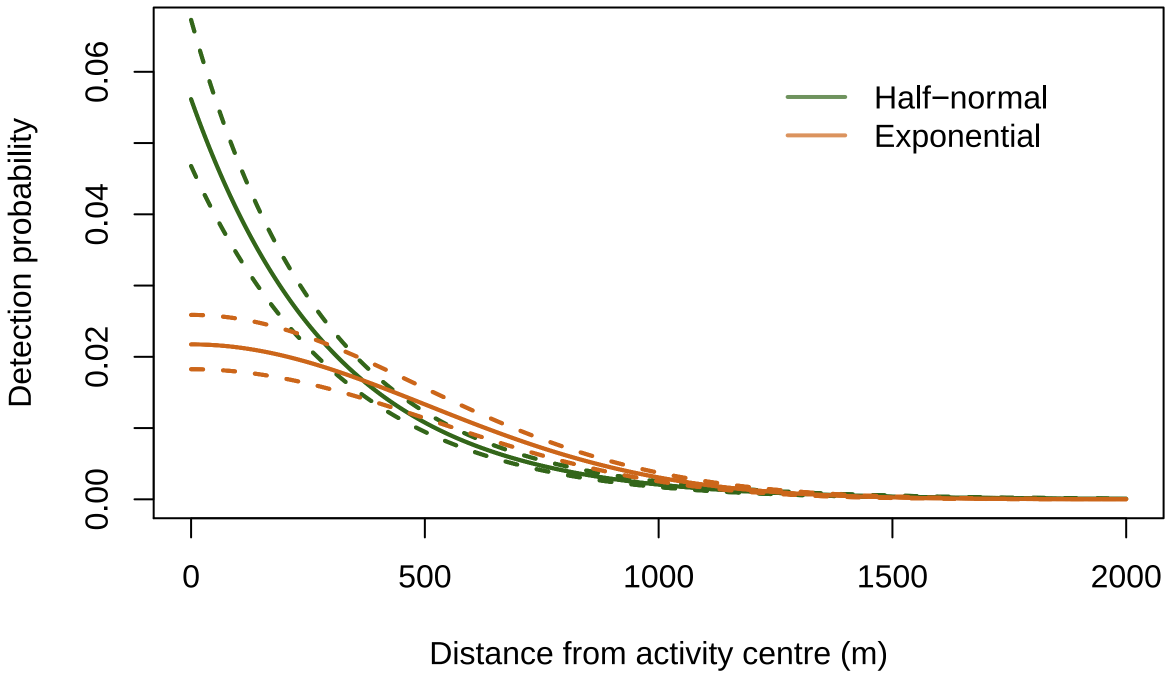

Figure 13: Detector function shapes (solid line) and 95% confidence intervals (dashed lines) tested for the Otway region.

Table 6: Akaike's Information Criterion values for detector functions in the Otway region.

Detector function	Parameters	logLik	AIC	AICc	dAICc	AICcwt
exponential	3	-5591	11188	11188	0	1
half-normal	3	-5743	11493	11493	304.5	0

7.2.2 Candidate model fits

Table 7: Akaike's Information Criterion values adjusted for small sample size for feral cat density models in the Otway region; model set 1 (ordered in decreasing AICc scores).

Density	Detectability	Parameters	logLik	AICc	dAICc
year	1	5	-3550.63	7111.67	0
year	T	6	-3549.83	7112.25	0.574
year + vegetation	1	7	-3550.04	7114.86	3.19

Table 8: Akaike's Information Criterion values adjusted for small sample size for feral cat density models in the Otway region; model set 2 (ordered in decreasing AICc scores).

Density	Detectability	Parameters	logLik	AICc	dAICc
year + fox_occ	fox_occ	8	-3541.8	7100.6	0
year + s(fox_occ, k = 3)	s(fox_occ, k = 3)	11	-3538.59	7101.07	0.475
year	s(fox_occ, k = 3)	9	-3541.07	7101.4	0.803
year	fox_occ	7	-3543.44	7101.65	1.05
year + fox_occ	1	6	-3548.26	7109.09	8.493
year + s(fox_occ, k = 3)	1	7	-3547.47	7109.72	9.121
year	1	5	-3550.63	7111.67	11.073

Table 9: Akaike's Information Criterion values adjusted for small sample size for feral cat density models in the Otway region; model set 3 (ordered in decreasing AICc scores).

Density	Detectability	Parameters	logLik	AICc	dAICc
session	year + foxbaiting_012	16	-3521.22	7078.47	0
session	year	12	-3532.86	7091.97	13.495
session	foxbaiting_012	12	-3538.08	7102.4	23.925
session	1	8	-3548.37	7113.74	35.264

session - *landscape deployment (n = 6)*

year - *year of deployment (2017-19)*

foxbaiting_012 - *fox-baited or not, but with separate effects in 2018 and 2019 for the impact landscape*

1 - *constant*

T - *linear time trend (g0 only)*

vegetation - *vegetation type (wet forest, heathy woodland or cleared native vegetation)*

fox_occ - *spatial occupancy probability of foxes derived from generalised additive models*

s(fox_occ, k = 3) - *non-linear smooth of fox_occ with three knots*

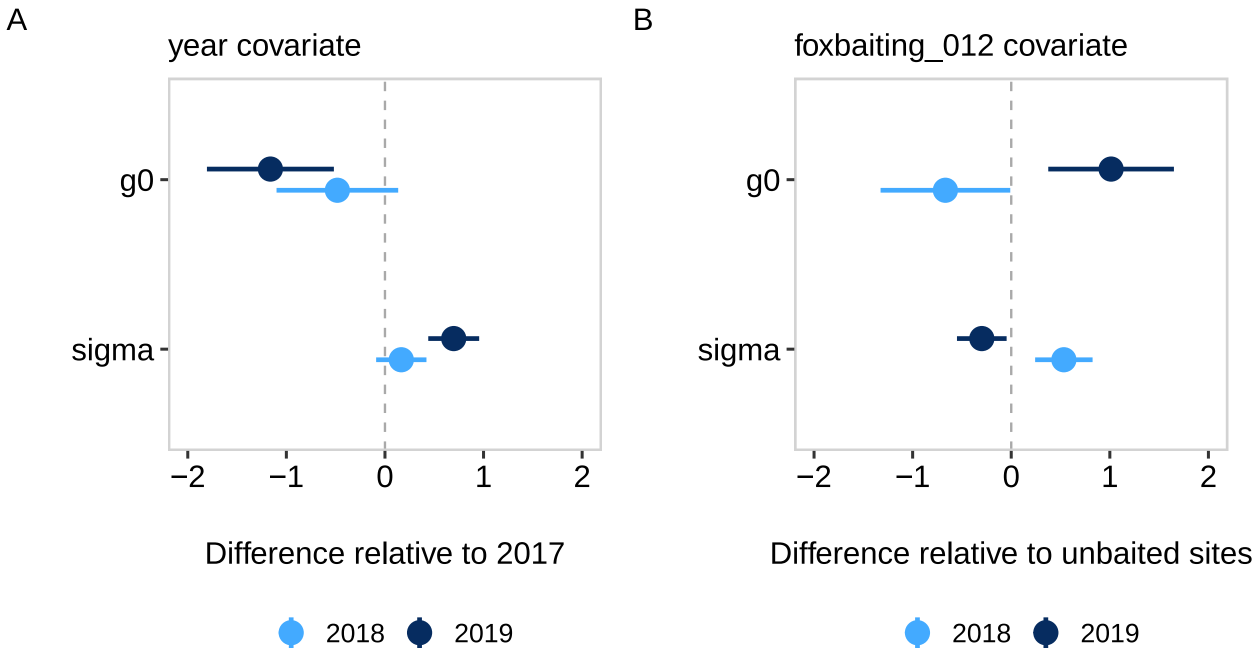

Figure 14: Estimates of covariate effects for the top-ranked experimental model in the Otway region: year categorical covariate with 2017 the reference level (A), and foxbaiting_012 categorical covariate with all unbaited surveys as the reference level, and seperate effects for the 2018 and 2019 surveys in the impact landscape (B). Error bars represent 95% confidence intervals.

8 Session information

R version 3.6.3 (2020-02-29)

Platform: x86_64-apple-darwin15.6.0 (64-bit)

locale: en_AU.UTF-8||en_AU.UTF-8||en_AU.UTF-8||C||en_AU.UTF-8||en_AU.UTF-8

attached base packages: *stats*, *graphics*, *grDevices*, *utils*, *datasets*, *methods* and *base*

other attached packages: *sp(v.1.4-5)*, *sf(v.0.9-6)*, *viridis(v.0.5.1)*, *viridisLite(v.0.4.0)*, *patchwork(v.1.0.1)*, *gratia(v.0.6.0)*, *pander(v.0.6.3)*, *RColorBrewer(v.1.1-2)*, *camtrapR(v.2.0.3)*, *mgcv(v.1.8-33)*, *nlme(v.3.1-144)*, *secr(v.4.4.1)*, *forcats(v.0.5.0)*, *stringr(v.1.4.0)*, *dplyr(v.1.0.2)*, *purrr(v.0.3.4)*, *readr(v.1.3.1)*, *tidyr(v.1.0.0)*, *tibble(v.3.1.2)*, *ggplot2(v.3.3.3)*, *tidyverse(v.1.3.0)* and *bookdown(v.0.21)*

loaded via a namespace (and not attached): *fs(v.1.5.0)*, *overlap(v.0.3.2)*, *lubridate(v.1.7.10)*, *httr(v.1.4.2)*, *tools(v.3.6.3)*, *RcppNumerical(v.0.4-0)*, *backports(v.1.2.1)*, *rgdal(v.1.4-7)*, *utf8(v.1.2.1)*, *R6(v.2.5.0)*, *KernSmooth(v.2.23-16)*, *DBI(v.1.1.1)*, *colorspace(v.2.0-1)*, *raster(v.3.4-10)*, *withr(v.2.4.2)*, *tidyselect(v.1.1.0)*, *gridExtra(v.2.3)*, *compiler(v.3.6.3)*, *cli(v.2.5.0)*, *rvest(v.1.0.0)*, *xml2(v.1.3.2)*, *labeling(v.0.4.2)*, *scales(v.1.1.1)*, *classInt(v.0.4-3)*, *mvnfast(v.0.2.5)*, *digest(v.0.6.27)*, *rmarkdown(v.2.7)*, *pkgconfig(v.2.0.3)*, *htmltools(v.0.5.1.1)*, *highr(v.0.8)*, *dbplyr(v.1.4.2)*, *rlang(v.0.4.11)*, *readxl(v.1.3.1)*, *rstudioapi(v.0.13)*, *farver(v.2.1.0)*, *generics(v.0.1.0)*, *jsonlite(v.1.7.2)*, *magrittr(v.2.0.1)*, *Matrix(v.1.2-18)*, *Rcpp(v.1.0.6)*, *munsell(v.0.5.0)*, *fansi(v.0.4.2)*, *abind(v.1.4-5)*, *lifecycle(v.1.0.0)*, *stringi(v.1.5.3)*, *yaml(v.2.2.1)*, *MASS(v.7.3-51.5)*, *grid(v.3.6.3)*, *parallel(v.3.6.3)*, *crayon(v.1.4.1)*, *lattice(v.0.20-38)*, *haven(v.2.2.0)*, *splines(v.3.6.3)*, *hms(v.0.5.2)*, *knitr(v.1.31)*, *pillar(v.1.6.1)*, *codetools(v.0.2-16)*, *reprex(v.0.3.0)*, *glue(v.1.4.2)*, *evaluate(v.0.14)*, *data.table(v.1.12.6)*, *RcppParallel(v.5.1.4)*, *modelr(v.0.1.6)*, *vctrs(v.0.3.8)*, *cellranger(v.1.1.0)*, *gtable(v.0.3.0)*, *assertthat(v.0.2.1)*, *xfun(v.0.22)*, *broom(v.0.5.5)*, *e1071(v.1.7-2)*, *class(v.7.3-15)*, *units(v.0.6-5)* and *ellipsis(v.0.3.2)*

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DELWP. (2020). *Bioregions and evc benchmarks.* Victorian Government Department of Environment, Land, Water; Planning, Melbourne. Accessed June 2021). https://www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks

Niedballa, J., Sollmann, R., Courtiol, A., & Wilting, A. (2016). CamtrapR: An r package for efficient camera trap data management. *Methods in Ecology and Evolution*, *7*(12), 1457–1462.