Spring 2023

Understanding invasive predation: detections of feral cats (Felis catus) on Kangaroo Island’s Western River Refuge

Leah Boget

SIT Study Abroad

Understanding invasive predation: detections of feral cats (*Felis catus*) on Kangaroo Island's Western River Refuge

By Leah Boget

Project Advisor: Vanessa Messmer, Ph.D.

The Australian Wildlife Conservancy, Western River Refuge

Kangaroo Island, South Australia

Academic Director: Tony Cummings

Home Institution: College of William and Mary

Major: Biology

Submitted in partial fulfillment of the requirements for Australia: Rainforest, Reef, and Cultural Ecology,

SIT Study Abroad, Spring 2023

SCHOOL FOR INTERNATIONAL TRAINING

STUDY ABROAD

ISP Ethics Review

(Note: Each AD must complete, sign, and submit this form for every student's ISP/FSP Internship paper.)

The ISP paper by Leah Boget (student) does/does not* conform to the Human Subjects Review approval from the Study Abroad Review Board (SARB), the ethical standards of the local community, and the ethical and academic standards outlined in the SIT student and faculty handbooks.

*This paper does not conform to standards for the following reasons:

Completed by: James Anthony Cummings

Academic Director:

Program: Cairns: Rainforest, Reef, and Cultural Ecology

Date: May 12, 2023

Abstract

Feral cats (*Felis catus*) are a priority-level threat for small to medium-sized native vertebrates across Australia and especially so in insular environments like that of Kangaroo Island, South Australia. The island is home to several endangered and geographically restricted species, including the Kangaroo Island Dunnart (*Sminthopsis aitkeni*), an endangered marsupial endemic to Kangaroo Island. When bushfires spread across the island and burned x percent of native vegetation in late 2019 to early 2020, these populations were critically impacted and post-fire feral cat predation on the island risked their extinctions, motivating the creation of a refuge with predator exclusion fencing around remaining unburnt vegetation to protect surviving dunnarts and other threatened species. The Western River Refuge was created for this purpose and protecting the area has included trapping feral cats in a variety of ways. As continued trapping is necessary, it is important to analyze capture and camera trap data to understand trapping efficiency and success rates, and how these might be improved.

This study reviewed six months of capture data and camera trap photographs from the WRR property in order to identify individual feral cats and any patterns in detections prior to either capture or disappearance from cameras, as well as in comparison to AI-targeted Felixer first detections. Camera trap photographs were filtered through the AI system eVorta for high confidence (>0.99) cat photographs. Twelve cats were captured during the study period and 110 instances of cat detections were recorded on camera traps and Felixer target photos. 53.64% of detections were matched to individual cats. All detections were an average of 1.67 days (±0.27 SE) apart. Cats averaged 51.9 days (±16.66 SE) between first camera detection and capture. 58.33% of captured cats were recorded as targets by Felixers while 41.67% were either not detected or not identified as targets. Felixer activation will increase speed of removing cats from the area, but various trapping methods are still necessary to catch all cats that enter the area. Higher levels of detections in the WPA indicate the successes of trapping and align with capture hotspots, but all conclusions are limited by small sample sizes and require further data collection.

Keywords

Conservation, AI system eVorta, exclusion fencing, soft jaw leg holds, cage traps, Felixers

Table of Contents

Acronyms

ISP -- Independent Study Project

KI -- Kangaroo Island

AWC -- Australian Wildlife Conservancy

WRR -- Western River Refuge

WPA -- Wilderness Protection Area

SIT -- School for International Training

AI – Artificial Intelligence

Acknowledgements

I would like to acknowledge Vanessa Messmer for advising me on this project every step of the way, including every morning rounds of the fence and every drive between Kingscote and the refuge. Thank you for hosting us for the month and for going out of your way to show us beautiful places around Kangaroo Island. Thank you to Jason Laverty for welcoming us into the office space and lending us a helping hand (and a dog for rounds), and especially for your QGIS lessons and advice. Thank you to Murray Schofield and Luke Frost for showing us around the property and all their assistance. A special thank you to Buddy and Molly for being the sweetest dogs on the property and lending their emotional support.

I would like to thank the Australian Wildlife Conservancy for giving us the opportunity to visit the refuge, collect data, and gain firsthand conservation experience. Finally, I would like to thank Tony Cummings and Jack Grant for their support and teachings during this program that prepared us for this independent study process.

Introduction

Global biodiversity has declined by 44% in the past 50 years (van Goethem and van Zanden 2021). Introduced predators are considered one of the most important causes of extinctions and biodiversity loss worldwide as they are twice as harmful to native prey species' population levels as native predators (Salo et al. 2007). Species in island regions are particularly vulnerable to alien hunting techniques and often experience higher levels of negative impacts than their mainland counterparts (Salo et al. 2007). Australia is particularly affected by introduced predators, to the tune of Australian data points skewing the results of the 2007 study by Salo et al. with the consistent intensity of alien predation effects. The large island nation has experienced a marked decline of native biodiversity with 30 native mammal species going extinct in the past 200 years (Legge et al. 2017, Spencer et al. 2016). Introduced predators, such as feral foxes and cats, are implicated in the vast majority of these declines and extinctions (Doherty et al. 2015, Legge et al. 2017, Spencer et al. 2016). Australian wildlife is particularly vulnerable to these introduced pressures due to its evolutionary isolation from different predation methods, whereas the relatively frequent faunal exchanges between the African, Eurasian, and American continents have caused shared terrestrial predator archetypes (Sale et al. 2007). Evolutionary exposure to the varied predation methods of the connected continents have exposed native species in those regions to novel predators and allowed them reduced naiveté (Salo et al. 2007). As an isolated continent, Australia and its wildlife did not experience any such occurrences. While Australian ecosystems have experienced marsupial predators since the Miocene, ground predators have become extremely limited with megafauna extinctions and the placental predators that dominate the majority of the world's continents were never introduced to the island before human involvement (Salo et al. 2007, Spencer et al. 2016). Because placental mammals may use tracking and hunting techniques that differ from marsupial species, Australian prey species were not prepared them, and further, the majority of these extinct native predators were specialists (Salo et al. 2007, Spencer et al. 2016). Many Australian species have relatively low reproductive outputs, making species vulnerable to rapid decline or extinction with new predation pressure (Legge et al. 2017). Further, fire regimes and introduced herbivores heavily impacting habitats and vegetation levels across the continent have contributed to a reduction in shelter availability for terrestrial native mammals, a factor that is often vital in evading predation (Hodgens et al. 2022, Legge et al. 2017). Many native Australian wildlife is therefore more highly susceptible to novel predators than the native species of other regions (Legge et al. 2017).

Feral cats (*Felis catus*) are medium-sized generalist ground predators that were introduced to the Australian continent from Europe approximately 200 years ago (Spencer et al. 2016). This approximation is dated to the beginning of European settlement, which itself coincides with the beginning of a rapid decline of native Australian wildlife, notably medium-sized mammals (0.03–3.5 kg) (Spencer et al. 2016). Feral cats pose an explicit threat to native wildlife globally and locally, with documentation of causing 21% of global extinction or near-extinction events worldwide and estimations of 70 million animals consumed per day across Australia (Doherty et al. 2015, Spencer et al. 2016). A strong correlation between feral cat density (following wet periods) and the attrition rate of non-flying mammals has been documented on both Australian islands and the mainland (Legge et al. 2017). A recent review found evidence of cat predation on four endangered species and three critically endangered species listed on the Australian IUCN index (Hodgens et al. 2022). Small to medium-sized vertebrates (35–5500 g) are particularly at risk to cat predation pressures, and species with small local abundances are the most likely to become critically endangered or extinct from introduced predation (Spencer et al. 2016). Feral cat predation is more impactful and dangerous than other introduced predators as cats respond strongly to hunting stimuli rather than their satiation cues, which leads to hunting and killing native species as surplus. This further explains how even small numbers of feral cats can significantly negatively affect threatened species (Legge et al. 2017).

The Australian feral cat population was recently estimated to fluctuate between 2.1 to 6.3 million individuals depending on rainfall, populating over 99.8% of the country's land area (Legge et al. 2017). The species spread across the entire continent (~7.6 million km^2) in approximately 70 years, an unprecedented rate of ecological invasion (Spencer et al. 2016). This rapid spread was possible due to the adaptability of the generalist predator to the variety of Australian landscapes; feral cats are opportunistic hunters that are able to sustain themselves in arid climates with no ground water sources when live prey is available, which they can stalk both on land and arboreally (Legge et al. 2017, Nogales et al. 2004, Spencer et al. 2016). While they are generally solitary, cats have a high reproductive capacity which often facilitates rapid density increases with prey and periods of high rainfall, likely following a pulse of prey species (Legge et al. 2017, Spencer et al. 2016). While there is little published data on cat movement patterns in Australia, a 2008 study of male feral cats in central Australia found that long-term home ranges were a mean of 2219.5 hectares and 24-hour ranges were smaller at 249.7 ha. (Edwards et al. 2008). While varying prey availability was recorded to motivate long distance movement, individuals were observed to shift their 24-hour range periodically and within their larger home range (Edwards et al. 2008). As of 2016 there were only 19 predator exclosure areas in Australia designed to protect vulnerable native populations from introduced predation, three of which were compromised at the time. From these predator exclusion areas it was calculated that there are 274 km^2 of effective exclosure area, or 0.0036% of Australian land area (Legge et al. 2017). As eradication efforts have increased, there have been increased accounts of positive responses of threatened species to exclusion or effective control of feral cats, as well as to translocation to cat-free islands (Legge et al. 2017, Nogales et al. 2004).

Island habitats have historically been sanctuaries from both native and introduced predators, marking them as key spaces to protect in order to retain native biodiversity (Spencer et al. 2016). However, many qualities that make them refuges have also put their inhabitants at risk of invasive predation, such as a lack of natural predators and prey naiveté (Nogales et al. 2004). Feral cats have invaded 98 Australian islands, which accounts for 77.4% of total island area when excluding Tasmania, and are absent from only 25% of large islands (>100 km^2) (Legge et al. 2017). Islands often support appreciably higher densities of feral cats than their mainland counterparts, likely due to the relative abundance of prey resources as well as continuous washed-up marine life (Legge et al. 2017). However, islands have a better chance of eradicating introduced predators such as the cat due to a limited immigration of new individuals, which is often seen as a marker of doom for the mainland (Algar et al.

2010, Spencer et al. 2016). Several island nations have successfully eradicated populations, such as Faure Island off the western Australian coast (Algar et al. 2010). The majority of these successes, however, have occurred on small islands (<5 km^2) and minimal eradications have occurred on islands larger than 10 km^2 (Algar et al. 2010, Nogales et al. 2004). Islands with successful attempts each vary considerably from each other in climate, terrain, prey availability and fluctuations, and established population size (Algar et al. 2010). As success hinges on the intersection of these variables, each island provides a unique challenge that must be custom fit with potential eradication measures. Eradication methods have historically included trapping, hunting with dogs and/or guns, poisoning via baits, and viral disease introduction (Nogales et al. 2004). Most eradication efforts have combined two or more of these methods, therefore limiting conclusions on the effectiveness of any one method (Nogales et al. 2004). Techniques on when to emphasize a particular technique have seen trends, but are only applicable on small islands. Nogales et al. recommended developing new techniques for eradication efforts on islands greater than 50 km^2, as one of the few recorded successful efforts on an island over 15 km^2 took 15 years of intense effort, and additionally human population increases complications. Based on their 2017 study of cat presence across Australia, Legge et al. recommended eradicating smaller numbers of feral cats from high-value conservation areas as a more effective solution to protecting biodiversity than attempting to eradicate millions of cats across the country.

Kangaroo Island (KI), situated off the southern coast of South Australia, is the third largest Australian island at ~4400 km^2 (Hodgens et al. 2022). The eastern end of the island saw vast clearing and native bushland fragmentation post-WWII, while the western end was recently identified as a key biodiversity hotspot for endangered and endemic species (Hodgens et al. 2022). Introduced to Kangaroo Island at approximately the same time as the Australian continent during the 18th century, feral cats quickly spread and currently have a higher relative abundance than the mainland (Hodgens et al. 2022). In late 2019 into early 2020, KI suffered several wildfires started from dry lightning strikes in remote vegetated sections of the island (Hodgens et al. 2022). Originating in the northwest, the fires were extensive and severe, damaging large swaths of the key biodiversity habitat. The KI dunnart notably saw

95% of its habitat burned (Legge et al. 2022). Cats are known to have amplified impacts on native populations following fires as they are attracted to burn scars, likely due to the increased effectiveness of their hunting in areas with reduced vegetation and shelter sites (Hohnen et al. 2023). Post-fire surveys measured feral cat populations to have decreased by over 50% of their pre-fire numbers, but a post-fire cat gut contents study across several locations on the island still identified the predator as an immediate and direct threat to the surviving native wildlife (Hodgens et al. 2022, Hohnen et al. 2023). Several small to medium-sized native mammals occur on Kangaroo Island and previously became endangered due to threats such as habitat fragmentation and introduced predation pressures. Two of these species are the Kangaroo Island Dunnart (*Sminthopsis fuliginosus aitkeni*) and the Southern Brown Bandicoot (*Isoodon obesulus obesulus*), both of which were discovered in the cat gut contents post-fires (Hodgens et al. 2022). Both species are rare on the island with small geographic ranges and small local abundances, but KI dunnarts are endemic and found only on the western end of this island (Bryant et al. 2018, Hodgens et al. 2022). Further, the 2019-2020 KI wildfires are estimated to have burned 95% of the dunnarts' known and predicted habitat (~342 km^2), enhancing their listing to critically endangered with ~500 individuals remaining (Hodgens et al. 2022). In order to protect the few individuals left on the island from feral cat predation, several unburnt areas were quickly converted to refuges with predator exclusion fences and trapping measures. The size of the island has previously discouraged true eradication efforts as individuals and populations have remained undetected or untrapped and continued breeding, reestablishing populations through dispersal. However, the heightened vulnerability of several endemic and endangered species due to the bushfires increased the urgency to enhance trapping efforts.

One unburnt fenced patch is the Western River Refuge (WRR), a 0.12 km^2 plot located on the northwest end of KI operated by the Australian Wildlife Conservancy (AWC) (Hodgens et al. 2022). Further fencing, traps, and cameras were added to the property on several occasions after the initial fencing in order to mediate consistent, long-term protection and cat eradication measures. Preliminary studies showed high levels of native non-target bait taking on KI and low tolerance to 1080 poison, and therefore highly discouraged poisoned baiting on the island (Hohnen et al. 2019). Baited cage traps and lured soft jaw leg holds were implemented around the exclusion fences

Trapping efforts have been continuous for four years since the wildfires and feral cat predation assessment, but as the threat of predation continues, it is necessary to assess the efficiency and success of current trapping methods, as well as work to identify any viable improvements or notable feral cat behaviors that may be taken advantage of. For these reasons, the aim of this paper is to analyze current and past data from trapping efforts and camera trap photographs on the WRR properties in order to discern feral cat movement patterns and comparable levels of trapping success. Understanding the proportion of known local individuals caught compared to those who evade capture will inform methods in order to better protect the vulnerable native species.

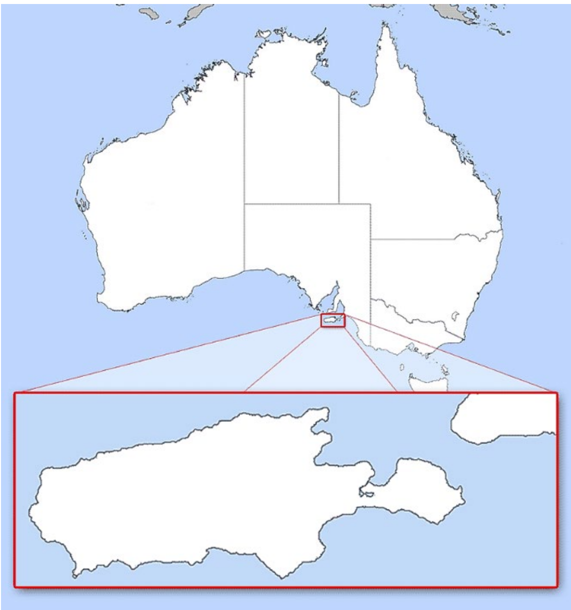

Figure 1. Map of Kangaroo Island location and size in relation to mainland Australia from WorldAtlas.

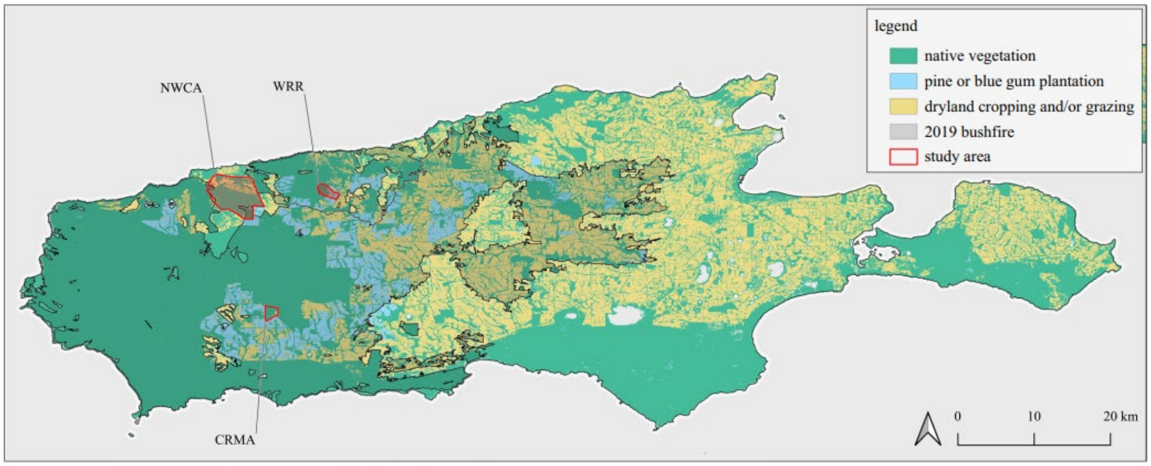

Figure 2. Hodgens et al. (2022) QGIS map of Kangaroo Island vegetation overlayed with 2019-2020 bushfire range. Red areas represent three of the island's conservation areas, including the Western River Refuge.

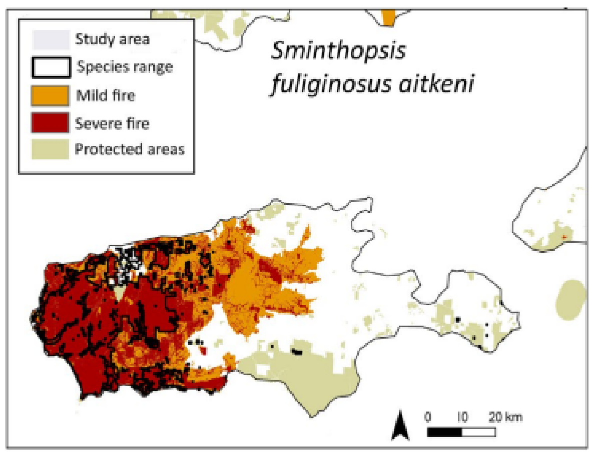

Figure 3. Legge et al. (2022) map of Kangaroo Island 2019-2020 bushfire spread and severity compared to the range of the KI Dunnart (*Sminthopsis fuliginosus aitkeni*). 95% of the dunnart's range burned, 90% of which was in severe fire.

A. 

B. 

Figure 4A and B. Both images show feral cats recorded on KI camera traps carrying Southern Brown Bandicoots that they have hunted in killed. Neither photo is from WRR but were both were from KI conservation properties with trapping efforts. Images provided by KI AWC staff.

Methods

Study Site

Kangaroo Island is located 13.5 km southwest from its closest point along the mainland of South Australia. This study took place within the Western River Refuge (35 44' 06" S, 136 59' 51" E), an Australian Wildlife Conservancy property on the northwest of the island, 70 km from Kingscote. The refuge contains a predator exclusion fenced zone of burnt vegetation erected by December of 2020, with a small section of unburnt vegetation from the first post-fire species protection efforts in February of 2020. This study utilized capture data from outside the fenced area and camera data from the WRR and neighboring WPA property. This study looks at data from 01 November 2022 to 03 May 2023 for a 6-month range. WRR cameras operated consistently from set up, which varied from 06 November 2022 to 13 April 2023. WPA cameras were set up before this time period. There was a total of 22 cameras and 30 traps utilized in this study.

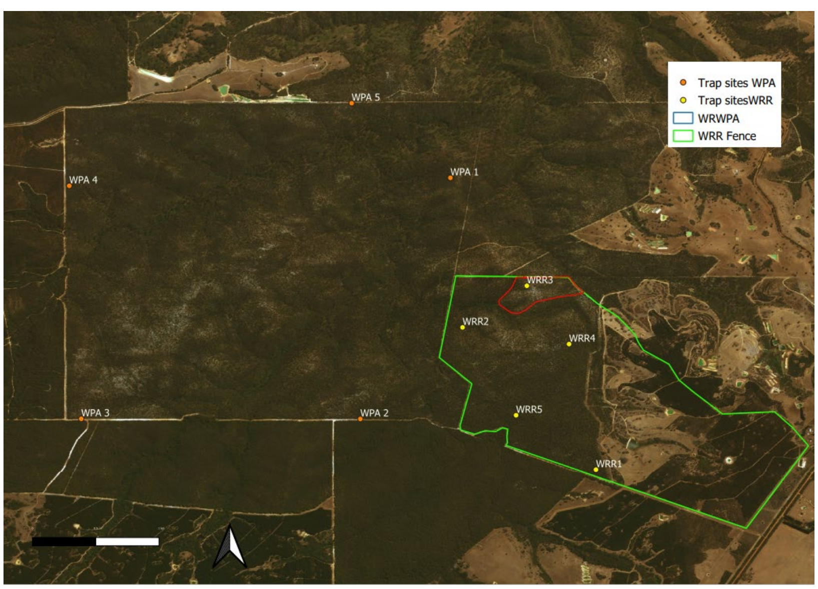

Figure 5. Map of WPA (left plot) and WRR (right plot) properties with select camera locations and previous trap locations marked. Green represents the current extent of the predator exclusion fence. Red

represents the Critical Refuge fence and range, which is merged with the larger WRR fence along the outer northern limit. Provided by Vanessa Messmer from the AWC.

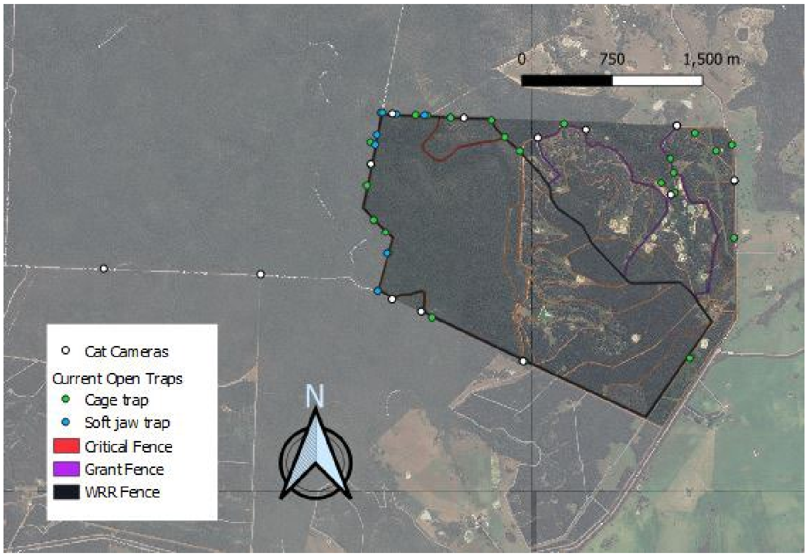

Figure 6. Map of camera and trap locations for the duration of the study. White represents camera traps, green represents cage traps, and blue represents soft jaw leg hold traps. Red represents the Critical Refuge fence, purple represents the grant fence, and black represents the larger WRR predator-exclusion fence. WRR property represented in comparison to grayed-out neighboring properties, including the WPA in the top left corner with two camera traps. Map made with data provided by the AWC through Fulcrum and formatted in QGIS.

Data Collection

The methods used during this project are part of the regular trapping methods used by AWC staff on the Western River Refuge property in order to reduce predation pressure on native species.

Cage traps were set by double hooking raw chicken wings, 19 were regular traps reset during the week and three were new traps placed along the Grant Fence tracks during the field study period. Soft jaw leg holds were set by placing the trap on an elevated stump to reduce bycatch and covering lightly with dirt or sand, with a lure set above the stump with the available scent(s) per reset. All traps were checked each morning in order to collect target captures or document and release non-targets. Felixers were set to photo mode for the duration of the field work period, but continued differentiating between target and non-target detections. Camera traps were running continuously since November 2022 and were checked on rounds to ensure no dirt obscured lenses. SD cards were changed at the beginning of each month and batteries were changed as needed. SD card photos were downloaded to an office computer and uploaded to AI system eVorta to be sorted and labeled for trained target species. Felixer target photos for the study period were downloaded. Caught cats were photographed on each side, which were uploaded to the app Fulcrum along with capture location and date, weight, and sex. These photos and information were downloaded in order to compare with camera trap photographs.

Data Analysis

Identifying Individuals:

Photos sorted through AI system eVorta were assigned confidence levels. High confidence (>0.98) photos were viewed by hand and all confirmed cats were recorded as a detection with the date, time, camera number, available appearance information, and whether the photo was downloaded. Only photos with identifiable markings were downloaded and inserted into a PowerPoint presentation along with Felixer target photos. Caught cat photos were also inserted into the PowerPoint, and each was compared with detection photos in order to match individuals by unique patterning and create timelines of detections and captures. The most helpful identifiers were comparing large noticeable patterns (e.g. “swirls”), tail stripes, foreleg stripes, and/or coloration (for colored photos). These matches were reviewed by several AWC staff to reduce bias and increase confidence.

Tracking Detections:

Using identifications of individual cats from photograph comparisons, detections were sorted by camera and color coded for each individual, or unidentifiable, cat. Cats were named alphabetically in the order of their capture (A through L) with one exception. The average number of days between all detections and detections of each identified cat, as well as standard error, were calculated and graphed. The number of days between the first detection and the capture of each cat was calculated and graphed, as well as the number of days between an individual’s first camera trap detection and first Felixer target photo. The number of days between the first Felixer target detection and capture of a cat was calculated and put in a table.

Mapping:

Maps were made by exporting AWC camera and trap data from Fulcrum to QGIS, where irrelevant data was filtered out and current WRR and WPA data was formatted. Detections per camera was tallied and added to the camera trap attribute table in order to make a frequency heat map, as well as for the numbers of captures per trap location. Each map was exported as a layout with a scale bar, North arrow, and legend.

Results

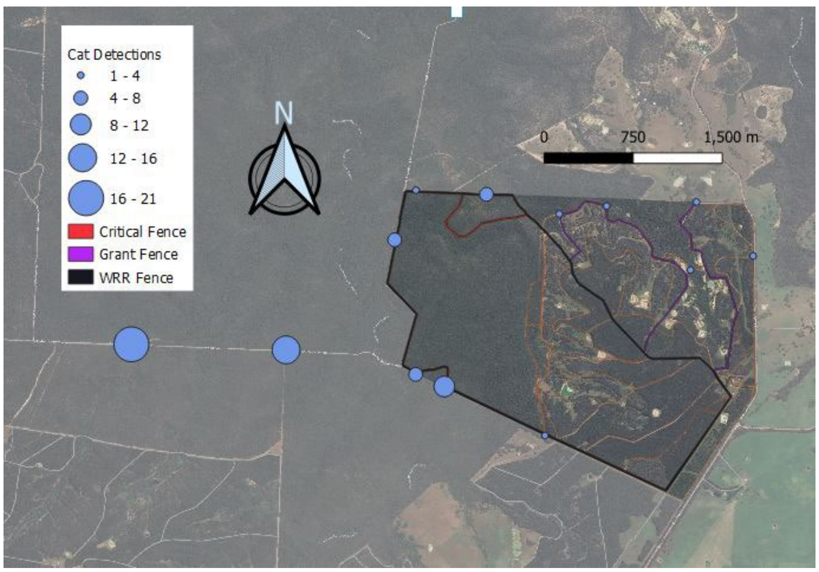

Figure 7. WRR and WPA Cat Detections over Duration of Study. Blue circles represent cat detections where circle size represents the number of detections at a single camera trap location in increments increasing by four, where smallest circles represent 1-4 detections and largest circles represent 17-21 detections. Red represents the Critical Refuge fence, purple represents the grant fences, and black represents the larger WRR exclusion fence. Map made with data provided by the AWC through Fulcrum and formatted in QGIS.

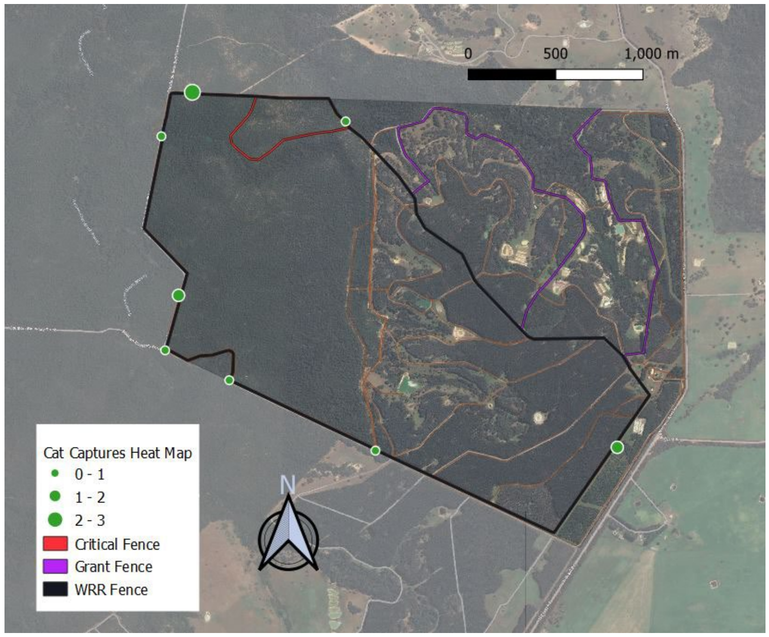

Figure 8. WRR Cat Captures over Duration of Study. Green circles represent cat captures where circle size represents the number of captures at a single trap in increments increasing by one, where the smallest circles represent one capture and largest represent three. Red represents the Critical Refuge fence, purple represents the grant fences, and black represents the larger WRR exclusion fence. Map made with data provided by the AWC through Fulcrum and formatted in QGIS.

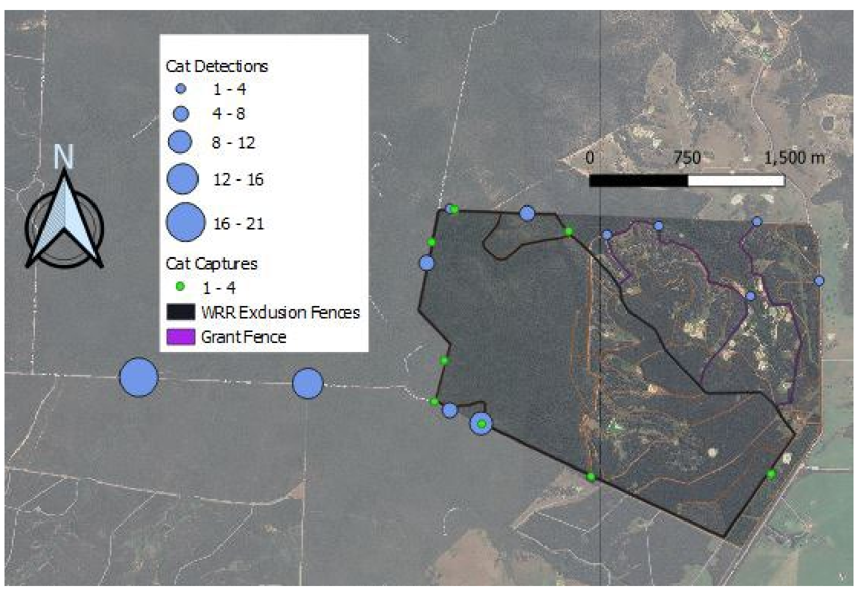

Figure 9. Cat Detections Compared to Cat Captures. Blue circles represent cat detections where circle size represents the number of detections at a single camera trap location in increments increasing by four, where smallest circles represent 1-4 detections and largest circles represent 17-21 detections. Green circles represent cat captures where all circles are one size representing one to three captures, adjusted to be comparable to detection circle size representations. Red represents the Critical Refuge fence, purple represents the grant fences, and black represents the larger WRR exclusion fence. Map made with data provided by the AWC through Fulcrum and formatted in QGIS.

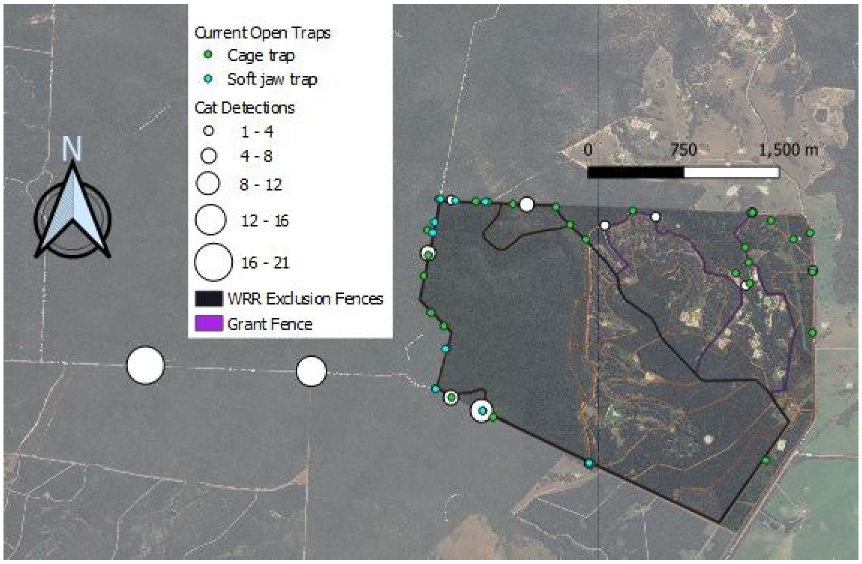

Figure 10. Cat Detections Compared to Current Trap Locations. White circles represent cat detections where circle size represents the number of detections at a single camera trap location in increments increasing by four, where smallest circles represent 1-4 detections and largest circles represent 17-21 detections. Green represents cage trap locations and blue represents leg hold locations. Purple represents the grant fences, and black represents the combined Critical Refuge fence and larger WRR exclusion fence. Map made with data provided by the AWC through Fulcrum and formatted in QGIS.

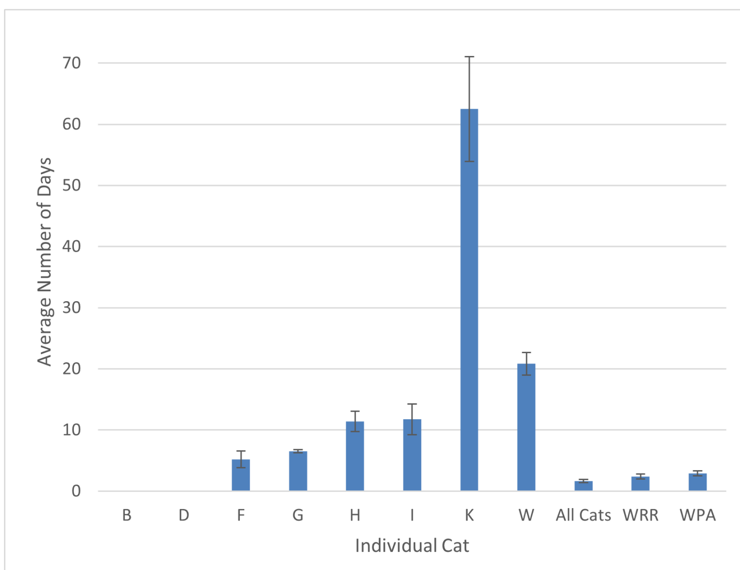

Figure 11. Average Number of Days Between Detections. Bars represent the average number of days between the detections for individual cats B through K and cat W as well as for all cat detections, only WRR detections, and only WPA detections. Cats A, E, J, and L were excluded due to one or no detections within the study time period.

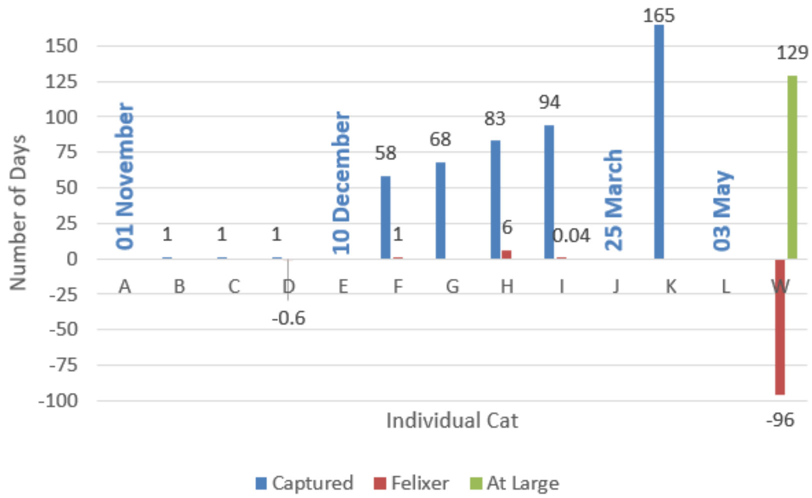

Figure 12. Number of Days between Individual First Detections and Other Variables. Blue bars represent the number of days between the first recorded detection of an individual on a camera trap and its capture. Red bars represent the number of days between the first recorded detection of an individual on a camera trap and the first target photo of the same cat on a Felixer. Only five cats were recorded as Felixer targets that had a camera trap detection. Negative values show that a Felixer target photo was taken prior to the first camera trap detection. Green bars represent the number of days between the first recorded detection of an individual on a camera trap and the last date of the study, as the individual has not been captured. Blue text represents the date of capture for individuals with no camera trap detections.

Table 1. Comparison of Felixer Target Photos to Individual Capture Dates. Felixer First Photo represents the first photograph of an identified cat recorded by a Felixer as a target. Cameras First Photo represents the first photograph of an identified cat recorded on one of the camera traps. Cat W was the only identified cat that was not captured by the conclusion of the study.

Cat	Felixer First Photo	Cameras First Photo	Capture Date	Days from Felixer Detection to Capture
D	22 November 2022	22 November 2022	23 November 2022	1
F	22 November 2022	21 November 2022	18 January 2023	57
H	27 November 2022	21 November 2022	12 February 2023	77
I	18 December 2022	18 December 2022	22 March 2023	94
W	25 December 2022	31 March 2023	N/A	129

Detections and Identifying Individuals

From 01 November 2022 to 03 May 2023 there were a total of 110 detections (Figure 7) across 22 cameras (Figure 6) on the Western River Refuge and Wilderness Protection Agency properties. There were 12 cats captured during this 6-month time period, locations shown in Figure 8. 59 of the detections were visually matched to one of the caught individuals, which averaged 4.18 detections (±1.09 SE) each. 51 detections were unidentifiable beyond the species, making up 46.36% of all detections. Detections per individual and by date shown in Appendix 1. There was one identified cat (W) that was not caught as of the end of the study period but was identifiable by its coloration, while all other identified cats (A-L) were identified in comparison with post-capture photographs. There was an average of 1.67 days (±0.27 SE) between cat detections on all cameras, 2.42 days (±0.41 SE) between detections on WRR cameras, and 2.92 days (±0.41 SE) between detections on WPA cameras (Figure 11). Three identified cats had had only one detection pre-capture and two had zero days between recorded detections (all detections occurred in the same day). Cat A had no recorded detections before its capture and was excluded from data analysis. Of the individual cats, K had the longest absences, averaging 62.5 days (±8.57 SE) between detections. The next largest average was W at 20.83 days (±1.85 SE). There were on average 51.9 days (±16.66 SE) between first detection of caught cats and their capture. Raw data shows a split in tendencies, where Cat K was first detected 165 days before its capture, while cats B, C, and D were first detected the day before their captures.

Felixer Targeting

Of the 12 cats captured during the study, 58.33% were recorded as a target species by the four Felixers on the WRR property (Figure 12). There were seven individual cats recorded by the Felixer target photos, six of which were captured. Cat W was the uncaptured individual, first recorded 96 days before the end of the study. Two of the seven cats on Felixer cameras were low confidence identifications. Of the five high confidence Felixer detections (cats D, F, H, I, and W), all but cat D were recorded as Felixer targets several months earlier than they were captured (between 57 and 129 days later) (Table 1). Five identified cats were not recorded as targets on any Felixers for the 6-month study duration, making up 41.67% of the captured cats.

Mapping Hotspots

Mapping of capture locations showed three sites with multiple captures, the highest being three at leg hold WRL2 on the northwest corner, then two at cage trap WR28 and two at leg hold WRL5 (Figure 8). Mapping detections shows moderate levels on the northeast throughout the grant fencing tracks, higher levels through the northwest and southwest corners, and no detections along the straightaway of the southern fence (Figure 7). The highest levels of detection occur at the two closest WPA cameras (21 at WPA2 and 16 at WPA1), where no trapping occurs. Overlaying detections with current traps shows high levels of trapping where detections occur along the main fence, notably none along the WPA track, and differing levels of detection and trapping locations along the grant fence tracks (Figure 10).

Discussion

Individual Detection Patterns

The ability to match the majority of identifiable cat detection photos to captured individuals allows further conclusions to be made, especially with the understanding that many of the unidentifiable pictures are likely one of the caught cats. However, this cannot be proven and so all conclusions drawn must be limited by the understanding of a large number of unknown detections and a small sample size of identified individuals. Taking this into account, we can say that the vast majority of cats caught on camera around the fence have been captured (12 of 13 identified individuals) and therefore that long term trap evasion is generally not occurring. However, two individuals are single identifications with low confidence and have been excluded from further conclusions. Only one individual has been identified that has not been caught, likely due to its unique white socks on its hind legs that enable easy identification across time and space. This exception, cat W, has been identified across both camera traps and felixer target photos from 25 December 2022 up to 29 April 2023. Cat W has multiple multi-week temporal gaps between detections, including from 26 December to 31 January and from 31 March to 29 April, with an average of 20.83 days (±1.85 SE) between detections. This indicates that the cat likely enters the area for short amounts of time before leaving, which would decrease the chances of it becoming hungry or curious enough to trigger a trap as it might if it remained in the area for longer periods of time. Comparatively, with the exception of cat K, all caught cats have lower average times between detections. However, when examined more closely, nine of the 11 caught cats were never detected in the area for longer than three days before leaving for at least a week, often more. Cat I averaged 11.75 days (±2.48) between detections, but the raw data shows that it appeared once on 15 January 2023 and then not again until it investigated and subsequently triggered a leg hold trap on the night of 21 March 2023. Cat F was recorded on 21 and 22 November before leaving for 41 days and reappearing on 02 January for less than two hours before leaving again until 11 January. Cat D was detected four times within the same day before its capture the next morning. On the extreme, cat K was detected twice in mid-November before leaving for 119 days, reappearing on 19 March, and only captured on 28 April. Cats G and H were consistently documented in the area, but even then, H was documented on and off for three weeks from late November to early December before disappearing for over a month until detection on 18 January. Cat G was the most consistently documented even with two multi-week disappearances from late November to early January, after which it was detected at least once a week until its capture in early February. Eight of its ten detections occurred on the WPA cameras, the two detections on WRR cameras were both along the western edge of the property, and it was captured on a western fence leg hold, leaving a relatively small known range. Notably, cat G was photographed with three kittens on 12 and 14 January and may have been pregnant in the 28 November detection. As an outlier on two fronts, this indicates a strong possibility that cat G was only consistently in one area in order to raise and protect the young kittens. Looking at all of the known detection ranges indicates that the KI feral cats do not stay in one location for long periods of time and that they have not been patrolling the fence or WRR property, however this conclusion must once again be tempered by the small sample size and limited confidence with 51 unidentified detections. While the cutoff for camera trap data at the beginning of November 2022 makes it impossible to say for sure, it is likely that the cats do not trigger traps on their first foray into an area. From this it could be concluded that checking camera traps frequently or increased control efforts following a detection are actions that are unlikely to improve capture rates, and further emphasizes that consistent and long-term trapping is a necessity to capture individual feral cats.

Eight of the 12 identified and photographed individuals were detected in November, and three of those were caught within the month. Four new individuals (including the low confidence E and J photos) were identified after November, but several reinvasions by repeat individuals occurred as previously discussed. This would rule out the idea that new cats would invade an area due to the fact that a previous resident or visitor had been captured, as cats were coming and going at various rates and with various intersections for the entire study period. This aligns with the previous 2008 data by Edwards et al. that documented male feral cats in central Australia as periodically shifting their 24-hour ranges across their larger home ranges, as the KI cat data could be interpreted as short term range patrols before shifting to another section of territory. The majority of identified cats in this study did return following a multi-week period, which could be consistent with spending one-to-three-day shifts in other 24-hour ranges in their territory. Lastly, this would also help explain how the large number of individual cats that all entered the area within the month of November are able to share the resources for one area due to their temporary residence in any one location.

Felixer Targeting

In the majority of Felixer target photos (4 of 5 high confidence identifications), active Felixers would have decreased the number of days that an individual cat was hunting around the refuge and other KI land, as the Felixer in active mode would spray poison at target individuals. Cat D is the exception as it was trapped less than a day after its Felixer detection, but cat F was the next most recent capture at 57 days after Felixer targeting and cat W was the longest as it is still “at large” 129 days since its first Felixer targeting. Earlier Felixer kills hold more significance with the possibility discussed above that feral cats are not likely to trigger a trap on their first visit to an area, whereas Felixer spraying has no such reserves or reliance on a cat's curiosity or hunger on any particular day. This said, the 41.67% of cats that were captured but did not appear on Felixer target photos are not insignificant and indicate the importance of several trapping methods at any one time and location. A combination of Felixer activation and continued cage and leg hold trapping methods is therefore likely to yield increased cat eradication levels in a shorter time period.

Mapping Hotspots

Detection levels show cat activity hotspots along the WPA tracks and at the southwest corners. The WPA notably has no trapping while the WRR has dozens of traps consistently set for almost four years, indicating that trapping efforts are making an impact on cat presence around the immediate refuge area. While part of the grant fence area (the northeast corner) is well laden with cage traps, several areas with multiple recent detections are slightly mismatched from traps. Trapping in these areas could be shifted to ensure trap presence in areas with documented cat activity. Further, the grant fence area camera traps (northeast corner) were installed on 13 April 2023, so the 10 detections across five cameras in less than a month allows for the possibility that with more time those areas may see detections at the same level or higher than other WRR fence locations. Captures for the last six months show leg hold dominance over cage traps with 10 and two respectively, but when it is taken into consideration that cage traps were not open for approximately five months of the six, a conclusion on this matter cannot be drawn. Further, the two cats captured in the month after the cage traps were opened on 11 April 2023 were caught in cages. Both of these cats were captured in cage trap WR28. While such a small sample size severely limits implications, the southeast corner where WR28 is situated has no cameras no other traps, which allows the possibility that increased cameras and traps in the area may increase trapping success and cat movement data. Capture data on the basis of fence location cannot be used for implications at large due to the closure of cage traps for 83% of the study period and the lack of leg holds at the majority of the property's cage trapping locations.

Conclusion

The data collected during this study held several implications for feral cat eradication efforts in Kangaroo Island's Western River Refuge, but cannot hold more confidence than implications due to the short-term nature of the study that allowed only small sample sizes, several low confidence identifications, and such a large portion of the detections to remain unidentified. However, even given these limitations, the implications taken from this study can still be utilized on the refuge. The evidence to support varied and consistent trapping methods, activation of Felixers, and several new trapping and camera locations can be implemented immediately as the staff of Western River Refuge continue to work daily to protect the rare and vulnerable native species on Kangaroo Island.

References

Algar, D. et al. (2010) Eradication of Feral Cats on Faure Island, Western Australia. *Journal of the Royal Society of Western Australia* **93:** 133-140.

Bryant, D. et al. (2018) The Occurrence of the Southern Brown Bandicoot *Isoodon obesulus obesulus* and its Habitat on Chinaman Island, Western Port, Victoria. *The Victorian Naturalist* **135:** 128-139.

Doherty et al. (2015) A Continental-Scale Analysis of Feral Cat Diet in Australia. *Journal of Biogeography* **42:** 964-975. https://doi.org/10.1111/jbi.12469.

Edwards, G.P. et al. (2008) Home Range and Movements of Male Feral Cats (*Felis catus*) in Semiarid Woodland Environment in Central Australia. *Austral Ecology* **26:** 93-101. https://doi.org/10.1111/j.1442-9993.2001.01091.pp.x.

Hodgens, P. et al. (2022) Cat Predation of Kangaroo Island Dunnarts in Aftermath of Bushfire. *Scientific Reports* **12:** 7272. https://doi.org/10.1038/s41598-022-11383-6.

Hohnen, R. et al. (2018) Detecting and Protecting the Threatened Kangaroo Island Dunnart (*Sminthopsis fuliginosus aitkeni*). *Conservation Science and Practice* **1:** 1-11. https://doi.org/10.1002/csp2.4

Hohnen, R. et al. (2019) Investigating Cat Control Methods for Western Kangaroo Island. *Threatened Species Recovery Hub* Technical Report.

Hohnen, R. et al. (2023) Abundance and Detection of Feral Cats Decreases after Severe Fire on Kangaroo Island, Australia. *Austral Ecology* 1-16. https://doi.org/10.1111/aec.13294.

Legge, S. et al. (2017) Enumerating a Continental-Scale Threat: How Many Feral Cats are in Australia? *Biological Conservation* **206:** 293-303. http://dx.doi.org/10.1016/j.biocon.2016.11.032.

Legge, S. et al. (2022) The Conservation Impacts of Ecological Disturbance: Time-Bound Estimates of Population Loss and Recovery for Fauna Affected by the 2019-2020 Australia Megafires. *Global Ecology and Biogeography* **31:** 1-20. https://doi.org/10.1111/geb.13473.

Nogales, M. et al. (2004) A Review of Feral Cat Eradication on Islands. *Conservation Biology* **18:** 310-319.

Salo et al. (2007) Alien Predators Are More Dangerous than Native Predators to Prey Populations. *Biological Sciences* **274:** 1237–1243. https://doi.org/10.1098/rspb.2006.0444.

Spencer, P.B.S. et al. (2016) The Population Origins and Expansion of Feral Cats in Australia. *Journal of Heredity* **107:** 104-114. https://doi.org/10.1093/jhered/esv095.

Van Goethem, T. and van Zanden, J. (2021) Biodiversity Trends in a Historical Perspective. *How Was Life Volume II: New Perspectives on Well-being and Global Inequality since 1820*. OECD Publishing, Paris. https://doi.org/10.1787/2c94883d-en.

Appendixes

Detection Date	Time	28	29	30	31	32	33	34	35	36	37	38	39	WPA1	WPA2	WPA6	19	24	CR2	F30187	F30224	F30225	F30226
01 November 2022	11:05:15													B									
01 November 2022	18:21:52													B									
10 November 2022	0:10:14														X								
10 November 2022	4:47:21																						
11 November 2022	0:36:57																	x					
11 November 2022	20:15:42	C																					
14 November 2022	19:15:12				K																		
15 November 2022	5:12:49															x							
20 November 2022	19:11:39				K																		
21 November 2022	0:30:49						H																
21 November 2022	2:42:50			x																			
21 November 2022	22:08:58			F?																			
21 November 2022	23:00:46		F?																				
21 November 2022	23:56:51	F?																					
22 November 2022	0:26:34				x																		
22 November 2022	1:17:59																					F	
22 November 2022	1:46:30																					F	
22 November 2022	4:06:22																				D		
22 November 2022	19:21:01																		D				
22 November 2022	19:28:40			D																			
22 November 2022	20:40:12																				D		
22 November 2022	22:53:29													H									
26 November 2022	23:10:04													H									
27 November 2022	3:17:04				x																		
27 November 2022	3:57:16																					H	
27 November 2022	5:01:46						x																
28 November 2022	0:48:51													G									
30 November 2022	23:27:49														x								
05 December 2022	20:53:23					H																	
07 December 2022	21:20:31													x									
10 December 2022	3:04:29					H (?)																	
10 December 2022	4:11:34																			E			
14 December 2022	2:05:37														x								
18 December 2022	22:11:30					I																	
18 December 2022	23:14:53																			I			
21 December 2022	2:43:11																			I			
21 December 2022	2:48:11																			I			
21 December 2022	18:40:08														G								
21 December 2022	20:27:34													x									
21 December 2022	23:02:24													x									
22 December 2022	19:58:49					X																	
25 December 2022	1:18:44																				W		
25 December 2022	22:09:46																x						
25 December 2022	23:11:30																				W		
26 December 2022	21:35:53																				W		
27 December 2022	0:03:58														x								
02 January 2023	2:25:25			F																			
02 January 2023	2:50:04							X															
02 January 2023	3:09:41																				F		
02 January 2023	3:33:43																						F
04 January 2023	3:58:05														x								
06 January 2023	23:22:09														G								
09 January 2023	0:48:02													X									
11 January 2023	0:35:31			F																			
11 January 2023	21:28:46																						F
12 January 2023	4:24:47														x								
12 January 2023	19:17:20														G+								
12 January 2023	20:21:08		F																				
12 January 2023	20:29:07														x								
13 January 2023	23:03:28													X									
14 January 2023	3:28:04													x									
14 January 2023	17:03:55													G+									
14 January 2023	22:54:06														x								
15 January 2023	0:12:52													x									
15 January 2023	1:02:36																			I			
15 January 2023	1:45:22																			I			
17 January 2023	20:27:45		G																				
17 January 2023	23:25:34														x								
18 January 2023	1:13:09													x									
18 January 2023	6:39:51														G								
18 January 2023	8:27:42														G								
18 January 2023	22:12:39																			H			
19 January 2023	0:02:44														x								
21 January 2023	0:32:23														x								
22 January 2023	22:06:05														x								
22 January 2023	23:22:59															x							
24 January 2023	2:42:54						G																
26 January 2023	8:52:18														G								
28 January 2023	0:52:06														x								
31 January 2023	2:57:58																				W		
03 February 2023	22:14:01						x																
13 February 2023	3:46:03														X								
14 February 2023	2:10:57													x									
18 February 2023	7:14:58																				J?		
03 March 2023	5:57:40				X																		
03 March 2023	6:25:03																	X					
03 March 2023	19:24:00						x																
05 March 2023	0:16:29						x																
12 March 2023	22:07:15																				W		
16 March 2023	2:23:45							x															
19 March 2023	2:17:11		K																				
21 March 2023	20:50:08						I																
21 March 2023	21:25:06																			I			
22 March 2023	1:27:31						I																
31 March 2023	2:54:11		W																				
11 April 2023	0:01:56						x																
14 April 2023	2:52:50												x										
15 April 2023	22:01:10										x												
16 April 2023	18:51:08										x												
16 April 2023	20:34:59											x											
17 April 2023	4:10:34								x														
19 April 2023	19:54:48									x													
27 April 2023	22:18:28										x												
29 April 2023	5:49:54						x																
29 April 2023	20:52:18						x																
29 April 2023	23:33:08				W																		
01 May 2023	19:56:59									x													
02 May 2023	5:34:00								x														
02 May 2023	5:35:28									x													
02 May 2023	22:59:57						x																

Appendix 1. Detection Dates and Cameras by Individual Cat. All recorded detections from camera traps and Felixers on the WRR and WPA properties were organized by date and time, marked by camera number, and color coded by individual cat detected. Cats A and L were never detected, red represents B, orange represents C, yellow represents D, bright green represents E, army green represents F, light blue represents G, dark blue represents H, purple represents I, pink represents J, and brown represents K. Gray boxes represent detections that were unidentifiable beyond species level, while all other white X cells represent unidentified cats that might be matched to individuals with further study. Darker shaded boxes mark the camera that the detection was recorded on. "?" represents uncertainty with matches and + represents recorded with kittens. The light green columns demark WPA cameras and the light teal columns demark Felixer target photos. Cameras 28-39 are located on the outside of the predator exclusion fence while cameras 19, 24, and CR2 are located inside.

SIT SCHOOL FOR INTERNATIONAL TRAINING
STUDY ABROAD

Access, Use, and Publication of ISP/FSP

Student Name: Leah Boget

Email Address: leahboget@mail.sit.edu

Title of ISP/FSP: Understanding invasive predation: detections of feral cats (*Felis catus*) in Kangaroo Island's Western River Refuge

Program and Term/Year: Cairns: Rainforest, Reef, and Cultural Ecology. ASE SP 23

Student research (Independent Study Project, Field Study Project) is a product of field work and as such students have an obligation to assess both the positive and negative consequences of their field study. Ethical field work, as stipulated in the SIT Policy on Ethics, results in products that are shared with local and academic communities; therefore copies of ISP/FSPs are returned to the sponsoring institutions and the host communities, at the discretion of the institution(s) and/or community involved.
By signing this form, I certify my understanding that:

1. I retain ALL ownership rights of my ISP/FSP project and that I retain the right to use all, or part, of my project in future works.

2. World Learning/SIT Study Abroad may publish the ISP/FSP in the SIT Digital Collections, housed on World Learning's public website.

3. World Learning/SIT Study Abroad may archive, copy, or convert the ISP/FSP for non-commercial use, for preservation purposes, and to ensure future accessibility.
   - World Learning/SIT Study Abroad archives my ISP/FSP in the permanent collection at the SIT Study Abroad local country program office and/or at any World Learning office.
   - In some cases, partner institutions, organizations, or libraries in the host country house a copy of the ISP/FSP in their own national, regional, or local collections for enrichment and use of host country nationals.

4. World Learning/SIT Study Abroad has a non-exclusive, perpetual right to store and make available, including electronic online open access, to the ISP/FSP.

5. World Learning/SIT Study Abroad websites and SIT Digital Collections are publicly available via the Internet.

6. World Learning/SIT Study Abroad is not responsible for any unauthorized use of the ISP/FSP by any third party who might access it on the Internet or otherwise.

7. I have sought copyright permission for previously copyrighted content that is included in this ISP/FSP allowing distribution as specified above.

Leah Boget May 11, 2023

Student Signature Date

Withdrawal of Access, Use, and Publication of ISP/FSP

Given your agreement to abide by the SIT Policy on Ethics, withdrawing permission for publication may constitute an infringement; the Academic Director will review to ensure ethical compliance.

☐ I hereby withdraw permission for World Learning/SIT Study Abroad to include my ISP/FSP in the Program's office permanent collection. Reason: NOT APPLICABLE

☐ I hereby withdraw permission for World Learning/SIT Study Abroad to release my ISP/FSP in any format to individuals, organizations, or libraries in the host country for educational purposes as determined by World Learning/SIT Study Abroad. Reason:

☐ I hereby withdraw permission for World Learning/SIT Study Abroad to publish my ISP/FSP on its websites and in any of its digital/electronic collections, or to reproduce and transmit my ISP/FSP electronically. Reason:

Leah Boget May 11, 2023

Student Signature Date

Academic Director has reviewed student reason(s) for withdrawing permission to use and agrees it does not violate the SIT Study Abroad Policy on Ethics.

James Anthony Cummings May 12, 2023

Academic Director Signature Date

Note: This form is to be included with the electronic version of the paper and in the file of any World Learning/SIT Study Abroad archive.