Research to address our wildlife cat-astrophe

When the cat is away, will the rats play?

Cats and foxes after fires

Australia's cat stats

Tiwi Island's action on cats

Protecting Australian mammals

Toxoplasmosis

Improving baiting

Cat and rabbit interactions

Hugh McGregor in the spotlight

Threatened Species Recovery Hub

National **Environmental Science** Programme

IMAGE: HUGH MCGREGOR, ARID RECOVERY

Editorial…
Addressing our wildlife cat-astrophe

IMAGE: HUGH MCGREGOR

Predation by cats is a key threat to at least 123 threatened species in Australia. Better understanding and reducing the impact of feral cats on susceptible wildlife has been a major area of research for the Threatened Species Recovery Hub. Hub Deputy Directors Professors **Sarah Legge** and **John Woinarski** take a look at our research to address Australia's cat problem.

Conservationists have worried about what cats do to Australian wildlife for over a century. For example, Archibald Campbell, a prominent naturalist, wrote in a 1906 issue of *The Emu*: "Undoubtedly, if many of our highly interesting and beautiful birds, especially ground-loving species, are to be preserved from total extinction, we must … at no distant date face squarely a wild-cat destruction scheme." But these warnings didn't precipitate much action.

The very quality that makes cats such appealing pets – their spectral, cagey guile – makes them noncompliant subjects for research and management. Until recently, compared to other invasive vertebrate species like foxes and rabbits (for which research and management was prioritised because of their recognised detriment to agriculture), we knew much less about cat ecology and the extent of their impacts, and cats had a reputation for being impossible to control.

However, over the past decade or so, there have been some noteworthy successes in the control of feral cats, especially the development of a cat-specific poison bait presentation (Eradicat®) in Western Australia, and eradication of cats from islands and from within large fenced areas on the mainland, with consequent benefits to many threatened species.

From about 10 years ago, some key technological advances, including the miniaturisation of tracking devices and the advent of affordable camera traps, as well as innovations such as using tracking dogs, have enabled new research approaches for cats, and many other relatively small, cryptic species.

The surge of cat research and management has been supported by policy leadership from governments, including the Australian Government, which shone a spotlight on cats in the Threatened Species Strategy, revised the national Threat Abatement Plan for cats, encouraged greater alignment of policy and management of cats across the states and territories, and funded a body of research to improve cat management through the Threatened Species Recovery Hub of the National Environmental Science Program.

This issue of *Science for Saving Species* showcases some of the hub's portfolio of interlinked and collaborative research projects on cats, developed following a large workshop held in 2015 that identified major knowledge gaps and opportunities. This portfolio has two broad components; one component has gathered the evidence base for the extent and scale of cat impacts, by comprehensively synthesising published and unpublished work. This research established the first estimate for the cat population size in Australia and built on that to describe spatial patterns of cat predation (and overall tolls) on mammals, birds, reptiles (page 6), with estimates for frogs and invertebrates available soon.

IMAGE: NICOLAS RAKOTOPARE

ABOVE: Dr Hugh McGregor from the University of Tasmania is working with Arid Recovery to fill important knowledge gaps about cat diets, hunting behaviour and relationships with rabbits.

Inside the Summer 2020 issue of *Science for Saving Species*

Threatened Species Recovery Hub

National **Environmental Science** Programme

The hub has many on-ground research projects about how to reduce cat impacts, shown here grouped by broad management option. The map of Australia shows the spatial variation in cat density during wet years, new knowledge which was produced by the evidence-gathering component of the program.

Integrated control of cats and introduced prey

Managing cat and black rat predation of eggs and chicks of Christmas Island birds

Managing rabbits to reduce cat density and impacts at Arid Recovery

Managing fire and grazing to maintain habitat refuges and reduce predation impacts

Brush-tailed rabbit-rats on the Tiwi islands

Small mammals in Kakadu and northern Australia

Northern bettongs in the wet tropics

Kowari in the stony deserts of South Australia

How foxes and cats interact with fire in south-east forests

Can poison-baiting reduce cats without affecting native species in north Australia?

Can poison-baits be used on Kangaroo Island to protect dunnarts and other species?

Trialling different poison-baits to protect bridled nailtail wallabies from cats in Qld

Expanding and improving poison-baiting approaches

cat density
0   1   2 >2
cats/km2

More efficient trapping

Smart removal of problem cats to protect night parrots

Manipulating dingo density temporarily to reduce cat activity at Ethabuka

Fox and cat density and interactions at Scotia

Integrated predator management

Using guardian dogs to protect eastern barred bandicoots from cats and foxes in Victoria
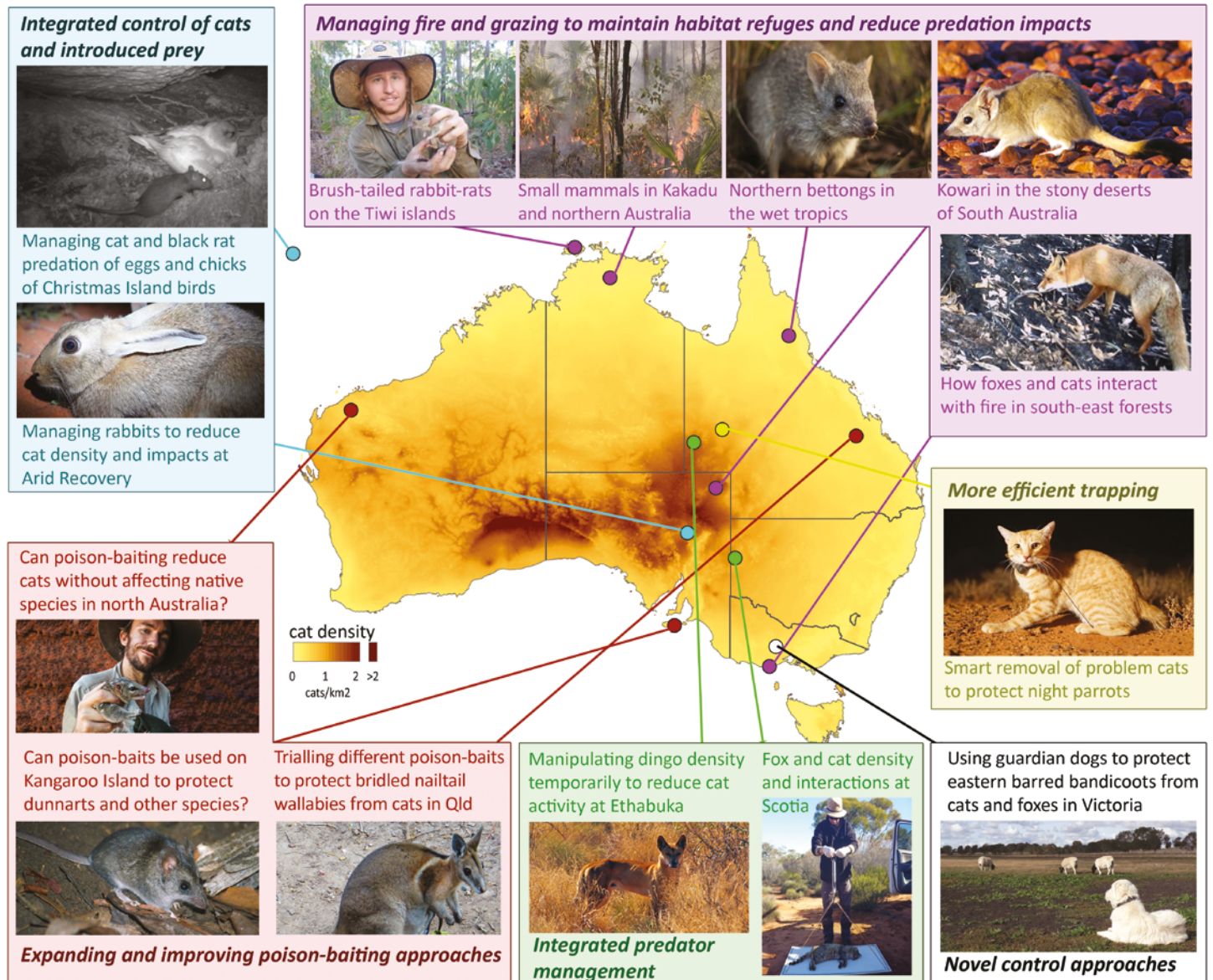
Novel control approaches

Photo credits (clockwise from top left): Rosie Willacy, John Davies, Jaana Dielenberg, Stephanie Todd, William La Marca, Bronwyn Hradsky, Hugh McGregor/Arid Recovery, Linda van Bommel, F L'Hotellier, AWC, William La Marca, Diver Dave - Wikimedia - CC BY SA 3.0, Jody Gates, Nicolas Rakotopare , Hugh McGregor/Arid Recovery.

The approach is currently being extended to foxes; the complementary suites of cat and fox studies will help us understand how the relative impacts of these two predators vary over space and time, and thus guide the relative investment in control efforts for foxes and cats.

The evidence-gathering component of the cat research program has also identified which mammal and bird species are most sensitive to predation by cats. Some native species can persist only in the near-absence of cats (and foxes), and have survived extinction only because populations naturally exist on, or have been translocated to, islands or mainland fenced areas that are cat- and fox-free. The hub's research identified which of these species were currently inadequately protected, and recommended sites for future island and fencing projects that would increase the level of protection most effectively and efficiently across the set of predator-susceptible mammal species.

The second component of the hub's cat research program comprises a suite of field-based projects that aim to improve the way we manage cats at different scales (from sites to landscapes) using existing as well as novel control options. This has included work to extend and improve the way we use existing poison-baits, in places as diverse as Kangaroo Island, the Pilbara and the Queensland brigalow (page 16). At Pullen Pullen, research is aiming to make cat trapping and shooting "smarter" by identifying when and where individual cats need to be removed to protect populations of highly threatened species like night parrots.

An example of research into a novel approach involves trials of whether "guardian dogs" can effectively repel foxes and cats from around populations of eastern barred bandicoots in Victoria.

Several field projects are investigating how we can reduce cat impacts across very large landscapes by managing other threats that interact with cat predation. For example, reducing rabbits can dramatically lower cat density, especially if matched with integrated cat control to minimise prey-switching events (page 20). In a reverse example, a project on Christmas Island aims to find out if black rats will increase as a result of the island's cat eradication program, and how rats can be monitored for increases that could affect populations of endemic birds (page 12).

Earlier work showed that managing fire and livestock grazing in ways that maintain structurally diverse ground vegetation can reduce cat predation, at least in some circumstances. Fire and grazing management is an approach to cat control that could be implemented across very large landscapes, with multiple benefits, so the generality of the interactions between predators, fire and grazing is being investigated in habitats as diverse as the Victorian Otways, Kakadu, the stony deserts, the wet tropics and the Tiwi islands (page 9).

Considering cats and foxes after the bushfires: Fewer pests but more impact?

The 2019–20 bushfires have been extensive and – in some areas – of very high severity. Many threatened species have had most of their distributions burnt, and fire is likely to have imperilled many species not previously considered threatened. One of the post-fire challenges to population recovery that many native species will face is increased risk of predation, including by introduced foxes and cats. Some hub researchers have worked in detail on the interactions between fire and predation by cats and foxes: **John Woinarski, Sarah Legge, Hugh McGregor, Bronwyn Hradsky, Chris Dickman and Tida Nou** describe these interactions and discuss options for their management in these complex and challenging circumstances.

Many cats and foxes will, like many native animals, have been killed in extensive and severe wildfires. However, the cats and foxes that survive will compound the toll taken by fire on native wildlife. This is because fire will have removed much of the shelter (shrubs, grass cover, hollow logs) available for many native animals, rendering cats and foxes much more efficient predators. Both cats and foxes are generalist predators, able to survive on whatever prey has made it through the fire, and also able to scavenge off dead animals (although cats prefer not to). Finally, they are both able to move large distances to capitalise on wherever prey has survived and can be hunted.

Reducing cat and fox densities across intensely burnt landscapes may help the native animals that survive in those areas. This could potentially be achieved with broadscale poison-baiting programs. Even cats, which normally avoid taking poison baits, may be more likely to consume baits after fire, if they are hungry due to a lack of prey. However, if cats do not take the baits, the removal of foxes is likely to advantage cats, and neutralise any benefit from fox reduction.

In addition, it is unclear how much fox and cat density would need to be reduced, and for how long, after such a fire event to achieve measurable outcomes for native species. Monitoring outcomes of feral predator control following the 2019–20 fires presents an opportunity to fill these knowledge gaps.

Alternatively, strategic, intensive fox and cat control carried out at specific locations will be critical for protecting key populations of native species that have been badly fire-affected. Strategic locations could include places where threatened species are known to have persisted through the fire, perhaps because the fire intensity at that location happened to be lower, or because the location acts as a fire-protected refuge, such as a rocky area (e.g., brush-tailed rock wallabies, Mt Kaputar rock skink).

Priority strategic locations include the unburnt patches in an otherwise burnt landscape, which may contain most of the post-fire survivors of some species. Finding these patches as quickly as possible, and then protecting the inhabitants of these patches from predation by cats and foxes (as well as other threats) is a critical action

for supporting post-fire recovery, because cats and foxes are likely to concentrate on unburnt patches once they have exhausted their hunting opportunities in the burnt landscape. Some unburnt patches could be quite small, supporting only low numbers of any one species, and those numbers could quickly be reduced to zero by just a handful of predators.

There are a range of options for undertaking strategic control, including intensive shooting and trapping, and localised poison-baiting (including the use of Felixer™ traps). Not all options involve killing cats and foxes. For example, constructing artificial shelters may help some species evade capture from predators, and excluding predators from remnant populations of native species with predator-proof fencing is also possible.

As many cats and foxes will have been killed by these fires, there is an opportunity, if post-fire pest control is strategic and maintained, to achieve meaningful reductions in the numbers and impacts of introduced predators in our environment, at least at strategic sites if not in the landscape more broadly.

Bushfire affected area in a Queensland state forest.

IMAGE: JAANA DIELENBERG

There is an immense outpouring of community willingness and intent to support the recovery of wildlife following the bushfires. Many different groups including private land managers will be involved in the recovery process. Outcomes will be maximised when actions are collaborative, well coordinated and strategic. Developing a post-fire recovery plan which identifies management options and recovery priorities, and stakeholder responsibilities and resourcing is a valuable process. It will also help to ensure precious resources are best used and important actions are not missed.

More information

Along with other concerned conservation biologists, researchers from the Threatened Species Recovery Hub have developed a "blueprint" for management responses to the 2019–20 fires. It is hoped that the blueprint will provide valuable evidence-based guidance to a wide range of individual agencies, conservation NGOs and other groups.

Chris Dickman, Don Driscoll, Stephen Garnett, David Keith, Sarah Legge, David Lindenmayer, Martine Maron, April Reside, Euan Ritchie, James Watson, Brendan Wintle, John Woinarski (2020) *After the catastrophe: A blueprint for a conservation response to large-scale ecological disaster*, Threatened Species Recovery Hub, January 2020.

Editorial (...continued from page 3)

Other research in western New South Wales and the Simpson Desert is investigating the interactions between cats, foxes and dingoes, and whether manipulating the densities of larger predators could influence the density and or activity of smaller predators.

The hub's cat research has generated enormous interest in the print, online and television media, and has contributed to a heightened awareness about cat impacts, and greater support for their management in Australia compared with other countries. This support shouldn't be taken for granted; in the past year, new research directions have included a focus on how we can continue to shape the conversation about cat impacts and management with a broad cross-section of the public by working with key stakeholders on targeted information exchange (page 22). To support this initiative, recent work has compiled detailed evidence about the impacts of pet cats on wildlife, and the economic burden of cat-borne diseases like toxoplasmosis that have substantial effects on human health and livestock production. Stay tuned for these results in future issues of *Science for Saving Species*.

Campbell was right to worry about cats, and a century later we are still worried. But our understanding of cat impacts, which native species are most at risk, and the range and effectiveness of management options, have improved considerably. Cat management is challenging but not impossible, and blue-sky ideas including using gene drives to reduce cat populations, and accelerating selection for predator avoidance, are just emerging. With continued policy and public support, management effort and research innovation, we may be able to win the fight that Campbell advocated so long ago: to protect our wildlife from the deadly threat posed by cats.

Sarah Legge
The Australian National University
The University of Queensland
Charles Darwin University

John Woinarski
Charles Darwin university

IMAGE: LINDA VAN BOMMEL

ABOVE: Successfully used to protect agricultural species, guardian dogs are being trialled by the hub to see whether they can effectively protect populations of eastern barred bandicoots in Victoria.

BELOW: Hub research has identified which Australian mammal species are the most highly susceptible to cat predation and should be prioritised for inclusion in Australia's havens network of cat- and fox-free islands and fenced areas.

IMAGE: JAANA DIELENBERG

Cats eat animals. But how many?
Which species? And what are the impacts?

The mathematics
of cats

Working with many collaborators, researchers from the National Environmental Science Program's Threatened Species Recovery Hub have now completed a set of national-scale studies that tally the number of cats in Australia and the number of animals that they kill. The results are an astonishing – and alarming – set of numbers that paint a grim picture of the toll that feral and pet cats are taking on native animals. Charles Darwin University's **Professor John Woinarski**, **Dr Brett Murphy** and **Dr Leigh-Ann Woolley** and **Professor Sarah Legge** from the Australian National University and The University of Queensland guide us through what the numbers reveal about cats and their prey in Australia.

Counting cats in Australia

Counting feral cats is challenging. Our research team collated cat density information from about 100 local studies across Australia, modelled these data (to identify factors influencing spatial variation in density) and then applied these models to estimate the total numbers of feral cats in Australia.

We determined that the average density of feral cats in largely natural Australian landscapes is about 0.3 cats per km^2, that their density is much higher on islands (especially smaller islands) than on the Australian mainland, and that density in arid and semi-arid Australia varies appreciably depending upon rainfall conditions. Based on our models of variation in density, we estimate that there are 2.1 million feral cats in natural environments in Australia, increasing to almost 6 million in times of plenty in central Australia.

Feral cats occur pervasively across mainland Australia except where they have been removed from conservation exclosures (which collectively cover about 275 km^2) and they also occur on nearly 100 islands (including all islands larger than 1000 km^2). So, cats occupy – and have impacts on wildlife in – more than 99.9% of the Australian land mass.

In addition to tallying feral cats in natural environments, we estimated that there are about 0.7 million feral cats in highly modified environments ("strays" in urban areas and the like). Pet cats are much more readily and precisely counted, and public surveys report that there are about 3.8 million pet cats in Australia: hence, the total Australian population is about 6.6 million cats in most years.

Quantifying the death toll

These population figures provide a foundation to estimate the total numbers of animals killed by cats. Essentially, such tallies can be calculated by multiplying the cat density in any area by the number of animals any cat in that area has in its stomach, with these tallies then summed across Australia and across 365 days to derive an annual toll. Such tallying rests on some assumptions, notably that an animal eaten by a cat was killed by that cat. This assumption will not always be met, for cats do take some carrion.

However, feral cats preferentially hunt for their prey rather than eat already-killed carcasses and, in some counter-balance, cats will kill or mortally wound some animals without eating them.

There are now many studies that have examined the diet of cats in Australia, with such information hard won through the unglamorous method of teasing apart cat faeces or inspecting the stomachs of dead cats. We collated such information from about 100 studies, widely spaced across Australia, with a total of about 10,000 cat samples. Comparable collations undertaken in other countries have been based on far smaller sample sizes. The Australian collation also allows for analysis of spatial variation in cat diet, for example, by identifying areas in which native mammals or, conversely, introduced mammals, comprise the bulk of cat diet.

The toll on wildlife

We have now published our results for the numbers of Australian birds, reptiles and mammals killed by cats, and we will shortly be publishing comparable papers on the numbers of frogs and invertebrates killed.

We estimate that an average feral cat in natural landscapes kills 129 birds per year, summing to a national tally of 272 million birds killed per year by all feral cats in natural landscapes, with 99% of these being native Australian birds. We estimate that feral cats in highly modified environments kill a further 44 million birds per year, and that pet cats kill about 70 million birds per year. Hence, collectively, the Australian cat population kills more than one million birds per day. The number of birds killed by cats per km² is higher on islands than on the mainland, with many island seabird colonies suffering very high predation rates.

Reptile and mammal tolls are even higher. We estimate that feral cats in natural landscapes kill about 470 million reptiles per year (almost all native species), and the total Australian cat population kills about 650 million reptiles per year. We estimate that 815 million mammals (mostly native species) are killed per year by feral cats in natural landscapes, and 1.14 billion mammals are killed by all Australian cats each year. There is marked geographic variation in the proportion of native mammals (compared to introduced mammals) killed by cats, with the introduced rabbit and house mouse making up much of the mammal component of cat prey in large parts of southern Australia, but native mammals forming the bulk of cat diet elsewhere.

Which species?

We also collated information – from hundreds of sources – on the species of animals known to be eaten by cats in Australia. Cats are now known to prey on 357 bird species in Australia (about half of Australia's native non-vagrant species), including most of Australia's threatened bird species. Cats are more likely to prey on bird species that are island endemics, are of intermediate body mass (60–300 g), and that nest and forage on the ground, such as button-quails and rock-pigeons.

The equivalent tally for Australian reptiles is 258 species (about one-quarter of all Australian reptile species), including 11 threatened species. For mammals, cats are known to prey on 151 species in Australia

IMAGE: JOHN READ

LEFT: Cats prey upon a wide range of vertebrates and invertebrates.

IMAGE: BRETT MURPHY

ABOVE: The proportion of native to all mammals in the diet of feral cats in Australia: 100% indicates that all mammals eaten by cats are native; 0% indicates that all are introduced mammals. The solid black line indicates relative frequency of 50% (i.e., native mammals and introduced mammals occur at equal frequencies).

(just over 50% of the Australian terrestrial species' complement), including 50 threatened mammal species. The non-flying mammals most likely to be preyed upon by cats are of intermediate body weight (100–800 g), and occur in arid areas but not rocky habitats, such as mulgaras and kowaris.

What impacts?

Numbers are slippery. Although these tallies seem astonishingly large, and are based on an unusually substantial data foundation, they do not necessarily imply that cat predation is having a significant impact. However, our tallies represent an important piece of the jigsaw of such an assessment.

Nobody yet knows the total population size of Australian mammals and reptiles, but for birds, our estimate is that cats are killing about 4% of the total population each year. However, this pressure falls unevenly across species, and those with small population sizes, with cat-preferred traits, and with low reproductive output (as is typical of many Australian species) are unlikely to be able to sustain the unrelenting loss of individuals taken by cats. Furthermore, this persistent predation pressure of cats compounds the impacts of the many other factors that threaten much of Australia's biodiversity.

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Feral cats:
An Australian Government perspective

Oliver Tester from the Office of the Threatened Species Commissioner tells us about the Australian Government's action on feral cats.

Feral cats pose a significant threat to our wildlife. They prey on our precious native species, and spread diseases such as toxoplasmosis and sarcosporidiosis. Since European arrival, feral cats have been implicated in the extinction of at least 20 mammal species and currently threaten a further 124 nationally listed species.

The Australian Government formally recognised this threat in 2000 by listing predation by feral cats as a Key Threatening Process under national environmental law. To support this listing, a Threat Abatement Plan was developed that outlines research, management and other actions needed to ensure the long-term survival of native species and ecological communities affected by feral cat predation.

In 2015, the Australian Government focused national attention on this invasive predator through the launch of the Threatened Species Strategy. The Strategy includes ambitious control targets for feral cats to build momentum for community support and drive national action. By June 2020, the Strategy aims to eradicate feral cats from five islands, establish 10 mainland feral cat–free fenced areas, undertake best practice feral cat control on 12 million hectares and cull two million feral cats across Australia.

The Strategy highlighted the need for new information about the impacts of feral cats and effective control techniques for them. New research led by the National Environmental Science Program's Threatened Species Recovery Hub has answered this call with research that has gained global attention. The hub is supporting constructive and evidence-based conversations around the polarising issue of lethal feral cat control. Importantly, this research has improved our understanding of the impacts of cats and how to strategically manage the threat they pose, as well as directly informing policy approaches to both domestic and feral cats across all levels of government.

The Australian Government is using recent research led by the hub about a national stocktake of predator-free safe havens. This research demonstrated the need for a more strategic approach to the future

construction of conservation infrastructure and is informing a $10 million fund to support projects which can fill critical gaps in the national safe haven network.

The feral cat research undertaken by the hub will also be vital for responding to the bushfire crisis taking place across south-eastern Australia at the time of writing. Research on how feral cats react to environmental disturbance such as fires, assess the suitability of various control tools including baits, and quantify the predator susceptibility of species will be integral to informing the response.

Over the past four years, significant progress has been made towards improving control efforts for feral cats in Australia. However, there is still a lot of work to do. Ongoing investment by the Australian Government in science, control tools and coordination will help tackle this significant threat to Australia's native wildlife and contribute to achieving the Threatened Species Strategy's Year Five targets. You can see how Australia is tracking in the Threatened Species Strategy Year Three Progress Report (www.environment. gov.au/biodiversity/threatened/publications/ threatened-species-strategy-year-three-progress-report).

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IMAGE: OFFICE OF THE THREATENED SPECIES COMMISSIONER

LEFT: Oliver Tester in Kakadu National Park.

Using fire to **reduce cat impacts** on the Tiwi Islands

RIGHT: Tiwi Land Ranger Colin Kerinaiua setting fire to pandanus as part of early dry season burning on the Tiwi Islands.

IMAGE: NICOLAS RAKOTOPARE

A partnership between Charles Darwin University and the Tiwi Land Rangers is investigating the relationships between small native mammals, cats, habitat and fire on the Tiwi islands. The rangers are also working with **Dr Hugh Davies** to monitor mammals while they utilise traditional cool burning strategies, to reduce bushfires and maintain habitat that helps mammals avoid cats.

The Tiwi Islands, 60 km north of Darwin, remain one of the only bioregions in Australia to retain its complete mammal assemblage, including threatened species like the brush-tailed rabbit-rat. However, the continued persistence of these mammal species cannot be taken for granted, as monitoring has indicated that mammal populations may be exhibiting the initial signs of decline.

The pattern follows one that has been occurring for the past 30 years across mainland northern Australia's tropical savannas, where declines have been linked to a loss of critical resources and increased predation, especially by feral cats. These two factors are both exacerbated by grazing by large introduced herbivores such as cattle, horses and buffalo, and an increase in the occurrence of large and intense fires.

Grazing and frequent intense fires simplify vegetation structure and diversity. This simplification has significant negative impacts on the native mammals that rely on the food resources and shelter provided by thick and diverse vegetation. Furthermore, the reduced structural complexity of the vegetation results in a more open environment, making it easier for predators, such as feral cats, to hunt.

The Tiwi Islands support the largest remaining populations of the brush-tailed rabbit-rat (*Conilurus penicillatus*). Worryingly, our monitoring has indicated that the distribution of the brush-tailed rabbit-rat on Melville Island (the larger of the two main Tiwi Islands) has been contracting. The species is now restricted to areas with fewer feral cat detections and high shrub density. This emphasises that feral cats pose a threat to the species, but it also indicates that there is potential to manage habitat to help small mammal populations to persist.

We have also been looking at cat density, distribution and activity across the islands and what we have found is that cat activity is higher in areas that have experienced frequent, intense fires and/or heavy grazing by buffalos and horses. This most likely reflects the better hunting conditions in these areas due to the suppressed vegetative complexity. What this again tells us is that management that reduces these disturbances, and maintains more dense vegetation, may offer significant benefits to native mammals.

In combination, what we have learnt gives confidence to the Tiwi Land Rangers that their new fire management strategies will help conserve Tiwi Island native mammals. They have begun implementing island-wide programs of low-intensity burning in the early dry season. This will help to decrease the frequency and extent of high-intensity wildfires late in the dry season, while also leaving plenty of patches of unburnt vegetation, to help species like the brush-tailed rabbit-rat survive in a world with cats.

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AWC ecologists manoeuvring a feral cat which will be GPS collared.
IMAGE:AWC

Effective conservation
of Australian mammals threatened by cats

Australia has many unique small- to medium-sized mammals, which are vulnerable to predation by cats and foxes, two carnivores introduced to the continent with European arrival. For many of these species, effective conservation means heavy or total suppression of cats and/or foxes. Chief Science Officer **John Kanowski** and Regional Ecologist SW **Michael Smith** from the Australian Wildlife Conservancy discuss the far-reaching work their team is doing to protect vulnerable mammals from predation by these two introduced predators.

Thirty-seven native mammals have been identified as extremely vulnerable to the introduced predators cats and foxes, and of these, 25 species (i.e., two-thirds) have gone extinct. Another 52 native mammals are ranked as highly vulnerable, and 29 of these species are threatened. For these species even low densities of cats and foxes are a major threat.

Our mission at the Australian Wildlife Conservancy (AWC) is the effective conservation of Australian wildlife and their habitats. We currently manage (alone or in partnership) 29 properties across Australia, with a total area of over 6.5 million ha. Given the difficulty of totally eliminating cats from open and connected landscapes and the high vulnerability of many small- to medium-sized mammals, we have also established a network of introduced predator–free areas (or safe havens), at eight of these properties.

This includes 5000 ha Faure Island in Shark Bay, Western Australia, and seven fenced areas on the mainland, ranging in size from 275 ha to 9500 ha. There are already 15 threatened mammal species in these havens, with another six species to be added to the network in coming years.

We are a partner in the Threatened Species Recovery Hub and have been undertaking research on a number of issues important to the conservation of Australian mammals concurrently with our conservation programs.

Improving reintroductions

One area of our research focus has been how to improve outcomes for threatened mammals reintroduced to safe havens. On-ground research has been integrated with reintroductions to our fenced introduced predator-free area (or safe haven) at AWC's Mt Gibson Wildlife Sanctuary where eight species of threatened mammals have been reintroduced to date, and another two reintroductions are planned for 2020–21.

As the reintroductions occur, AWC ecologists are conducting research on survival, home range, habitat use and population dynamics of reintroduced mammals. For example, we have found that, given the right circumstances, zoo-sourced numbats (*Mymrecobius fasciatus*) can survive as well as wild-sourced numbats reintroduced to feral predator-free areas.

Successfully establishing secure populations in cat- and fox–free areas is vitally important

IMAGE: AWC

Camera trap image of GPS collared feral cat at AWC's Scotia Wildlife Sanctuary, New South Wales.

to prevent the extinctions of many species, but the long-term goal is to also re-establish native species into broader landscapes from which they have been lost. Being able to estimate the density of cats and foxes in the landscape is an important step in achieving this goal, because before we can release animals we need to ensure that cat and fox densities are at or below the levels we think are required to allow reintroduced native mammal populations to survive.

Movement and density

To address this, a second area of our research has looked at the ecology of cats and foxes, their movements and how to estimate their density in the landscape from remote camera arrays. Most of this work has been undertaken by Dr Andrew Carter and Dr David Roshier at AWC's Scotia Wildlife Sanctuary in semi-arid western New South Wales.

Since 2015, AWC has been undertaking intensive camera-trap monitoring while catching and tracking cats and foxes, to determine their movements and density, and to refine statistical models. More recently, this work has been applied to examine the responses of cat and fox densities to fox control efforts.

We are also building on this research to better understand the ecology of cats and foxes in other biomes. For the past year, Andrew Carter has worked with other AWC ecologists in the Pilliga forests of central-west New South Wales to catch and track cats and foxes, and measure their density in the landscape – a project that is part of the New South Wales Government "Saving our Species" (SoS) program.

The research is revealing that at both Scotia and the Pilliga forests, many cats are travelling over long distances (tens to hundreds of km), a finding with major implications for attempts to control cats at a local scale.

Moving "outside the fence"

In 2019–20, AWC will be extending the design and statistical methods developed at Scotia to measure the outcomes of large-scale aerial baiting of foxes and cats at Mt Gibson, ahead of proposed "outside the fence" reintroductions. Dr Michael Smith is leading a team that has established two large grids of camera traps:

IMAGE: MURRAY SCHOFIELD

ABOVE: Fitting a GPS collar to a sedated fox in order to learn more about their spatial patterns of habitat use.

the first across the 32,000 ha "treatment" grid where baiting will occur, and a second camera grid across a "control" area that will stay unbaited. The team will then measure the density of cats and foxes in both areas before and after bait delivery, to determine the effectiveness of the baiting and the cat and fox densities that are achieved.

Assuming we effectively reduce cat and fox density, AWC will attempt to re-establish populations of the locally extinct western quoll (*Dasyurus geoffroii*), outside the fenced area. We also hope that, with effective control of introduced predators, some of the mammals reintroduced to the fenced area at Mt Gibson will be able to establish populations in the broader landscape. We know that individuals of several species – woylies (*Bettongia penicillata*), numbats and red-tailed phascogales (*Phascogale calura*)

can escape over or through the fence, but at present these individuals are highly vulnerable to cat and fox predation once "on the lam".

In compiling all available monitoring data on threatened mammal populations, the Threatened Mammal Index is demonstrating the extent of the positive contribution that safe havens are making to populations of species vulnerable to cats and foxes. As part of the Threatened Species Recovery Hub, the research of AWC ecologists is making these safe havens even more effective. This new knowledge will also underpin the greater challenge of re-establishing populations of threatened mammal species into open landscapes.

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Further reading

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BELOW: Camera trap image of a numbat within Mt Gibson's cat- and fox-free safe haven. The research found that zoo-sourced numbats fared just as well as wild-sourced numbats in the reintroduction.

IMAGE: AWC

When the cat's away will the rats play?

RIGHT: A juvenile rat braves the jungle floor during the day on Christmas Island – the domain of red and robber crabs, which are likely predators and competitors of rats.

IMAGE: ROSALIE WILLACY

Christmas Island is home to a suite of native animals found nowhere else, but also to invasive species including Asian wolf snakes, giant centipedes, feral cats and black rats. These invasive animals have contributed to many extinctions and declines of Christmas Island's native species. The Australian Government is undertaking a range of conservation initiatives to safeguard the island's native wildlife, including an island-wide cat eradication program. A Threatened Species Recovery Hub collaboration with Parks Australia is investigating the potential outcomes of the cat control, including whether rats will need concurrent control. Researchers **Michaela Plein** and **Rosalie Willacy** from The University of Queensland report.

IMAGE: ROSALIE WILLACY

Cats and rats are recognised as the most damaging invasive predators for island species, and mitigating their impact is a top priority. On other islands, controlling the top invasive predator has sometimes led to increased abundances of smaller invasive species. For example, numbers of rats increased in some parts of Little Barrier Island, New Zealand, after cat eradication, with reduced breeding success for native birds. While there is potential for negative effects from controlling invasive species in this way, outcomes are uncertain and vary between places, habitats and even over time.

Parks Australia, who manage Christmas Island National Park, want to maximise the outcomes of cat control on Christmas Island by anticipating and managing any unintended consequences. Our research is assisting them to predict potential outcomes, particularly the potential for rat (*Rattus rattus*) numbers to increase following cat eradication, and whether this would impact nesting birds.

Current and potential future rat impacts are uncertain for Christmas Island due to data deficiencies and because birds co-existed with (now extinct) native rodents as well as abundant land crabs – which may make them less vulnerable to rat impacts.

We tackled the problem in two ways: first, PhD candidate Rosie Willacy weathered the tropical storms and magic of Christmas Island to collect evidence in the field; and second, postdoctoral researcher Michaela Plein developed a predictive computer model.

Fieldwork warrior Rosie

Rosie describes a typical day: "I get up early on Christmas Island – it will get hot after 11 am – so we will need to finish the field work by lunch at the latest, then we'll be back out in the field in the late afternoon. Today we will check the battery life of motion-sensor cameras that are monitoring the breeding success and causes of nest failure for the ground-nesting seabird the red-tailed tropicbird (*Phaethon rubricauda*).

LEFT: A one- to two-week-old red-tailed tropicbird chick. Parents begin leaving chicks unattended around this age for extended foraging trips at sea. While unattended, chicks are extremely vulnerable to predation.

We will scramble around the sharp cliffs, where the nests are tucked away under bushes and in holes of the limestone. The nests are so well hidden that sometimes nothing but the loud alarm call of the adult breeding bird will alert you to their presence."

Previous studies from 2008 to 2010 showed a mortality rate of up to 95% for red-tailed tropicbird chicks, mostly due to cat predation. Cats have been controlled near one of the colonies since 2010, and breeding success seems to have improved. However, there has been little monitoring to see whether cat predation is continuing, or if rat activity around nests has increased recently. To assess the effects of both cat and rat predation on red-tailed tropicbirds and other threatened Christmas Island species, Rosie is examining patterns of rat abundance and activity across the island, and relating this to forest bird abundance and nesting success, and to seabird nesting success.

Whereas the red-tailed tropicbird has been the seabird "exemplar", Rosie has used the Christmas Island thrush (*Turdus poliocephalus erythropleurus*) as the "exemplar" for forest birds. Over the past three years, Rosie has completed almost 200 transect surveys to estimate the abundance of the Christmas Island thrush and other forest birds in parts of the islands with differing numbers of rats. She has also monitored about 200 thrush and tropicbird nests with motion sensor cameras to detect predation.

Rosie's work depends on gathering data on rat abundance across Christmas Island. To achieve this, she needed to outwit the superabundant, curious and hungry land crabs. During the wet season (and especially during crab migration season), red crabs and robber crabs frequently interfered with traps, making rat detection extremely challenging. For this reason, Rosie first needed to evaluate which method (ink-card tracking, camera traps, cage trapping or DNA hair traps) was best for monitoring rat abundance in this unique ecosystem.

Rosie also measured several other ecological factors (like crab density, crazy ant presence, habitat type) that might explain any variation in rat density, and help us understand the relationships between cats, rats, other species on the islands, and whether cat removal is likely to lead to more rats.

Desktop warrior Michaela

Meanwhile, Michaela Plein reports from her desk: "While I sit in front of my desktop staring at my code, my mind wanders back to the meeting with Parks Australia staff the previous day. Did we include all the important species in the interaction network for Christmas Island? Do feral cats and black rats really eat all these animal species? Would predation by red and robber crabs on rats affect the rat population?

And how heavy are feral cats and black rats on Christmas Island? Because that affects how much they need to eat. Finally, my computer spits out yet another result for the eradication scenarios and I wonder how to best show the uncertainty in these estimates."

Modelling the potential outcomes of invasive species eradications is difficult; often we know little about how the species interact, and the larger a species network the higher the potential for uncertainty.

We have investigated two key questions: 1) Can we predict the effects of eradicating cats only, versus eradicating cats and rats, on other island species?; and 2) What cat and rat densities threaten bird species like the red-tailed tropicbird?

The modelling allows us to estimate the rat numbers that will cause tropicbirds to decline, showing threshold rat density that should not be exceeded if the tropicbird population is to survive over time.

Two tactics come together

While Michaela's modelling allows us to broadly explore the influence of cats and rats on key species, Rosie's field work is providing baseline data on the rat populations of Christmas Island and the impacts of rats on forest and seabirds, as well as developing methods for ongoing monitoring of rats during and after cat eradication.

The hope is that these combined efforts, in the field and on the screen, can help inform future rat management on Christmas Island to aid in the protection of the island's unique animals. Because of the similar stories of invasive species and biodiversity loss on other islands, we also hope that the monitoring and modelling approaches developed and information gained can be used to inform other cat eradication projects on islands across the globe.

IMAGE: ROSALIE WILLACY

ABOVE: Recently hatched Christmas Island thrush chicks. This Endangered subspecies is likely impacted to varying degrees by native land crabs and birds of prey, as well as invasive predators including cats, rats, giant centipedes and crazy ants. On other islands, island thrush subspecies have become extinct due to the impacts of rodents.

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BELOW: Rosie services a motion sensor camera installed at a brown booby nest. A number of brown boobies were monitored alongside red-tailed tropicbirds to compare breeding behaviour-related differences in predation impacts.

IMAGE: SCOTT MACOR

Could toxoplasmosis have a role in mammal declines?

Toxoplasmosis was introduced to Australia by cats, who continue to spread the disease. It is known that the disease affects Australian mammals, and that many Australian mammals are suffering dramatic declines. It was completely unknown, however, whether these declines are linked with toxoplasmosis. **Dr Nelika Hughes** from The University of Melbourne gives us the scoop on her team's investigation of *Toxoplasma gondii* prevalence across Australia and whether it has played a role in mammal declines.

ABOVE: The *Toxoplasma gondii* parasite can cause severe illness and death in infected mammals.

Loss of habitat and changes in fire regimes are often put forward as contributors to Australia's appalling mammal extinction rate. The role of introduced herbivores and carnivores has also received widespread attention. But several researchers have noted that significant historical declines occurred in some areas well before the establishment of rabbits and foxes.

Similarly, the recent and sudden decline in mammal species across northern Australia does not correspond with obvious changes in the usual suspects of fire, habitat loss or introduced species. In these – and other – instances of mammal decline, however, novel diseases introduced to Australia following European settlement might have played a role.

A strong candidate in this regard is toxoplasmosis. Caused by the ubiquitous protozoan parasite, *Toxoplasma gondii*, the disease was introduced to Australia with cats (the parasite's definitive host), but also needs to infect a different mammal or a bird (an intermediate host) to complete its life cycle.

When a cat is first infected it sheds infectious *Toxoplasma* oocysts in its faeces, contaminating the environment with approximately 2–5 million oocysts over a period of 1–2 weeks. This oocyst stage is important as it is the only time when the parasite is exposed to the environment.

Intermediate hosts become infected by consuming these oocysts while foraging or grazing, although transmission can also occur through the consumption of infected animals.

The effects on infected mammals and birds are twofold. The initial infection can make animals very sick, potentially leading to sudden death. But animals that survive this period also face challenges, including skewed sex ratios, reduced risk aversion and an attraction to cat odours, possibly increasing the risk that the infected animal will encounter a cat.

A role in mammal declines?

Cats are found across Australia, and *Toxoplasma* infects a wide range of native species. To learn whether *Toxoplasma* is playing a role in Australia's mammal declines we mapped the prevalence of *Toxoplasma* in feral cats across Australia, looked for any environmental factors associated with this distribution, and then extrapolated the likely exposure of native mammals to *Toxoplasma*.

Toxoplasmosis was introduced to Australia by cats, who continue to spread the disease.

To estimate the level of exposure that native mammals have to *Toxoplasma* we combined information on the density of feral cats across Australia (estimated by another hub project), with new knowledge on cat infection rates across the country that was estimated by this project.

We estimated cat infection rates by analysing feral cat tissue samples from 25 locations across the country. Feral cat control programs provided a ready supply of tissue samples in which to screen for the parasite, and we then used quantitative real-time PCR (qPCR) to screen these samples for *Toxoplasma*. Published data on *Toxoplasma* prevalence in feral cats from an additional 22 locations gave us a combined dataset of 1001 cats from 47 sites.

Next we built a model of *Toxoplasma* prevalence based on the infection data combined with data on temperature and rainfall across the country, as temperature and moisture are known to affect *Toxoplasma* oocyst survival. As conditions can be very different in urban areas compared to surrounding bush and rural areas in terms of cat density and environmental conditions, we also included urban areas in the model.

What we found

Approximately 40% of our sampled feral cats were infected with *Toxoplasma*, but we found that *Toxoplasma* prevalence in cats is highly variable across Australia. The main predictors of prevalence are temperature, rainfall and urbanisation and, in urban areas, cat density is also influential.

Toxoplasma prevalence decreases with increasing temperature and increases with increasing rainfall. Increasing rainfall also mitigates the effect of increased temperature, so *Toxoplasma* oocysts can survive in warmer areas, to some extent, as long as there is enough moisture.

North and centre too hot and dry

Toxoplasma appears to be either absent or at very low levels across large parts of central and northern Australia. While there is no shortage of cats in these regions, the environmental conditions appear unfavourable to the survival of the oocyst stage of the parasite. The finding of low prevalence in these regions argues strongly against *Toxoplasma* playing a major role in mammal declines — both recent and historical — in these areas.

High rates in cool and damp areas

Our results also show very high prevalence of the parasite in the cooler and damper parts of the country, particularly around the Great Dividing Range, and in Tasmania. Here, *Toxoplasma* may well have a substantial, underappreciated, impact on native mammal populations.
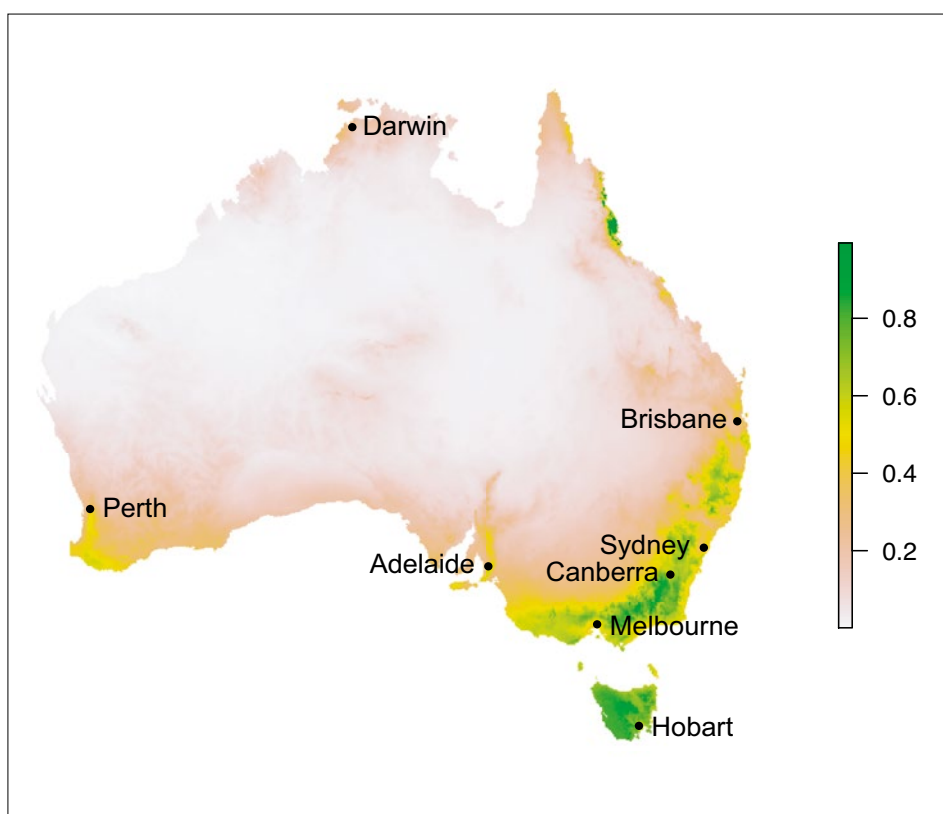

Figure 1. The predicted prevalence of *Toxoplasma gondii* in feral cats across Australia. The highest concentrations (green areas) are in the south-east and in urban centres.

The model predicts high prevalence of *Toxoplasma* in feral cats in Tasmania, along the eastern coast of Australia south of Brisbane, and along the southern coast of Victoria.

Urban reservoirs

Urban areas have high *Toxoplasma* prevalence rates. In urban areas temperature has a stronger effect on prevalence rates than rainfall, possibly because in urban areas water is generally not limited.

We also found that cat density becomes influential in urban areas, with increasing cat density resulting in increasing *Toxoplasma* rates. This finding has implications for human health, because controlling feral cats in urban areas may be a useful mechanism for reducing *Toxoplasma* risk to humans.

A worrying finding was that urban areas appear to act as reservoirs for *Toxoplasma* in otherwise unsuitable regions, giving rise to the possibility that this may allow the disease to adapt to the environmental conditions of these otherwise unsuitable regions. This could occur as urban areas will supply a steady stream of the *Toxoplasma* oocysts into surrounding areas (in cat faeces), the oocysts will be exposed to challenging environmental conditions on the edges of urban areas and, while most will perish, over time genetic variations may occur allowing some oocysts to survive until they are consumed by a secondary host. Natural selection will ensure that those best adapted survive to reproduce.

The threat of urban areas supporting adaptation of the parasite to hotter and drier conditions therefore provides an additional conservation-focused incentive to control feral animals in hot, dry urban areas.

A final word

While we did not directly examine infection prevalence in native wildlife, our results matched well with published data on *Toxoplasma* prevalence in native wildlife across Australia. While *Toxoplasma* looks to be exonerated from a role in mammal declines for central and northern Australia it may well be having a significant impact on Australia's mammals in wetter and cooler areas. Urban feral cat populations may also lead to greater adaptation of the parasite.

IMAGE: MATT GENTLE

Improving feral cat control

Baiting trials at Taunton National Park

Once commonly found throughout eastern Australia, bridled nailtail wallabies suffered range and population declines after European settlement and became restricted to a small population at Taunton National Park (Scientific) in central Queensland. **Dr Matt Gentle**, Principal Scientist in the Pest Animal Research Centre at the Queensland Department of Agriculture and Fisheries, takes us through the cat baiting trials at Taunton in this joint hub and Queensland Government initiative.

ABOVE: Eradicat® bait preparation.

Predation by feral cats is a key threat to the recovery of the wallaby at Taunton (where foxes are absent), so broadscale cat control is an important conservation action for park managers. In the past, broadscale cat control largely focused on trapping and shooting. Poison baiting options now also exist and have been effective in western and southern Australia, but their effectiveness has not been tested in eastern Australia.

Our project set out to test two of the most common poison bait options:

1. Fresh meat baits
2. Sausage-style bait known as Eradicat®.

We wanted to know how effective each bait was at suppressing feral cat numbers at Taunton National Park and whether there was any significant off-target (other animal) impact from the baits.

To measure effectiveness, before each trial, we trapped feral cats and fitted them with GPS collars then released them. We also set up a network of 90 remote cameras across Taunton and at a nearby, non-baited control area to monitor changes in the cat population due to the baiting.

Trial 1: Fresh baits

In mid-2016 we distributed 776 fresh meat baits across Taunton from the ground in line with current approved prescriptions for this bait. They were placed along the network of tracks and roads and each 125 g bait contained 6 mg of the poison 1080. Remote cameras were also placed at baits to determine their fate.

One out of nine GPS-collared feral cats were killed by the fresh baits (11%), while remote camera monitoring across the site estimated feral cat population reduction of up to 14%.

While feral cats did encounter 16% of the monitored baits, the baits were relatively unpalatable and often not taken.

BELOW: Collared cat.

Fresh meat baits can rapidly desiccate in dry conditions and attract ants, both of which contribute to decreased palatability to feral cats. Non-target species also removed many baits quickly, reducing availability to cats. Preliminary examination of the feral cat movement data also indicated little use of track habitats where baits were placed.

Collectively, these findings support previous observations that feral cats can consume fresh meat baits, but highlighted deficiencies in the bait type, bait distribution (i.e., track-based) and baiting intensity for effective broadscale control of feral cats. If fresh baits are used in line with existing approved prescriptions they can be expected to have poor effectiveness.

IMAGE: MATT GENTLE

Trial 2: Eradicat® baits

In July 2017, we undertook the first trial of Eradicat® in eastern Australia. A total of 5,530 Eradicat® baits were distributed along 500 m flight transects across Taunton by helicopter at the recommended density of 25–50 baits km². A subset of baits was monitored with cameras to determine bait uptake.

We estimated the impact on the cat population via the GPS-collared cats and the remote camera network. A bird count was also undertaken to determine changes in bird populations, which may be due to birds taking the baits.

Four out of 10 GPS collared cats (40%) died as a result of the baiting. The estimated cat population reduction at Taunton based on the camera monitoring was 38%.

The bait uptake monitoring cameras identified that ravens and crows interacted the most with Eradicat® baits, followed by the common brushtail possum. However, bird counts undertaken at both Taunton and nearby unbaited properties found no significant differences in bird densities pre- and post-baiting. Corvid densities at Taunton also remained high (4.8 birds km²) compared to the control site (2.8 birds km²) post-baiting. Similarly, analysis of camera monitoring data showed no significant difference in the abundance of the brushtail possum pre- and post-baiting. All three species remained widespread and abundant.

Wallabies bouncing back

Collectively, the results indicate that Eradicat® baits had higher efficacy than fresh meat baits.

There were no non-target mortalities observed during or post the baiting period and no significant changes in non-target species abundance.

The population of the Endangered bridled nailtail wallaby, known to be limited by feral cat, wild dog and dingo predation, continues to increase. Our results demonstrate that Eradicat® is an effective, safe and useful additional tool for feral cat control at Taunton National Park.

This Threatened Species Recovery Hub project is a collaboration between Biosecurity Queensland, the Queensland Department of Environment and Science and The University of Queensland. The feral cat control component is being funded through the Queensland Government Feral Pest Initiative, Biosecurity Queensland and the Queensland Department of Environment and Science. For more information visit the National Environmental Science Program website at http://www.nespthreatenedspecies.edu.au/ projects/feral-cat-control-for-threatened-species-in-queensland.

Further reading

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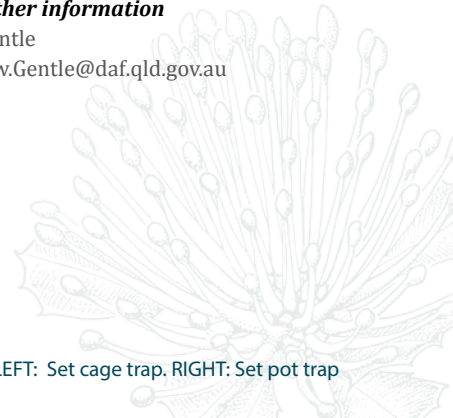

IMAGE: JAMES SPEED

ABOVE: Eradicat® bait preparation.

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BELOW LEFT: Set cage trap. RIGHT: Set pot trap

IMAGE: JOE JESS

IMAGE: JOE JESS

Rabbit burrows helping cats colonise new frontiers

RIGHT: Dr Hugh McGregor has tracked one of the collared cats to the burrow in the foreground of this photo.

Across Australia's arid zones feral cats are utilising micro-refuges, like rabbit burrows, to help them persist in areas that are otherwise unsuitable. **Dr Natalie Briscoe** from The University of Melbourne tells us about her research to explore and map the importance of micro-refuges for feral cats, which has important implications for cat management.

The European rabbit negatively impacts 321 threatened species in Australia, which includes many plant species and also some animals due to competition and habitat modification. Across large regions of Australia, rabbits also exacerbate the impact of feral cats and foxes. An obvious way they do this is by providing a plentiful supply of prey which can boost cat and fox numbers.

Our research has looked at another, less obvious way that rabbits are exacerbating feral cat impacts, particularly across Australia's vast arid zones: by providing deep burrows.

Micro-refuges

Rabbits dig burrows as effective micro-refuges that provide them with shelter from predators and from harsh environmental conditions above ground, enabling them to persist in areas that would otherwise be unsuitable.

Although a cat cannot construct its own refuge in the way a rabbit can, we believed that cats were also using micro-refuges to persist in areas which were otherwise unsuitable, and that rabbit burrows may be one of the micro-refuges that cats were using. Understanding more about this would potentially provide new strategies to manage cats.

What a cat needs

To gain a better understanding of how feral cats persist in the arid zone, our team at The University of Melbourne developed an eco-physiological model for cats and explored how behaviour and landscape features influence predicted energy and water requirements, as well as risk of mortality from heat stress.

We calculated that cats can survive without access to free water in Australia's arid zone, obtaining enough water from their prey, as long as they have protection from extreme heat. As such, the distribution of cats across Australia is likely to be influenced not just by ambient climate conditions but also by the availability of microclimates that cats can access.

To identify the range of microhabitats that cats utilise in the arid zone, we collaborated with ecologists from the University of Tasmania, Arid Recovery in South Australia and Australian Wildlife Conservancy's Scotia Wildlife Sanctuary in New South Wales to catch and GPS-collar feral cats.

We found that cats are using a number of hot weather refuges including rabbit and old fox burrows, piles of logs and sand adjacent to

LEFT: Collared cat ready for release.

tracks, runs under spinifex clumps, and dense stands of native cypress pines. Feral cats in the Victorian mallee have also been documented using burrows, deep shade and logs as daytime refuges.

Rabbits are not the only animal to dig a burrow, but rabbit burrows (due to their number, suitable size and depth) are likely to be the main type of burrow used by cats.

The data we collected at Arid Recovery and Scotia also included microclimate data every 2–15 minutes from cat collars and different microhabitats. Cats were collared and tracked between January and April at Arid Recovery and across the year at Scotia, to capture a range of conditions.

Burrows beat the heat

The field data reveal the difference that burrows can make for animals in the arid zone, providing a cool refuge to escape the heat on the surface. During hot days over summer, temperatures down burrows were substantially cooler than above-ground temperatures: on average, burrows were 5.4–6.3°C cooler than ambient air temperatures at Arid Recovery, with maximum hourly differences of up to 19°C recorded at Scotia during hot (>40°C) above-ground conditions.

Combining this new data on micro-refuge climates with the eco-physiological model enabled us to predict where cats can survive across Australia, and what features they would depend on to persist in an area. We used weather data from 2017 to predict what micro-refuges cats would depend on to survive across the year. The model could also be run for other weather scenarios, including potential future weather patterns under climate change.

We found that in the arid and semi-arid zones that cover about half of Australia, for at least part of the year, cats can only survive local conditions with the aid of burrows. Across about half of this region summer maximum temperatures are so high that cats can only survive by using deep burrows, such as those made by rabbits.

Natural cat-free zones

In a few small regions for at least a few weeks a year, temperatures are predicted to be too extreme for cats to survive, even if they have access to burrows. These areas may act as natural refuges from cats due to climate. While cats may venture into these areas at some times, modelling indicates that they would not be able to live in these areas permanently.

It is unlikely to be a coincidence that the kowari, a small carnivorous marsupial once widespread across arid zones, is now largely confined to these areas.

Lessons for management

Our results highlight the importance of micro-refuges, including rabbit burrows, for feral cats in the arid zone. Controlling rabbit numbers is known to help control cat numbers, but this research has shown that removing rabbit burrows could also be an effective management strategy to reduce feral cat densities in arid and semi-arid zones.

In regions where cats would depend on burrows to survive extreme temperatures, a strategy of removing rabbit burrows and keeping areas rabbit-free so new burrows are not excavated could be used to increase cat-free refuge areas.

This Threatened Species Recovery Hub project was led by The University of Melbourne, who worked in collaboration with Arid Recovery, the Australian Wildlife Conservancy and the University of Tasmania. It received support from the Australian Government's National Environmental Science Program.

For further information
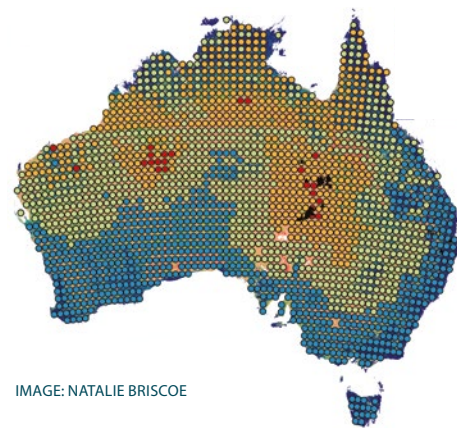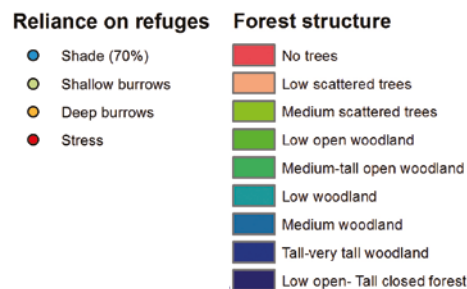Natalie Briscoe
n.briscoe@unimelb.edu.au

IMAGE: NATALIE BRISCOE

Reliance on refuges
- Shade (70%)
- Shallow burrows
- Deep burrows
- Stress

Forest structure
- No trees
- Low scattered trees
- Medium scattered trees
- Low open woodland
- Medium-tall open woodland
- Low woodland
- Medium woodland
- Tall-very tall woodland
- Low open- Tall closed forest

ABOVE: Features cats are predicted to depend on to maintain energy and water balance based on 2017 weather data. In green and orange zones, cats could not survive temperature extremes without seeking the shelter of burrows for at least part of the year. Even with the shelter of burrows the climate in red zones is too harsh for cats for at least part of the year. Black triangles show kowari records from 2000–2017 – note the overlap with red zones.

IMAGE: JAANA DIELENBERG

In this part of outback New South Wales feral cats are predicted to depend on burrows to survive extreme daytime temperatures for at least part of the year.

When rabbits are off the menu, what's for dinner?

IMAGE: NICOLAS RAKOTOPARE

Rabbits and feral cats are individually two of the most widespread and destructive pest species in Australia. When rabbit numbers are abundant they also boost feral cat populations. As a result, over the long-term, rabbit bio-controls can be effective in reducing both rabbit and feral cat populations. But what happens when rabbit numbers first crash; do cats prey-switch and create a bigger threat than usual for native wildlife? We asked **Dr Hugh McGregor** from the University of Tasmania about his landscape-scale experiment at Arid Recovery in South Australia which is tackling these questions.

ABOVE: Hugh McGregor sets up a motion detection camera to monitor feral cats and native mammals at Arid Recovery in South Australia.

Rabbits are a major problem for Australia. They are one of our most damaging pests, directly impacting hundreds of threatened species, most of which are plants. With enough time they can level whole woodlands and other habitats, by preventing new trees and plants from regenerating.

In contrast, cats and foxes are a major threat to native animals. Cats are Australia's most widespread feral predator and negatively impact at least 123 threatened species. Foxes impact at least 95 threatened species. They have been implicated in the decline of most threatened Australian mammal species.

IMAGE: NICOLAS RAKOTOPARE

As if these individual impacts were not enough, when they occur in the same area rabbits can also exacerbate the impacts of cats and foxes. This is likely occurring in southern Australia, where abundant rabbit populations support high densities of feral cats and foxes. Like a town providing free food, rabbits provide an endless source of protein, and enable cats and foxes to breed to their maximum capacity, inflating their densities.

Kitchen is closed

But what would happen if an abundant rabbit population is suddenly reduced? Would cat or fox numbers quickly re-stabilise to match lower rabbit densities? Would they temporarily increase their predation on native species?

The most well-known instances of major reductions of rabbits occurred following the release of the bio-control agents myxoma virus in the 1950s and rabbit haemorrhagic disease virus (RHDV, or calicivirus) in the mid-1990s.

LEFT: A plains mouse at Arid Recovery.

In addition to achieving huge reductions in rabbits, these rabbit biocontrols also caused cat numbers to plummet in parts of arid Australia, where they have not rebounded to previous levels since. There is evidence to show that native wildlife benefitted from the reduction in cat numbers. However, when rabbit numbers first crashed, the hyper-abundant cats likely switched to eating native prey while the cat population restabilised to lower levels. Some studies reported more native animals in cat scats after rabbit numbers dropped.

A very large experiment

Our research looked in detail at the short-term response of feral cats when the abundance of rabbits is suddenly reduced. Do they switch from rabbits to other prey? Does the cat population size also suddenly reduce? We did this by conducting a landscape-scale experiment at the Arid Recovery Reserve in South Australia. We removed around 80% of the rabbit population from within a 37 km^2 experimental enclosure (2,215 rabbits removed from an estimated population of about 2,800).

To learn how this would affect the resident feral cat population within the enclosure, before the rabbit reduction we caught and GPS collared 30 cats, also putting video collars on many of them. We also collected and analysed scats and monitored the population sizes of cats and small mammals by counting their tracks along transects. From these data we were able to measure the survival, health, diet and hunting rates of the cats before and after the rabbit removal.

To ensure that any changes we observed were due to the change in rabbit numbers and not other factors like weather, we monitored cats and small mammals at both the experimental site and an adjacent control area where rabbits were not removed.

Rabbit-hunting specialists

Before the rabbit removal, we could tell rabbits were very important for feral cats. They were found in 80% of cat scats. Data from the GPS and video collars revealed that the hunting strategy of many cats was heavily focused on rabbits, and some GPS data looked like a join-the-dots picture of visits to rabbit warrens. We even recorded a rabbit kill on camera, and it was certainly a larger meal than anything else we saw the cats eat.

The effects of the rabbit removal on feral cats were substantial. Within a month, survival of collared cats decreased by 40%. Cat activity also declined by 40%. Surviving cats lost weight and condition, while we saw no change in cat body condition or activity in the nearby control area where there was no rabbit removal.

IMAGE: NICOLAS RAKOTOPARE

ABOVE: GPS-collaring of feral cats during the study revealed that many cats focus their hunting at rabbit burrows when rabbit numbers are high.

Hungry cats will eat carrion

Cat diet also changed substantially; after the rabbit cull, cats were more likely to eat novel food sources like carrion, reptiles and insects. Before the rabbit cull, we had even seen some instances on video collars of cats walking past reptiles and carrion without eating them. However, we did not observe an increase in the consumption of small mammals like plains mice or hopping mice after the rabbit cull.

We showed that prey-switching by cats will occur after rabbit populations are reduced. However, much of this involves switching to foods that are easy to find but were previously not preferred, such as carrion. Cats may be less likely to switch to harder-to-kill prey, such as small native mammals.

Given the perilous state of many native mammals, it was heartening to observe that following the rabbit cull impacts on native mammals did not significantly increase. However, the impacts to reptiles and insects in an area could still be significant.

A golden opportunity

Managing rabbit populations using biocontrols or warren-ripping leads to long-term reductions in cat populations, but it also creates opportunities for land managers to achieve even greater reductions in feral cat numbers. In particular, while cats do not readily take poison baits in general, they are likely to be extremely effective following a large reduction in rabbits.

Our research has shown that at these times, when their favoured prey is off the menu and cats are hungrier, they will take food sources that they would not otherwise consider, such as carrion and baits.

These findings will be valuable to informing feral cat management in all areas where rabbits are present.
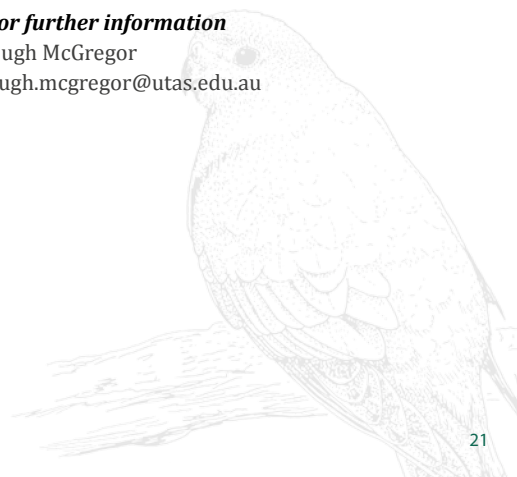
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BELOW: When rabbit numbers are abundant they also boost feral cat populations.

IMAGE: HUGH MCGREGOR

The conundrum of cats in Australia

Beloved companion animal and decimator of native wildlife – that is Australia's cat conundrum. Australia and Antarctica are the only continents without native felids. Our wildlife has evolved over millennia without defences against these supreme hunters. **Tida Nou** from The University of Queensland talks about a new Threatened Species Recovery Hub project which is synthesising the latest research on cat impacts and management, finding out how over 500 local governments across Australia are managing cats, and engaging with a broad range of groups to better inform Australia's national cat management conversation.

The Geelong Cats. The Cat Empire. Hello Kitty. Garfield. "Good luck" cat figurines ("Maneki Neko"). Fat Cat and Friends. Cat cuddle cafes. Top Cat. Cat memes. Felix the cat. The list goes on.

Against this setting of revered cat icons and lovable cat characters of popular culture and our everyday lives are more than 6 million pet and feral cats in Australia that are killing a minimum of 6 million (mostly native) animals every day. Not a single one of the cat cartoon characters or icons is depicted as a serial killer, yet that is what an outdoor cat is to many of our unique and precious Australian animals. Outdoor cats, whether they are pampered pets or rangy ferals, have a devastating impact on native wildlife. Australian animals – our bandicoots, quolls, numbats, ground parrots and blue-tongued lizards are defenceless against these highly efficient hunters.

In Australia, there is considerable community interest about cats, and a broad range of interest groups with divergent perspectives on cat welfare, and the environmental and health impacts of cats. Australia is now also a world leader in research on the impacts and management of cats, as demonstrated through an extensive body of knowledge and peer-reviewed research.

In August 2019, the Threatened Species Recovery Hub began a project to collate and disseminate this research to key stakeholder groups. For example, a component of the project is reviewing the cat management actions, information needs and current management approach of nearly 540 local governments in Australia. The project aims to gain a more comprehensive and up-to-date understanding of the depth and breadth of local government action on cats, as well as uncovering any knowledge gaps that constrain their ability to manage cats. We will use the results to identify research priorities, and to inform the development of tailored communication products that will support local government to build awareness about cat impacts and to consider management options for reducing those impacts.

In 2020, we aim to connect with a broader section of the public by running an online national art/photography competition and exhibition. The event aims to encourage people to think about cat impacts, by asking participants to submit a photograph or an art piece of a native species that cats are known to prey on.

This hub project will enhance the national conversation about the impacts and management of cats, and the evaluation of cat management. We aim to engage with and learn from a range of sectors, produce accessible information, and distribute it proactively and strategically across the community. By engaging with different stakeholder groups that are on the fringe of the traditional conservation sector, we hope that the project will promote a broad-based and considered discussion about cat impacts and management, and thus avoid the extreme polarisation of views that causes a stalemate in policy and management.

This Threatened Species Recovery Hub project is a collaboration between The University of Queensland, Charles Darwin University, and RMIT University, who are working with a wide range of government agencies, local councils, non-government conservation groups and animal welfare groups.

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Testing cat baiting on Kangaroo Island

A feral cat eradication program is underway on Kangaroo Island. Conservation managers want to know if poison baiting is suitable for densely vegetated and inaccessible areas characteristic of most of the island's conservation reserves. To answer this question, **Dr Rosemary Hohnen** from Charles Darwin University undertook a trial of non-toxic Eradicat® feral cat baits to test the risk to native animals and uptake by cats.

RIGHT: A brushtail possum eating one of the non-toxic baits in front of a camera trap.

IMAGE: ROSEMARY HOHNEN

The Australian Government has a plan to eradicate feral cats on five Australian islands by 2020, the largest of which is Kangaroo Island (4,405 km^2). Kangaroo Island is home to many endemic species and subspecies, including the Kangaroo Island dunnart and Kangaroo Island echidna and is a stronghold for some species that are declining on the mainland, including Rosenberg's goanna, the pygmy copperhead and the southern brown bandicoot.

Eradicating cats will benefit these species and will also benefit the island's agricultural sector, by reducing cat-borne parasites, which cost the island's sheep industry at least $2 million per year. The eradication program has already begun and is being led by Natural Resources Kangaroo Island and the Kangaroo Island Council, with the support of the South Australian and Australian Governments.

Used in conjunction with other approaches, poison baiting is a useful tool for feral cat eradication, and is one that could be particularly useful in the (formerly) densely vegetated and hard-to-access areas of western Kangaroo Island. The need to effectively manage cats on western Kangaroo Island is now even greater, as they are likely to be concentrating their foraging in the small patches of vegetation that remain after the January 2020 fire, some of the last habitat left for threatened small mammals like the Kangaroo Island dunnart. The 1080-based bait Eradicat® has been used widely in south-west Western Australia, where native plants naturally contain the toxin, and native mammals have a higher tolerance to 1080 than introduced species. However, the toxin does not occur at high concentrations in the flora of Kangaroo Island, so native animal species may have low tolerance.

Hence, prior to any broadscale baiting, it is important to test whether native animals would consume the baits.

Non-toxic trial

We undertook a trial of non-toxic Eradicat® baits. We deployed 288 baits across four sites within Flinders Chase National Park and Ravine des Casoars Wilderness Protected Area in August and again in November 2018. Baits were placed in open areas in front of motion-activated camera traps, which recorded which species approached the baits.

For this trial, the baits also contained Rhodamine B, because this dye can be traced to assess whether animals have consumed the bait: in this case, the dye is deposited in whiskers after consumption. Two to three weeks after each baiting period we trapped for six nights and took whisker samples to see if animals had consumed baits.

We found that many native animals consumed the baits: from whisker samples we saw that almost all brushtail possums caught during trapping had consumed baits; over half of the bush rats; and one-third of the western pygmy possums. Australian ravens, Rosenberg's goannas and southern brown bandicoots were also recorded approaching baits by the camera traps.

No Kangaroo Island dunnarts and only one southern brown bandicoot were captured during trapping, so bait uptake could not be determined. While the number of times these species approached baits was few, this may reflect the very low abundance of these species rather than lack of interest in the baits.

Low uptake by cats

Cats took less than 1% of the baits; they approached the baits only six times during the trial and took only one bait. This could reflect either an aversion to scavenging when live prey are readily available, which has been observed in feral cats in some parts of Australia, or the area over which the trials took place being smaller than the normal ranging area of a feral cat.

Overall, these results suggest that Eradicat® would be an unsuitable choice of bait for broadscale feral cat control on Kangaroo Island. Two other feral cat baits that are currently in development, Curiosity® and Hisstory®, may have lower impacts on native wildlife. This is because the poison is contained in a hard capsule in the middle of the sausage bait. While cats are expected to eat the entire bait, smaller native wildlife are expected to chew around and then discard the encapsulated poison pellet.

However, as we saw only low uptake of baits by feral cats, potentially the baits need to be deployed at a time of year when cats are hungrier, and/or at a higher density than was used in this study (60 baits per km^2) to increase the likelihood of cats encountering and consuming them.

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Hugh McGregor

Comprehending cats

Feral cats are one of the greatest threats to Australian wildlife – and one of the most enigmatic of creatures. They therefore offer an incredible subject for a research career.

My journey with cats began when I volunteered at the Arid Recovery feral-proof fenced reserve in South Australia many years ago. The thriving populations of so many threatened mammals within the fence contrasted so sharply with how few mammals there were outside, where the cats were. Like many ecologists before me, I was greeted with the confronting sight of radio-collared animals like threatened bilbies that had been killed by a cat the night before.

I was offered a great opportunity to do a PhD on feral cats in the Kimberley, Western Australia, under the supervision of Sarah Legge (then with Australian Wildlife Conservancy), and Menna Jones and Chris Johnson (both of the University of Tasmania). The focus of the project was on measuring how cats interact with fire and grazing regimes to better understand how these factors interact to drive declines in native mammal species in northern Australia.

I moved to the beautiful Kimberley. Doing my PhD embedded within an organisation (AWC) gave me a wonderful chance to understand other important parts of the conservation industry by getting involved with everything from philanthropy to fire-fighting. It gave me greater insight into cats and my research, too. We spent a week in the October of my first year fighting a wildfire, and were then amazed to map the movement points from my study of cats that showed them leaving their usual territories to go hunting in that fire scar. The evidence and insights about what drives cat hunting success continued to amass as I worked with staff, other students, neighbouring pastoralists, dog handlers and volunteers to piece the puzzle together.

I really wanted to get even further into the mind of a cat, so I started to develop video collars. It was hard going, and I had to fund and build the things myself. There was much heartache and not huge amounts of footage considering the amount of effort I put in – but it did pay off. I was able to see up close (really, really close!) the immense damage that cats do to native animals – killing native mice, frogs and lizards. Yet I also saw many beautiful moments, like cats playing with their kittens.

The Threatened Species Recovery Hub has given me another opportunity to get right in and understand cats in a new ecosystem. It also got me back to Arid Recovery, where it all began for me, this time looking at how cats interact with rabbits. You can read more about this research in the article on page 20.

My career in cat research has taken me to some diverse places. I've now helped to collar over 100 cats across Australia, in the Kimberley, Arnhem Land, Cape York, the Diamantina and South Australia. The cats seem different everywhere, and in every location I learn new insights into just how varied and adaptable they can be. Kimberley cats seem to avoid cage traps; Arid Recovery cats have no qualms about them. Cats in some places love fire scars and in other places avoid them. Whenever I feel I am starting to understand some patterns of cat behaviour, I get a new surprise. They seem to be constantly watching and learning from the landscape, ready to take advantage of any disturbance that tilts the ecology in their favour. They might be a tough animal to study, but they are certainly never boring.

IMAGE: NICOLAS RAKOTOPARE

Hugh McGregor with the tools of his cat tracking trade at Arid Recovery in South Australia.

Like others who study feral animals, I've developed a deep respect and regard for cats, which I balance with knowledge of the need to control them and manage their impacts. I don't see any point in hating cats themselves, only the damage that they cause our country and wildlife. They are incredible animals, and it is endlessly fascinating and rewarding coming to understand them and trying to develop tools to effectively limit their impacts.

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COVER IMAGE: FERAL CAT WITH A GPS TRACKING COLLAR.
(SEE PAGE 20 FOR THE FULL STORY.) IMAGE: HUGH MCGREGOR, ARID RECOVERY

Threatened Species Recovery Hub

National Environmental Science Programme