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Perspective

Searching for meaning in the interface between research and management

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Abstract. A key goal in conservation science is to generate information that helps to improve the effectiveness of management, and thus benefit threatened and declining species. I have worked on this issue at the interface of science and management, in both the non-profit and academic sectors. I present examples of some of this research, focussing on research into the causes of, and remedial management for, northern faunal declines. In particular, I present the values of research at large, realistic scales, of considering interactions between threats, and of pairing large-scale work with focal studies on the responses of individual animals to threats and their management. I reflect on the common gap between conservation science and management, and provide thoughts about how this might be bridged. Throughout the article, I try to infuse some of the personal and human elements that are the backstory to any conservation work.

Additional keywords: feral cat, fire management, threatened species

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Preamble – life before conservation science

I soodled into conservation science. Nothing in my family background pointed to conservation, except that as a child, my granny and I loved watching 'The World About Us' documentaries on BBC2, whilst eating chocolate digestive biscuits that were the shape of animals. And yet, I was nursing stray cats and crushing butterflies and flowers before I was 10 (slightly displaced activities for a future conservationist). In my teens, I went on solo walking and cycling tours through the Scottish Highlands, looking for pine martens and snow buntings, when other teens were going to dances. I don't speak Gaelic, but in hindsight, my motivation then, as it still is now, was 'cianalas'. There's no English equivalent for this beautiful word – a profound attachment to the 'place' where you belong, where you make sense. Wild places are *my* place.

At school, my evident interest in animals had my elders pushing towards a veterinary degree. I hope careers advice has improved since then. A couple of weeks in the Singapore SPCA, helping the vets spay endless stray cats, with nauseating medical interventions for maltreated 'pets' as sporadic diversions to that monotony, was helpful in revealing what I did not want to do. So, at Edinburgh University I glisked into English literature and history of art. There is no observable truth in the arts, I found the freeform challenging, and exhilarating. But I kept a toe in the science stream. In the late 1980s, Edinburgh was at the forefront of the new discipline of behavioural and evolutionary ecology; these courses propelled me out of a salty harr. I found my language – a way of framing my cianalas. I volunteered avidly for field research projects, including one on 'Scottish Tigers' (wildcats, *Felis silvestris*) on the elemental west coast of Scotland, that gave me a lifelong respect for the wiliness of cats, and also fed my addiction for the calming connectedness that comes from immersing oneself into a landscape and its creatures.

I left Auld Reekie at 22 without a return ticket, in search of The Wild. As people in their deliciously oblivious early 20s do, three friends and I mounted a zoology expedition to the Siberian taiga, surveying mammals and fish, meeting bears and bear hunters, helping Russian scientists on their research. We had so many adventures, including spending a few days walking to, and up, the biggest mountain in the area, to look out euphorically over endless chains of mountains stretching south to Mongolia. A few weeks into our expedition, we began eating our fish specimens to stay alive as supplies became ever more scarce leading up to 1991 August Putsch. Following the coup, the Communist hardliner radio broadcasts, as translated by our Russian friends, were dystopian: I recall a declaration to close schools and send the children to take in the harvest, and thus fix the food shortages. Great Plan. At the end of the summer, we used our specimen-pickling alcohol (money was worthless) to hitch a ride in an army truck out of the mountains, north to the trans-Siberian railway. It was indescribably humbling to spend time with our Russian hosts: self-sufficient, supremely generous, they turn suffering into an endurance sport and spit out great art in the process.

I headed next to East Africa, spending four years as a research assistant on the Serengeti Lion Project, run then (as now) by Craig Packer. It was a formative experience in self-reliance.

Craig was in the US, and communication was by hand-written snail mail at half speed; there were no emails, no phones. We used one of the early 'field-portable' GPS devices – a heavy box and aerial that you hoisted onto the car roof. It took 20 min to fix and was accurate to 200 m. I spent a lot of time alone, figuring out how to get out of fixes, ranging from extracting myself from all manner of bog-holes, 'repairing' bent tie rods, shattered U-bolts, and so on (usually with only rope, a spanner and a hammer for tools), crossing dodgy border areas without getting killed, and walking into lions without getting eaten. Incidentally, everyone should experience being prey: it is strangely unterrifying, with an amazingly heightened sense of awareness and being, and probably safer than taking drugs. I was fortunate to help with some first-rate and fascinating science. At that time, Craig's work focussed on the evolution of life histories, mating systems, and behaviour; the soap opera of the lions' lives was gripping. My first-ever paper was a commentary about game theory in cooperating lions (Legge 1996). In my last year there, we started noticing lions with strange neurological symptoms, and well-loved individuals were suddenly disappearing. For many long and distressing weeks, I tracked and tranquilised lions from dawn to dusk, helping the park vet (Melody Roelke) carry out spinal taps in the field to get samples of spinal fluid. Melody, with colleagues, confirmed that the Serengeti lions were experiencing an epidemic of canine distemper. It took out more than a third of the adults in just a few months.

When I left Tanzania for Australia, I had learned the value of studying a system from many angles (which was a feature of the broader research program in the Serengeti), and my fascination for evolutionary ecology was engrained. In Australia, I worked again on life histories, social and mating systems, but now with various birds, including the laughing kookaburra (for my Ph.D.), rainforest parrots in Cape York, and intratropical migrants in far north Queensland and New Guinea (postdoctoral research, much of it with Rob Heinsohn). I had lots of great colleagues, and my supervisor and mentor, Andrew Cockburn, pulled my critical thinking up by its socks. The fieldwork was challenging and fantastic, and it was an academically productive time. But I needed a new direction, I wanted to do something with more immediate impact.

I made a shift from evolutionary ecology to applied conservation research. In the shift, I took my previous field's proclivity for experimental approaches to answering questions, and for considering mechanistic as well as phenomenological responses, for example by looking at individual as well as population-level responses to threats and management interventions. I worked in the non-profit sector for many years, based in the Kimberley, north-west Australia, leading a science program that was balanced on the interface between land management and science. Three years ago I nudged back towards academia: as part of the leadership team of the National Environmental Science Program's Threatened Species Recovery Hub (NESP TSR Hub), I oversee the research theme that focusses on ways to improve the practical application of threat management, especially for threatened species recovery.

In the rest of this article, I will describe some of the research I have been involved in that has sought to provide information for conservation management, then touch on the common disconnect between conservation science and management, with thoughts about how this might be bridged.

Applied science on the ground

In northern Australia, pastoral settlement brought changes to fire regimes and an assortment of introduced species, precipitating reverberating effects through the savannas (Woinarski *et al.* 2007). Initial species losses were confined mainly to mammals at the southern and drier edges (Dahl 1926; Kitchener 1978; McKenzie 1981; Sawle 1988) and possibly occurred earlier in the east (Ziembicki *et al.* 2015; Perry *et al.* 2015). However, recent pollen and charcoal analyses suggest substantial vegetation change over the transition from pre-European to contemporary times even in more northerly, mesic sites (Connor *et al.* 2018). By the 1990s, it was apparent that declines were ongoing, affecting grass-dwelling and grass seed-eating birds (Franklin 1999; Woinarski and Legge 2013), small mammals (Woinarski *et al.* 2011; Ziembicki *et al.* 2015), riparian specialists (Skroblin and Legge 2010), and fire-sensitive plants and communities (Bowman and Panton 1993; Russell-Smith *et al.* 2002; Atchison 2009).

The northern fauna declines became my focus for over a decade, from 2004 on. I worked for a non-government organisation (Australian Wildlife Conservancy; AWC), based at an ex-pastoral property in the central Kimberley (Mornington) which had been bought for conservation. The central Kimberley is a sublime place; it smells of orange peel that has gone dry in the sun; its red rocks are polished by the sound of diamond doves and the feet of rock wallabies and ningbings. It is not far from the Tanami, and the winter brings that intense desert stillness that presses on your chest. In the summer, the monsoon directs a theatre of horizon-to-horizon thunderstorms, flashing floods and flowering spinifex. The area's Traditional Owners maintained physical connection to Country through the pastoral era and live in two small communities (Tirralintji and Yulmbu), coming and going from Derby, five hours drive away. I worked with an extraordinary group of people covering the full spectrum of stereotypes – right to left wing, country to city, young to old, Indigenous and not, idealists and rednecks, grizzled pastoralists and young female pastoralists, folded into a strange soufflé of tolerance that is common in remote areas. The aim was to put effective conservation management in place. In 2004, the impacts of the likely threats – fire, cattle, and cats – were understood to only varying degrees, leaving open the question of how to apply remedial conservation management. Answering this question was the central tenet of the research program. Yet, waiting for those answers was not an option – the research had to be integrated into the immediate management priorities: managing fire and stock.

Unmanaged fires in the Kimberley were immense 15 years ago – some fires exceeded a million hectares (Legge *et al.* 2011*b*). The main tool for managing fire in savannas is prescribed burning in the late wet to early dry season, when the grass is moist, temperatures and wind speeds low, and fires self-extinguish overnight. Done well, prescribed burning can be used strategically to prevent wildfires from reaching gargantuan proportions, and to protect sensitive and long-unburnt habitats. From smaller beginnings, we scaled up the ambition and

technical sophistication of our prescribed burning, and worked across boundaries in a regional fire management project (EcoFire), managed by AWC, and involving pastoralists and indigenous communities from ~12 adjacent properties covering 4 million hectares (the area has varied over the years) (Legge *et al.* 2011*b*). EcoFire won the WA State Environment Award in 2008 and helped to catalyse increased investment in fire management in other parts of the Kimberley. AWC's destocking program began soon after the property's purchase. Fencing and mustering in such rugged and remote terrain is the stuff of legends. The cattle were wild, they used their formidable horns to keep it that way. We slept in tents for a couple of years while the research centre was being built, and were tormented nightly by the screeching bellows of bulls trying to kill each other (sometimes they succeeded). Being trampled as collateral during a bullfight seemed a tangible possibility. The Traditional Owners were integral to the fencing and mustering. Younger men would do the work, supervised by elders who enjoyed reliving a golden era, when they had status as accomplished horse-riders and stockmen. A stalwart fencer-musterer and friend is Sammy Walker, the last surviving Andijn speaker, a man of calm dignity. Sammy's older brothers were young kids during first European contact in that area; their stories from the 1920s were a heart-aching privilege to hear. They have since passed away, leaving Sammy on his own, in the lingering reverie of times past.

The landscape-scale fire and stock management was the tapestry through which the research was threaded. Amongst other things, this research produced key evidence supporting the role of fire and cattle in the declines of northern ground-dwelling and riparian birds, and for the interactions between fire, cattle and cats in northern mammal declines (described further below). Features of this research that contributed to its value were carrying out natural and quasi-experiments at large, realistic scales, combining the large-scale work with focal studies on the responses of individual animals to threats and their management, and considering threat interactions.

Working at scale

One of our early research targets was the nationally Endangered Gouldian finch (*Erythrura gouldiae*). This species has shown one of the most dramatic declines of all the seed-eating birds (Woinarski 1990; Franklin 1999; Franklin *et al.* 2005). Working on rare, seminomadic birds is an acerbic experience: Steve Murphy and I spent three weeks searching daily to find the first bird. After 1.5 elated seconds the bird shot away over the horizon. Despite the inauspicious start, we got more proficient at finding different finch species and sampled thousands, including rainbows of Gouldian finches. Joanne Heathcote, who bubbles through life in a golden giggle of infectious joy, was my main partner in this work, but many other AWC staff and volunteers helped over the years. We sampled the health of populations living in large areas of the sanctuary (each almost 3000 km^2) with contrasting fire patterns. Birds exposed to larger and more frequent fires had poorer condition indices for many months each year compared with birds exposed to infrequent, small fires (Legge *et al.* 2015). Despite the species' high mobility (Bolton *et al.* 2016; Franklin *et al.* 2017), frequent, large fires reduce the spatio-temporal variability in grass seed production on which they depend when foraging (Liedloff *et al.* 2001). Over the next 3–4 years, as fire management reduced the size and frequency of fires in the 'treatment' area, condition indices of birds living there improved (Legge *et al.* 2015). The work clarified the period of the year during which Gouldian finches can face food shortages and demonstrated that restorative management was possible.

The finch research typifies the constraints of real-world conservation science: replicating fire treatments was impossible because of the scale of the birds' movements and the scale at which fire management is applied. There could be only a single control and a single treatment area. We improved confidence in our inference by simultaneously sampling two sympatric non-declining finch species. Moreover, Kim Maute, a slim American who moves like a dancing brolga, took this approach on-the-road for her Ph.D., sampling different finch species on different land tenures, with different combinations of fire and grazing impacts, across the Northern Territory and Cape York. Kim consistently found that she could identify vulnerable populations with this approach (Maute *et al.* 2013; Maute *et al.* 2015). Condition indices are a useful tool, but their interpretation depends on relative comparisons rather than absolute assessments. Another American student (this time of Russian descent, which explains her startling ability to consume gherkins), Olga Milenkaya, examined these issues in detail during a longitudinal study on a crimson finch population (Milenkaya *et al.* 2013). Other intrepid students and ecologists similarly mixed large-scale surveys with detailed studies of individuals to understand threat impacts on species like black grasswrens (*Amytornis housei*) (Clarke 2014), purple-crowned fairy-wrens (*Malurus coronatus coronatus*) (Skroblin and Legge 2012, 2013; Skroblin *et al.* 2014*a*), red-backed fairy-wrens (*Malurus melanocephalus*) (Murphy *et al.* 2010) and medium-sized mammals (Hohnen *et al.* 2015, 2016).

Interacting threats, and thinking about mechanisms

Our early work on mammals focussed at the main effects of fire and cattle, again at large scales. We showed that large, intense wildfire events caused an immediate decline in mammal numbers (Legge *et al.* 2008), and that reducing the frequency and intensity of fires was associated with increased mammal richness and abundance, as well as increased abundances of riparian birds, grass-dwelling birds, and small reptiles (Legge *et al.* 2011*b*). These studies contributed to the body of work on fire effects on northern mammals (Griffiths and Brook 2014; Ziembicki *et al.* 2015). We also found that cattle removal was followed by a rapid increase in small mammal species richness and abundance (Legge *et al.* 2011*a*). This was noteworthy as the role of cattle in northern mammal declines had been overlooked relative to the attention given to fire impacts (Kutt and Woinarski 2007). We started to think about interactions between threats, by scaling up the fauna sampling to include combinations of stocking status, fire regime and habitat over ~900 000 ha. We found that as the frequency, size and intensity of fires reduced, mammal richness and abundance increased, but only in areas where cattle had been removed (Ziembicki *et al.* 2015). In areas with stock present, the benefits of fire management were neutralised. The cipher explaining this fire–cattle interaction came in a companion piece of research – on cats.

We were part of a growing body of research, with many colleagues, zeroing-in on the role of cats in mammal declines. Experimental reintroductions of rodent species were unsuccessful unless cats were excluded from the release site (Fisher *et al.* 2014; Tuft *et al.* 2014). Comparative analyses showed that the species with greatest declines were those most likely to be hunted by cats (Fisher *et al.* 2014; Lawes *et al.* 2015). Meanwhile, Hugh McGregor had joined the team, in a willie-willie of muddled brilliance, to look at the ranging and hunting behaviours of individual cats in areas with varying cattle and fire impacts. He found that feral cats concentrated their hunting in areas affected by intense fires and grazing (McGregor *et al.* 2014, 2016) because the reduced ground cover substantially increased their hunting efficiency (McGregor *et al.* 2015). The interaction was confirmed in a focal study on two native rodent species. Lily Leahy (a slight young woman who scales buildings to unfurl advocacy banners) found that rodents survived intense fire events. However, over the next three months, their mortality risk was 21 times greater than for rodents in the unburnt control, due to predation, including by cats (Leahy *et al.* 2016).

This was revelatory stuff: intense fires and heavy grazing, by reducing ground cover, amplified cat predation – providing one mechanism to explain mammal declines with changes in land management. This possibility had been suggested in earlier work (e.g. Sutherland and Dickman 1999), but the empirical proof was sweet indeed. This detailed work on cats and rodents provided a likely explanation for the broader fire–cattle interaction we had observed. Freshly burnt ground attracts grazers (Archibald *et al.* 2005), and their nibbling attention removes all the post-fire regenerating grass, reducing cover for extended periods, amplifying predation. In destocked areas, the ground cover regenerates quickly following prescribed fire, and the cat genie stays in its bottle. The management implications are that fire and stock need to be managed in an integrated way. These findings were also consistent with the observation that potential cat prey species that have disappeared or declined from large areas, may persist where rocks or vegetation complexity provide microrefuge sites (McKenzie *et al.* 2007; Hohnen *et al.* 2016; Davies *et al.* 2017; Ibbett *et al.* 2017). Of relevance, recent work also shows that the predation rate of cats on birds and reptiles is also higher in areas with sparser vegetation (Woinarski *et al.* 2017*a*, 2018).

Research on biodiversity loss in savannas has tended to focus on threats individually (Woinarski *et al.* 2004; Andersen *et al.* 2005). This is odd, given that threats like fire and cattle are clearly related: grazers are attracted to burnt ground (Archibald *et al.* 2005) and grazing changes fire behaviour by reducing fuel loads (Liedloff *et al.* 2001; Bond and Keeley 2005; Fuhlendorf *et al.* 2009; Skroblin *et al.* 2014*b*). Our work showed that incorporating these potential interactions (and at large scales) into research design can improve interpretation, allowing management to be more effectively targeted (Didham *et al.* 2007; Brook *et al.* 2008; Doherty *et al.* 2015). For example, although there are no management options currently available for directly reducing cat density in northern Australian savannas (Doherty *et al.* 2017), managing fire (to avoid intense and large fire events) and removing introduced herbivores may be an alternative approach to reduce cat impacts, at least for some fauna, whilst other management options are developed (Ziembicki *et al.* 2015; Bowman and Legge 2016; Doherty *et al.* 2017; Kinnear 2017).

Applied science in a large research hub

The most rewarding aspects of working in the non-profit sector are working as a team, working for 'A Cause', working with a broad spectrum of people (including financial supporters, volunteers), and working hand-in-glove with managers to codesign threat management. Large research hubs have a different set of rewards. As part of the NESP TSR Hub I have had the opportunity to build on my background of site-based applied research, take a broader perspective on the links between policy, management and research, and work in much larger collaborations. For example, I have had the opportunity to lead and participate in work with publication outputs involving 30, 40 and even 70 authors from various universities and land management delivery organisations. With many colleagues, I am part of collaborative research that is improving our knowledge of the national context for cat impacts and management (Doherty *et al.* 2017; Legge *et al.* 2017; Woinarski *et al.* 2017*a*, 2017*b*, 2018), exploring ways of improving monitoring and adaptive management (Legge *et al.* 2018*a*; Scheele *et al.* 2018), improving our ability to predict and prevent extinctions, and improving conservation planning (Doherty *et al.* 2017; Geyle *et al.* 2018; Legge *et al.* 2018*b*; Ringma *et al.* 2018). I satisfy my partiality for site-focussed management conundrums by helping to supervise students and postdocs working in appealing places like Christmas and Kangaroo Islands, mostly on cat-related issues (I do have some jealousy issues to contend with, at times).

Bridging the gap between research and science

Australia produces some high-profile conservation science (Harrison 2006). Yet more broadly, much research is untied to management needs, and much research is ignored by practitioners and policy makers. This oft-heard lament contributes to conservation management that is neither evidence-based nor effective (Craigie *et al.* 2015; Legge 2015; Dasgupta 2017; Sutherland and Wordley 2017). I have straddled on-ground delivery and research sectors and felt the frustrations both ways: seeing research that purports to be helpful but, in reality, can only contribute to the paper-stack elevating my computer screen; seeing management that purports to be effective but actually exists in a fact-free fancy. There are many contributing factors to the poor coupling, and responsibility for 'fixing it' lies across researchers, managers, policy makers and funders; a key element of 'the fix' includes better mechanisms for collaboration and communication (Burbidge *et al.* 2011; Craigie *et al.* 2015; Langer *et al.* 2016; Robinson *et al.* 2018; Scheele *et al.* 2018).

Despite the general frustrations, there are some wonderful examples of applied research that have helped threatened species recovery (Garnett *et al.* 2018). There are also some promising initiatives underway that may help mediate the research–management gap over time. For example, the current Commonwealth Government's National Environmental Science Program (https://www.environment.gov.au/science/nesp) is encouraging enduring partnerships between scientists,

policy-makers, and managers (including Indigenous managers) that should pay dividends into the future. There are also exciting opportunities. The rights and expertise of Traditional Owners to care for their Country has been increasingly acknowledged over the past two decades, supported by formal mechanisms including the creation of Indigenous Protected Areas, and support for Indigenous ranger groups (Smyth and Grant 2012). Indigenous Protected Areas now number 74, covering 67 million hectares, or 45% of the National Reserve System, and 8.7% of Australia's land area (https://www.environment.gov.au/land/nrs/about-nrs/ownership). The Australian Government's Working on Country program currently supports over 100 Indigenous ranger groups, working across a range of mostly Indigenous tenures, employing almost 800 full-time ranger positions (https://www.pmc.gov.au/indigenous-affairs/environment/indigenous-rangers-working-country). Indigenous tenures cover more than half of Australia's terrestrial lands (Hill *et al.* 2013; Renwick *et al.* 2017), encompassing much of Australia's more intact landscapes and a substantial proportion of its biodiversity. The distributions of three-quarters of Australia's threatened species overlap with Indigenous tenures, with that proportion even higher for some groups like mammals (Renwick *et al.* 2017). Indigenous people have profound cultural responsibilities for looking after their country. These responsibilities are usually consistent with scientific conservation objectives, although the two knowledge systems may give different priorities to species, values and on-ground activities (Smyth and Grant 2012; Ens *et al.* 2015). If investment in Indigenous natural and cultural resource management can be grown and assured of long-term security, the opportunities for integrating conservation research and monitoring into these programs in a culturally respectful and effective way are enormous.

Footnote: Experience as a woman in science

This article would be missing a note if I failed to reflect on my experience as a woman in science. My experience is a product of my background and age (it's *almost* 50, OK?). Few girls did science at my school, few girls went on to have careers. After having my daughter, I found juggling motherhood with expectations at work insolvable; long hours and no weekends had been routine, but were no longer possible, despite my work commitments being as heavy as ever. The guilt over that bind is still curiously female, and to keep women in senior positions we need creative ways of loosening that bind. I have worked across a range of sectors (some very male-dominated, like fire management) and in many settings and countries, so perhaps it is not a surprise that I have witnessed and/or personally experienced much of the harassment and discrimination that can affect women, in the workplace and outside of it – physical intimidation, sexual intimidation, bullying of various shades, being overlooked, not being taken seriously. It does not happen all the time, but it happens, and usually goes unremarked, partly because it is normalised, and partly because drawing attention to the issue can make matters worse.

My older science role models overwhelmingly have been men; excellent men at that (thanks fellas). I have many excellent women colleagues of my age and younger, and of the students and postdocs I have supervised, 75% have been women. This skew, that sees women drop out over time, has been remarked on by many. For me – older women role models in science have been hens' teeth and I am in awe of them: Helene Marsh, who expertly chairs the Threatened Species Scientific Committee on which I also sit. Wendy Cooper, botanist, who fanned my secret childhood fantasy of being a plant-collector for Kew (except I was in Cape York, sending plants to her and Bill in Topaz). Penny Olsen, raptor expert, mega-author, role model for many young scientists. To compensate for the rarity of older women within, I sought (only just older) female role models outside of science; role models in life. Cait McAllary, who went to the Kimberley 35 years ago to become a good horsewoman and then stayed to manage a cattle station. Lea Ferris, sculptor and life guru. Trish Blann, calm and true. Tess Brickhill, my dear kingfisher buddy. And my late and sorely-missed friend, Wanee Betty Walker, a Ngarinyin woman of Balbaa country, who helped me understand cianalas.

Being female never held me back from doing what I wanted to do, but then again I cannot visualise the opportunities or choices that a male in my place would have faced. Maybe I missed out on things, or maybe I was made more considered, and more considerate. I think it turned out OK.

Conflict of Interest

I declare no conflicts of interest.

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