Biocultural assessment of critical weight range mammals in north-east Arnhem Land, Australia.

By

Bridget Campbell

A thesis submitted to Macquarie University

for the degree of Master of Research

Department of Earth and Environmental Sciences

June 2020

Contents

Abstract

Rapid declines in biological and cultural diversity are occurring across the globe, highlighting the opportunity and need to conserve connected 'biocultural' diversity. Following European colonization in 1788, Australia has had one of the world's worst records in biocultural diversity decline. Today, only 13 from 250 Indigenous languages are considered strong; and 100 endemic species have gone extinct, with over a thousand species listed as threatened. Across Australia, land is increasingly being handed back to Indigenous Traditional Owners, and Indigenous Protected Areas comprise 44% of Australia's National Reserve System. Despite significant investments in Indigenous land management, there is a paucity of research that respectfully combines Indigenous knowledge and Western science to address Australia's biocultural decline. This thesis aims to address this gap through a collaboration between the author and the Yirralka Rangers from the Laynhapuy Indigenous Protected Area, north-east Arnhem Land. We documented and mapped Indigenous knowledge of six mammal species in the critical weight range: *Isoodon macrourus*, *Trichosurus vulpecula, Dasyurus hallucatus, Sminthopsis virginae, Mesmbriomys gouldii,* and *Melomys burtoni*. Combining Indigenous knowledge and Western science, species distribution models for two well-known and culturally significant species (*wan'kurra* (*I. macourus*) and *marrŋu* (*T. v. arnhemensis*)) were produced. Our cross-cultural assessment of critical weight range mammals showed that despite some species being considered of least concern from a Western conservation perspective, Indigenous knowledge holders had not seen them in recent times, suggesting the need for a more inclusive and holistic approach to assessment of species conservation status, especially on Indigenous owned and managed lands. Indigenous knowledge holders maintained stronger knowledge of species with cultural significance demonstrating links between biological and cultural knowledge and conservation. This project showed that efforts to understand and address biocultural diversity, in partnership with Indigenous knowledge holders, offers a new transformative approach to biocultural conservation in Australia.

Declaration of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

(Signed)__[redacted]_____ Date: _____4/8/2020_____

Bridget Campbell

This project was approved by the Macquarie University Human Ethics Committee (Reference number 5201800178, Appendix 6).

Acknowledgements

This project was nothing if not a collaboration, and the hard work and support of many people made it possible. Firstly, I would like to express my thanks to my supervisor Emilie Ens, who first opened my eyes and gave me the oppurtunity to work in this space. Em, your passion and drive to see real world change has always inspired me, and your direction, expertise and support have been invaluable on this MRes journey.

A big thanks to the Yirralka Rangers, and *Yolŋu wäŋa wataŋu* from the Laynhapuy IPA, without whom this project would not have been possible. Thank you for your immense contribution to this collaboration, and for investing your time, resources and support. Thank you for the insight, and passion for looking after Country you brought to this project, and for welcoming me onto your Homelands. A special thanks to all of those who took the time to help me understand *Yolŋu* culture and patiently helped me learn some *Yolŋu-matha* (language). A further thanks to Gurrundul Marika, Nyembur Munungurr, Yalipuru Gumana, Yilpirr Wanambi, and Wesley Ganambarr for their help with filming and translating interviews. *Nhäma yalala!*

Thanks to Dave Preece and Gill Towler from the Yirralka Rangers, for their guidance and support with the project; to Rachel Gallagher from Macquarie University for her modelling expertise; to Daniel Sloane for his help in the field, Bud Lambeth for database searches; and finally to my family and friends who supported me through this process. Specifically to Tristan Guillemin for putting up with long absences in the field, and Sophie Carse for helping with edits.

I would also like to acknowledge the members of the Wattamattagal clan of the Darug nation, the traditional custodians of Macquarie University land, and pay my respects to elders past and present.

Funding**:** This research was supported by the Macquarie University Domestic Research Training Pathway Scholarship. Funding was provided by Macquarie University Higher Degree Research fund and an Australian Government Department of Industry, Innovation and

Science, Citizen Science Grant. The Yirralka Rangers generously shared their expertise, equipment, and accommodation.

1. Introduction

1.1 Global biocultural conservation

Many international and national policies established to conserve biodiversity also mandate for the conservation and engagement of Indigenous knowledge systems and peoples. These include the United Nations Convention on Biological Diversity (1992), the Intergovernmental Platform for Biodiversity and Ecosystem Services (2019) and Australian *Environmental Protection and Biodiversity Conservation Act 1999*. This reflects that globally, Indigenous people manage and/or hold tenure over around 25% of the earth's total land area, encompassing 80% of its biodiversity (Garnett et al. 2018). Increasingly, research is demonstrating the interdependence of biological, and cultural and lingual diversity, evidenced in part by their concurrent declines (Maffi 2001, 2007, Hill et al. 2011, Gorenflo et al. 2012, Maffi and Woodley 2012). Out of this research, the term 'biocultural diversity' has emerged to not only emphasize this interdependence, but incite more appropriate forms of holistic thinking that is needed to facilitate inclusive action for a sustainable future (Maffi 2001).

Global declines in biological and cultural diversity have been well documented. In 2019, the IPBES concluded that one million species are currently threatened with extinction, a number previously unseen in human history (IPBES 2019). This followed recent calculations suggesting that declines in earth's biodiversity had reached rates equivalent to previous mass extinction events (1000 times the background rate of extinction) (Pimm et al. 2014, Ceballos et al. 2017). Similarly, global assessments on the viability of languages has attributed significant decline the world's 7000 languages to colonization, globalisation and urbanisation (Maffi 2001, Simons 2019). Simons (2019) recently revised global language loss figures and suggested that 9 languages are lost per year and that 61% of languages from the Americas and Australia are 'dead or doomed.' Some have even suggested that Australian languages will cease to be spoken by the end of the century without effort to safeguard them (McConvell and Thieberger 2006). Further the disruption of Indigenous land custodianship has led to declines in cultural diversity and loss of biocultural knowledge (Sutherland 2003).

Although these biological and cultural declines have historically been explored separately by academia and governments, there is increasing top down (from international levels) and bottom up (from communities) pressure to investigate and address biocultural diversity decline. Whilst

collaborative biocultural conservation is gaining traction in many countries around the world, there has only been limited recognition of this opportunity in Australia (Ens et al. 2015). For example, in the wet tropics of northern Queensland, Hill et al. (2011) showed that through parallel processes of the recognition of rights, cultural values and roles in environment management, Indigenous communities can be empowered to reverse losses of biocultural diversity (Hill et al. 2011). This work highlights the value of revitalising biocultural knowledge and practices that have been used for millennia to maintan local biocultural diversity (Hill et al. 2011). Other emergent projects show Indigenous management of ecological systems can empower Indigenous communities through cultural revitalisation and affirmation (Rose et al. 2016).

1.2 Indigenous biocultural knowledge (IBK)

To combat the global decline in biocultural diversity, policy at international and national levels has called for the engagement of Indigenous peoples, and application of Indigenous biocultural knowledge (IBK) in biodiveristy conservation (EPBC Act 1999, IPBES 2019). IBK has been defined as: the cumulative sum of knowledge (data and ideas), practices and beliefs about the environment and connections to living beings that is passed down over consecutive generations via cultural transmission in Indigenous societies (Mailhot 1994, Berkes et al. 2000, Ens et al. 2015). Also known as 'Indigenous ecological knowledge' and 'traditional ecological knowledge' amongst other debated terms (Pierrotti 2011), the term IBK is being increasingly adopted as it acknowledges the continuity between culture and the biophysical world in Indigenous knowledge systems, that is largely absent in Western philosophy (Ens et al. 2015). Further, it also emphasizes that IBK should be understood as more than distillable knowledge, but rather as, "…a *cultural complex that encompasses language, naming and classification systems, resource use practices, ritual, and spirituality"* (ICSU 2002), that is embedded in a way of life (Nadasdy 1999). IBK has been described as locally specific, empirical and cumulative knowledge that has the potential to more accurately predict local scale environmental phenomena than generalized Western scientific models (Pierrotti 2011).

The integration of IBK with Western science in biodiversity conservation and natural resource management (NRM) is not new (Huntington 2000, Brook and McLachlan 2008). Rather, the integration of IBK and Western science has increased over time, alongside the growing number of international and national policies mandating implementation (Jentoft et al. 2003, Ens 2012, Ens et al. 2015). Many studies have indicated that IBK enhances biodiversity research and management

outcomes whilst also delivering socio-cultural benefits. These benefits include: improving local consensus about biodiversity conservation, enhancing the resilience of Indigenous languages and cultures (through transmission, translation, and recording), and encouraging sustainable development (ICSU 2002, Dolrenry et al. 2016, Ens et al. 2016, Wilder et al. 2016). Biocultural conservation projects that include Indigenous people and knowledge can produce more sustainable NRM solutions, especially on Indigenous lands where Indigenous people are the primary decision-makers (Ens et al. 2015). Yet, despite the acknowledged value and applicability of IBK and Indigenous engagement in conservation and NRM, the global consensus is that there remains a lot more to be done (IPBES 2019).

1.3 The decline of native mammals in Australia

Since European colonization, Australia has undergone a dramatic loss in biodiversity. Since 1788, 100 endemic species have gone extinct (Woinarski et al. 2019), and over a thousand species are considered threatened (Commonwealth of Australia 2020). Australia also accounts for 30% of global mammal extinctions recorded since the 1500s, and the extent of mammal decline and extinction in Australia is greater than that of any other taxonomic group (Woinarski et al. 2019). In total 11% (28 species), of Australian endemic terrestrial mammals are considered extinct and many more have experienced declines in abundance, and severe range restrictions (up to 90-95%) (Lomolino and Channell 1995, Woinarski et al. 2015). These declines occured predominantly from 1890-1950 across southern and arid or semi-arid regions of the continent, including large scale protected areas (Woinarski et al. 2011, Wayne et al. 2017). During this period small-medium sized terrestrial taxa within the 'critical weight range' (CWR: 35-5500g) were the most affected, primarily due to their vulnerability to introduced predators (Burbidge and McKenzie 1989). Whilst management strategies are still being developed and revised for these regions, recent studies suggest we must look to northern Australia, if we are to prevent a new wave of mammalian extinctions (Woinarski et al. 2001, Woinarski et al. 2015).

Since the 1960s, marked declines in native mammals have been reported across monsoonal northern Australia, despite previous consideration as a safe haven for mammalian taxa disappearing elsewhere (McKenzie et al. 2007, Woinarski et al. 2011). Here, similar to arid and temperate Australia, taxa within the CWR have and are continuing to undergo declines (Woinarski 2015). However, due to the paucity of historical records in this remote region, population trends have been difficult to define. Currently, there are two main explanations for observed declines: (1)

Habitat simplification caused by altered fire regimes, weeds, and over-grazing by herbivores (Pardon et al. 2003, Russell-Smith et al. 2003, Setterfield et al. 2010, Legge et al. 2011); and (2) Increased predation pressure from introduced feral cats (*Felis catus,* Linnaeus 1758) (Davies et al. 2017). Predation pressure has also been noted to increase in simplified habitats, suggesting these factors are working in concert (Lawes et al. 2015, McGregor et al. 2015, Leahy et al. 2016). In addition, cane toads (*Rhinella marina,* Linnaeus 1785) continue to drive declines in specific CWR species that are not resistant to its toxin (Burnett 1997, Watson and Woinarski 2003), although declines in these species may have begun prior to toad invasion (Hill and Ward 2010). Without rapid and effective cross-tenure management, many species could face imminent extinction, as documented for southern/arid species (Woinarski et al. 2001). Furthermore, little research on CWR species and drivers of decline has occurred across Indigenous owned areas of northern Australia, such as Arnhem Land. It is estimated that 45% of the Australian monsoonal tropics are under Aboriginal or joint management (Moritz et al. 2013), including 49% of the land area and 85% of the coastline of the Northern Territory (NT) (Altman and Whitehead 2003). To inform strategic decisions that are necessary to enact rapid management of CWR species across northern Australia, a more comprehensive understanding of their abundance and distribution across the full expanse of this region, including Indigenous owned lands and Indigenous Protected Areas, is essential.

1.4 Species distribution modelling (SDM)

Species distribution models (SDMs), have become a popular method in ecology for estimating species' distributions. Also known as 'ecological niche models' and 'habitat suitability models,' SDMs use environmental and species' occurrence data to model potentially suitable habitat (Elith and Leathwick 2009). An important ecological tool, SDMs are utilised for a range of applications, including: identifying conservation areas (e.g. Kebede et al. 2012, Kaky and Gilbert 2016, Bosso et al. 2018), predicting impacts of climate change (e.g. Fois et al. 2016, Vessella et al. 2017), identifying sites for conservation translocations (e.g. Draper et al. 2019, Miranda et al. 2019), assisting the recovery of threatened species (e.g. Skroblin et al. 2019), and guiding the location of new or remnant populations of conservation significance (e.g. Evangelista et al. 2008, Le Lay et al. 2010). SDMs provide a cost and time effective method of estimating a species distribution in comparison to traditional field survey methods; however, they require previously collected species occurence data to function (Le Lay et al. 2010, Evangelista et al. 2018).

Whilst SDMs can be used as a cost and time effective way to better understand species distributions and model their niche, it is important to keep in mind that SDMs only represent the potential distribution of a species, and steps to produce a realized distribution from a approximated potential distribution might be necessary (Calixto-Pérez et al. 2018). Numerous methods have been trialed in attempt to address these limitations and produce more accurate models. Such methods include: ground truthing the models using surveys; and using scientific or Indigenous expert knowledge holders to provide insight into, and/or guide the process (e.g. Calixto-Pérez et al. 2018, Skroblin et al. 2019).

1.5 Integration of IBK in SDMs

The inclusion of IBK has the potential to enhance the output of SDMs in a number of ways. Specifically, IBK can provide: observations that pre-date scientific data (Burbidge et al. 1988); more detailed or localised knowledge about habitat associations (Polfus et al. 2014); and local scale insight into species ecology and presence (Skroblin et al. 2019). Various studies have integrated IBK or local knowledge with occurrence data to model threatened mammalian species' distributions (e.g. López-Arévalo et al. 2011, Evangelista et al. 2018, Filho et al. 2018, Skroblin et al. 2019). In these studies, integration of IBK benefited the generation of SDMs by overcoming challenges such as the lack of scientific data and the inaccessibility of study regions, amongst other logistical and financial challenges associated with traditional ecological surveys (Evangelista et al. 2018, Skroblin et al. 2019). Further, projects that include 'expert knowledge' at multiple stages of the modelling process can aid in approximating a species realized niche and validating the model output (Calixto-Pérez et al. 2018). Specifically, these studies used IBK to generate historical occurence data for species and provide insight into habitat preferences that led the selection of environmental variables for models (Evangelista et al. 2008, Skroblin et al. 2019).

However, to ensure projects ethically engage with Indigenous peoples, and knowledge(s), significant time and effort is needed to conceptualise and enact the decolonization of traditional Western research methods (Smith 2013, Datta 2018). This is essential to ensure Indigenous priorities, perspectives and knowledge is given equal weighting and respect (Huntington 2000, Datta 2018). Commitment to ongoing communication, relationships and action before, during and after projects is necessary to ensure the mutually beneficial sharing of co-created research. Further, scientists would benefit from embracing multi-disciplinary research and social science methodolgies (Huntington 2000). Whilst these factors are important, there are no strict guidelines

around use of multiple methods (Mackey and Claudie 2015). Further, adoption of multi-disciplinary approaches may impose certain limitations on projects, especially those that require completion within certain time frames. Whilst SDM projects are beginning to synthesize Indigenous, or 'local' knowledge into models, even fewer projects report on decolonising methods that include priorities originating outside Western paradigms of biodiversity conservation.

Skroblin et al. (2019) present one of the first examples of IBK being used in a SDM for Indigenous management purposes in Australia. Working alongside Martu Traditional Owners (TOs), Skroblin et al. (2019) synthesized scientific and expert Martu knowledge to model the distribution of a threatened culturally significant species, the *mankarr* (Greater Bilby, *Macrotis lagotis,* Reid 1837). MaxEnt was used to produce multiple models of *mankarr* relative habitat suitability to inform *mankarr* management and recovery on Martu land. The present study similarly focused on bringing together Western science and Indigenous (*Yolŋu*) knowledge to better understand the distribution and population trends of CWR mammals in the Laynhapuy Indigenous Protected Area, northern Australia.

1.6 *Yolŋu* History and Law

A guide to *Yolŋu-matha* orthography and terms featured in this thesis can be found in Appendix 1 and 2.

The *Yolŋu* worldview is complex and cannot truly be communicated through several paragraphs of a thesis. However, I have attempted below, to synthesise the understanding I have garnered from my first hand experience on *Yolŋu* Country and the published literature. *Yolŋu* is the term used by Aboriginal (Australian First Nations) people in north-east Arnhem Land, that share *yolŋu-matha* (*yolŋu* language) to define themselves. *Yolŋu-matha* is a language group with many dialects that belongs to the larger Pama-Nyuŋun language family, which, before colonization, included close to 300 languages spoken across 90% of the Australian continent (Arthur and Morphy 2019). *Yolŋu* territory spans from the Walker River in south east Arnhem Land, north to Gove Peninsula, and west to Cape Stewart in the NT (Figure 1). This region has been maintained by *Yolŋu* since 'time immemorial'.

Following colonization of Australia, the full extent of Arnhem Land (approx. 97, 000km^2) (like all other parts of Australia) was proclaimed as British crown land in 1835, under the doctrine of *Terra Nullius.* In 1935, a Methodist Overseas Mission was established and became the township of

Yirrkala. Many *Yolŋu* moved from their clan estates to reside in this more permanent settlement. Before being subsumed by the colonial frontier, Arnhem Land was declared an *Aboriginal Reserve* in 1931, and later pronounced *Aboriginal Land*, under the NT *Aboriginal Land Rights Act* (ALRA) *1976*. The passing of the ALRA followed the efforts of *Yolŋu* to have their land rights acknowledged through the ignored *bark petitions* and failed litigation in the NT Supreme Court in 1968, which marked the beginning of the *land rights* era in Australia (Williams 1986). During the 1970s many *Yolŋu* left Yirrkala to return to their traditional clan estates in what became known as the *Homelands movement (Kerins 2010)*. Nevertheless, and regardless of Australian legislation*, Yolŋu* have always maintained the "…determination to preserve and protect their land according to their own law" (Williams 1986, p.19); a resolution that continues to present day. As Morphy (2017) explained, since *Yolŋu rom* (*Yolŋu* law) is directly grounded in the ancestral past and therefore is unchangeable by means of human agency, Australian law, created through such agency, should not overrule *rom.*

According to *Yolŋu rom,* the universe is divided into two complimentary moieties: *Dhuwa* and *Yirritja*. Every *Yolŋu* belongs to either a *Dhuwa* or *Yirritja* patrilineal *bäpurru* (clan group) and has rights to ownership of, and a responsibility to protect the land associated with their clan estate*.* Generally *Yolŋu* who share this joint ownership, speak the same *matha* (dialect), which is also inherited patrilineally, and *matha* is another term for *bäpurru* (Williams 1986). In total there are 10 *Dhuwa* and 10 *Yirritja bäpurru/matha,* some of which are divided into multiple smaller localised clan groups (Williams 1986)*.* Knowledge of *bäpurru* land ownership and tenure is complex, steeped in symbolism, and grounded in myths of ancestral times when landforms, sacred sites and clan boundaries were created by *waŋarr* (ancestral spirits) (Williams 1986). This knowledge, or *rom* is embodied by, and "...*comes from the land and sea, which are imbued with ancestral forces*" (Morphy 2017, p.81). Specific places where *yolŋu waŋarr* became part of the landscape are called *djalkiri wäŋa* (foundation places), and provide *birrimbirr* (animating essence) for *Yolŋu* (Morphy 2017). Any damage to the land, especially sacred sites like *djalkiri wäŋa*, 'damages' *rom* and disrupts the foundation of *Yolŋu* ontology and identity, should be avoided at all cost (Morphy 2017, p.81) .

In *Yolŋu* ideology, everything is grounded in the ancestral past. As Morphy (1991) explained: "The ancestral past is both a metaphysical system that provides explanations for the relations in the world by creating powers, values, origins, and destinies, and an integral part of the process of social categorization..." (p.292). *Yolŋu* knowledge of the ancestral past is encoded in artworks,

manikay (songs) and *buŋgul* (dance)*,* and ceremonial life plays a key role in its transmission (Williams 1986, Morphy 1991). Traditionally, a 'separate body of ancestral knowledge' was inherited by men through ceremony, and senior male members of a clan were generally considered the greatest holders of knowledge and *rom* (Morphy 1991, p.59). This knowledge was believed, like *rom,* to be passed down unchanged since its conception in ancestral times. However, in recent times this has changed in response to "...the process of continual adjustment and transformation as a consequence of the impact of both colonialism and incorporation [of *Yolŋu*] within the Australian poltical and economic system..." (Morphy 1991, p.303-304). Through these adjustments, *Yolŋu* continue to restructure their society to incorporate non-Indigenous peoples, and allow for discourse with them (Berndt 1962, Maddock 1972, Morphy 1983). Over time, this has meant that restrictions around knowledge have loosened, increasing women's access to sacred knowledge (Morphy 1991). Today, women are proud holders of knowledge and *rom* (Burarrwanga et al. 2019).

1.7 Laynhapuy Indigenous Protected Area

In 2006, *Yolŋu wäŋa wataŋu* (country-holder, or Traditional Owner, as described in the ALRA) from 12 different Homelands declared the Laynhapuy Indigenous Protected Area (IPA) (Figure 1) by volunteering a parcel of their lands as part of the federal government's IPA program. Initiated in 1997, the IPA program was developed to provide conservation-based funds to Indigenous Australians (with rights to land) for establishment of protected areas that would be: 1) incorporated into the Australian National Reserve System (NRS); 2) managed under IUCN protected area category V or VI; and 3) managed by Indigenous rangers. It proved a popular program, with the majority of Arnhem Land now covered in IPAs including contiguous and overlapping sections of adjacent IPAs (Figure 1). After 23 years, IPAs comprise 44% of the Australian NRS (Australian Federal Government 2020). This figure continues to grow as applications for new IPAs and IPA extensions are still being submitted and processed (Australian Federal Government 2020). To supplement the IPA program and other Indigenous land management initiatives, the Australian Government also developed the Indigenous Ranger or *Working on Country* program in 2007. In 2020, over 100 separate Indigenous Ranger groups and over 800 Rangers across Australia are supported through this program (National Indigenous Australians Agency 2020).

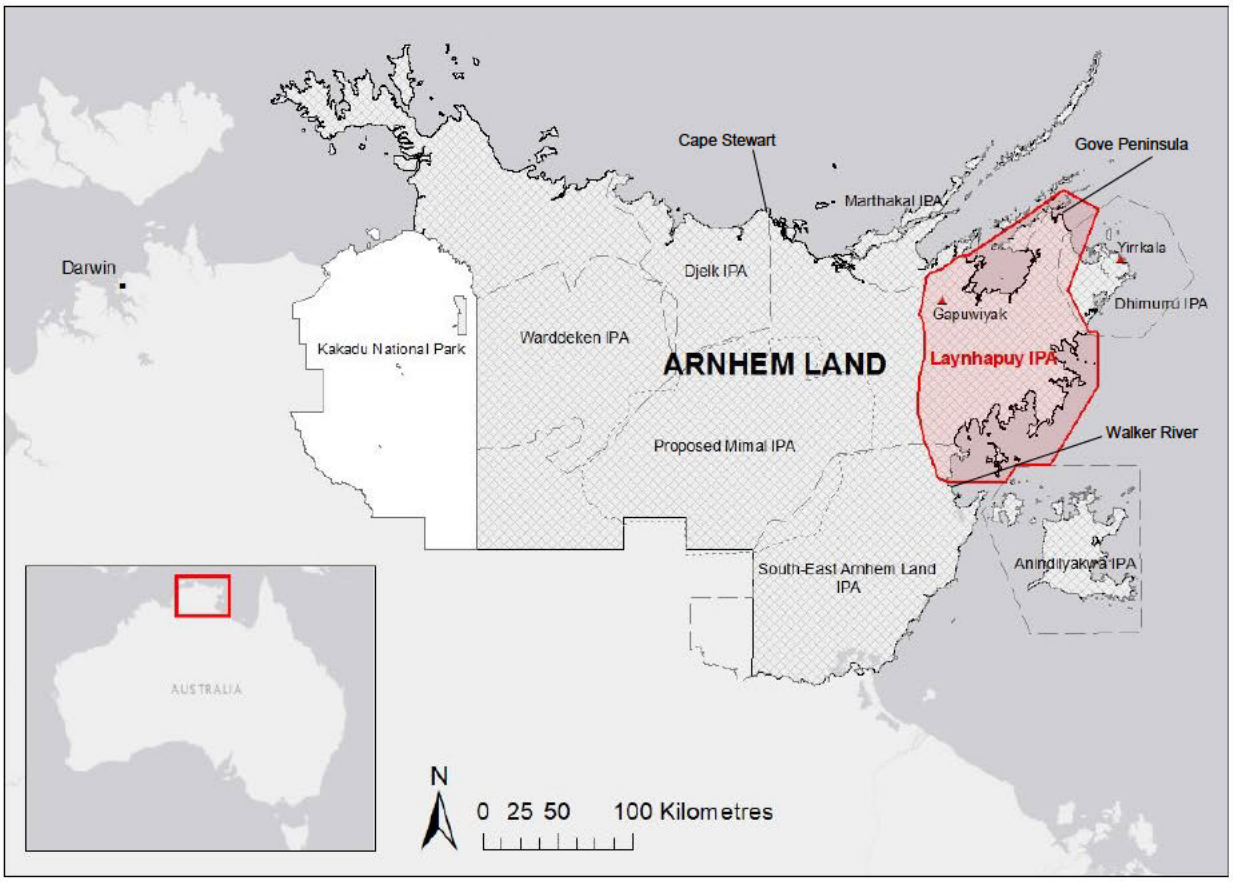

Figure 1. Map of Arnhem Land Indigenous Protected Areas, highlighting the Laynhapuy IPA, in relation to Kakadu National Park.

Today the Laynhapuy IPA (Figure 1) comprises approximately 17,000km^2 of *Yolŋu* owned land and sea Country, largely untouched by largescale Eurocentric change. Spanning both the *Central Arnhem* and *Arnhem Coast* bioregions, it also includes two regions of international conservation significance: The *Blue Mud Bay and associated coastal floodplains* and *Gove Peninsular and north-east Arnhem coast* areas (Australian Government 2019). Multiple ecosystem types can be found within the IPA borders including: savanna eucalypt woodlands, moonsoon rainforest, extensive wetlands and floodplains, heathland, mangroves and saline flats. As a result, the IPA provides habitat for numerous species, including those listed as vulnerable and endangered species (Laynhapuy IPA Management Plan 2017-2020; (Yirralka Rangers 2017)) and 17 native mammal species in the CWR.

IPA management is undertaken by the Yirralka Rangers in accordance with the *Working on Country* program. With their headquarters in Yirrkala, the 40 or so *Yolŋu* rangers operate under a decentralised model, and are spread across bases in 12 different *yirralka* (clan estates, or Homelands). Aside from federal funding, the Yirralka Rangers also recieve funding from other sources such as the *Laynhapuy Homelands Aboriginal Corporation*, the *Indigenous Land and Sea*

Corporation (ILSC) (which fund the *Miyalk* (women's) ranger program), and other fee for service work such as carbon abatement through fire management (Yirralka Rangers 2017). Managing the IPA consistent with the IUCN Category VI Protected Area Guidelines, ranger *djäma* (work) includes: weed and feral animal management, protection of sacred sites, fisheries patrols and biodiversity surveying/monitoring and much more, all whilst maintaining cultural values and facilitating intergenerational knowledge transfer (Yirralka Rangers 2017).

One of the key strategies outlined in the Yirralka Rangers Management Plan is to "Integrate our Indigenous Knowledge with scientific research to increase understanding of biodiversity values and natural systems..." (Yirralka Rangers 2017, p.17) within the IPA. To achieve this the Yirralka Rangers seek partnerships with industry and research partners, such as Macquarie University. The present project built on a 12 year partnership between the Yirralka Rangers and Macquarie University ecologist, Dr. Emilie Ens (Masters Project supervisor), and aimed to investigate the percieved 'decline in small mammal diversity and abundance' (Yirralka Rangers 2017, p.16) within the IPA, by combining both *Yolŋu* and western scientific methods.

Historically, limited systematic fauna surveys have been conducted across Arnhem Land, especially in the north east, delineated by the Laynhapuy IPA (Figure 1). The earliest "scientific" records of species from this region were made by Europeans followed the explorations of Mathew Flinders in 1803. In the 1930-40's, anthropologist Donald Thomson was sent to north east Arnhem Land to 'live amongst the *Yolŋu* people' and amassed substantial zoological and anthropological collections. His zoological collection was one of the first to include discrete spatial data that can link species decidedly to north-east Arnhem Land (although exact locations are not recorded). In total, he recorded 17 native mammal species from this region. In 1948, the 'American-Australian Scientific Expedition to Arnhem Land' lead by the Smithsonian Institute surveyed the fauna around three base camps in the Arnhem Land, including Yirrkala. Like Thomson, the researchers on this expedition were assisted by *Yolŋu* who showed them where to look for different species, acted as their guides, and willingly imparted "...some of their profound knowledge of animal life" (Specht 1964, p.ix). Since this time, scarce surveying work occurred, although has increased since the establishment of IPAs.

1.8 Study species

Six CWR species were selected for this study based on previous observations in the IPA, cultural significance and distinguishable appearance. These include the: *wan'kurra* (Northern Brown Bandicoot, *Isoodon macrourus,* Gould 1842), *marrŋu* (Northern Brushtail Possum, *Trichosurus vulpecula arnhemensis,* Collet 1897), *nyiknyik/guthin* (Red-cheeked Dunnart*, Sminthopsis virginiae,* Tarragon 1847)*, barkuma* (Northern Quoll, *Dasyurus hallucatus,* Gould 1842), *dhuliumbarr* (Black-footed Tree-rat, *Mesmbriomys gouldii,* Gray 1843)*,* and *nyiknyik* (Grassland Melomys*, Melomys burtoni,* Ramsay 1887) (Table 1, Figure 2 and 3).

The six study species are variably classed under international (IUCN), national (EPBC Act) and state (NT) threatened species lists (Table 1). The *nyiknyik*s, Grassland Melomys and Red-cheeked Dunnart, are considered of Least Concern under all lists although it is noted as Data Deficient in the NT. Interestingly, the larger of the six study species, the *wan'kurra* and *marrŋu* are considered Least Concern at the international and national levels, although Near Threatened in the NT. The *dhuliumbarr* and *barkuma* have been consistently recognised as Vulnerable and Endangered respectively, although at the national level both are listed as Endangered. All six species are considered by the IUCN to have extant populations in north east Arnhem Land, except the *barkuma* which is considered extinct in this region, despite documented earlier records (Figure 3).

Table 1. The international (IUCN), national (EPBC Act) and NT conservation status' of the study species.

Yolŋu yaku	**Common name**	**Scientific name**	**IUCN**	**EPBC**	**NT Status**
wan'kurra	Northern Brown Bandicoot	*Isoodon macrourus*	LC (S)	-	NT
marrŋu/rupu	Common (Northern) Brushtail Possum	*Trichosurus vulpecula* (*arnhemensis*)	LC (D)	-	NT
nyiknyik/guthin	Red-cheeked Dunnart	*Sminthopsis virginiae*	LC (S)	-	DD
barkuma	Northern Quoll	*Dasyurus hallucatus*	E (D)	E	CR
nyiknyik	Grassland Melomys	*Melomys burtoni*	LC (S)	-	LC
dhuliumbarr	Black-footed Tree-rat (WA/NT subspecies)	*Mesmbriomys gouldii (gouldii)*	V (D)	E	V

DD = Data Deficient, LC = Least Concern, NT = Near Threatened, V = Vulnerable, E = Endangered, CR =Critically Endangered, (S) = Stable population, (D) = Decreasing population. '-' Not Listed.

Figure 2. Study species: **a)** *wa<u>n</u>'kurra* (*I. macrourus*), **b)** *marrŋu* (*T. vulpecula*), **c)** *barkuma* (*D. hallucatus*), **d)** *nyiknyik/guthin* (*S. virginiae*) **e)** *dhuliumbarr* (*M. gouldii*), **f)** *nyiknyik* (*M. burtoni*). Photo credits: **a,c,f)** Yirralka Rangers; **b)** (Schecter 2011); **d)** (Franklin 2019); **e)** (Brennan 2012).

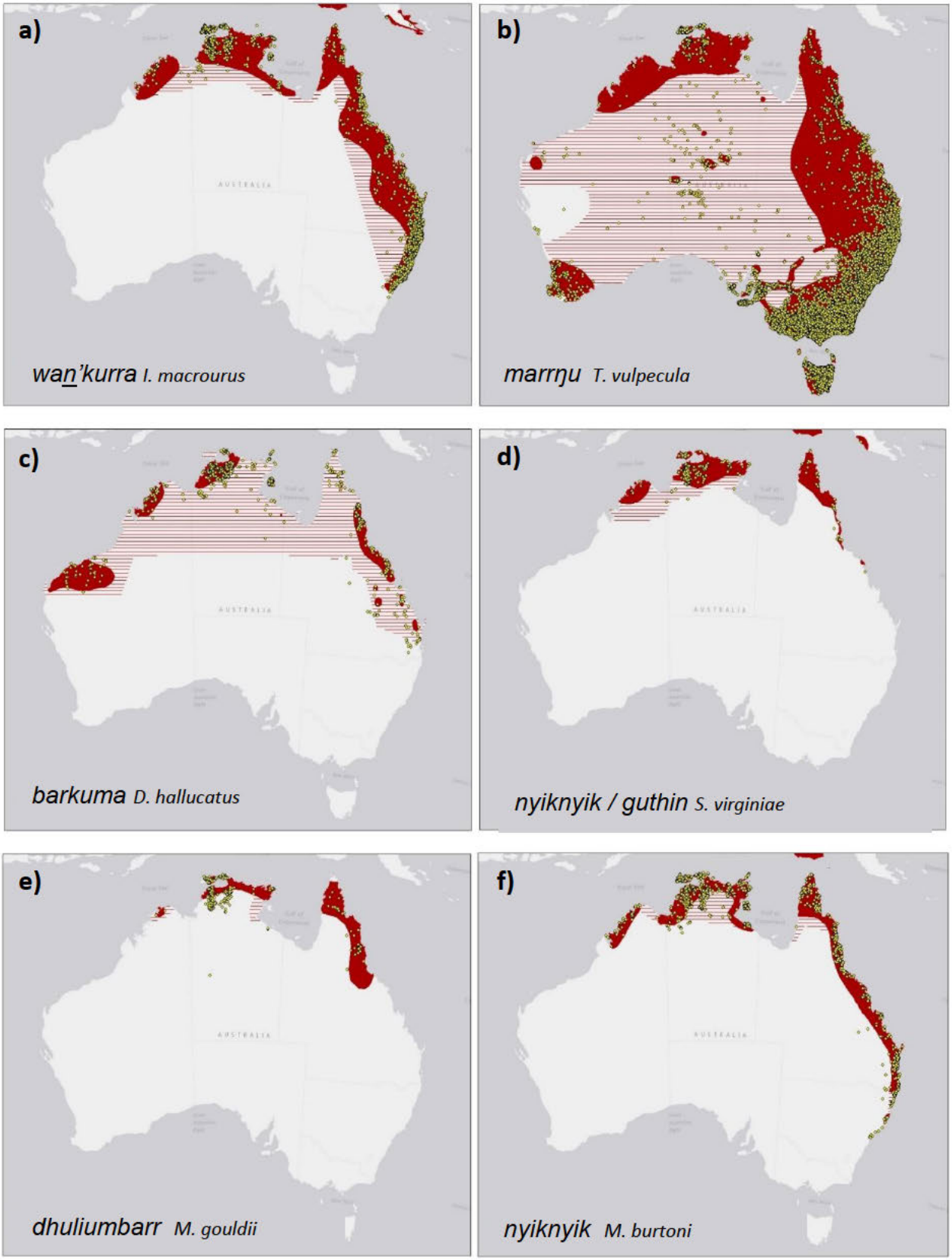

Figure 3. Australian distributions of the study species. The solid red area, and striped area represent the extant and extinct ranges, respectively, recognized by the IUCN. Yellow dots represent Atlas of Living Australia (ALA: https://www.ala.org.au/) species occurrence records Distribution data are from the IUCN (https://www.iucnredlist.org/, accessed: 19/5/2020), and *wan'kurra, nyiknyik/guthin, nyiknyik* (Mckay 2017), *marrŋu* (Bannister 2019), *dhuliumbarr* (Menkhorst and Knight 2011), *barkuma* (Kelly and Phillips 2019).

Wan̲'kurra (Northern Brown Bandicoot)

The ***wan̲'kurra*** is a small-medium sized native marsupial, which has been noted as undergoing significant declines even across protected areas and refuges of northern Australia (Pardon et al. 2003, Woinarski et al. 2010, Ziembicki et al. 2013, Davies et al. 2018). ***Wan̲'kurra*** have a large range across northern and eastern Australia (Figure 3a) and are largely limited to mesic regions (<300 km of coast), with exceptions in regions with higher or more persistent rainfall, and riverine systems (Gott 1996). *Yolŋu* knowledge of this species was previously recorded by Thomson and the Smithsonian expedition. Thomson recorded that this species was referred to as *wanggura*, but noted that *Yolŋu* recognised only one type, or species of bandicoot, but used different names for 'different' phases. '*moiny moiny'* was used for the 'small phase' that Thomson recognised as the smaller species *I. auratus* (Golden Bandicoot) which is now considered regionally extinct across the mainland (Palmer et al. 2012). However, neither Thomson, or Specht (1964) recorded the Golden Bandicoot in their collections. Like Specht (1964), Thomson recorded forested areas, as well as grassland savanna and swamp as the preferred habitat types (Dixon and Huxley 1985). He also noted that it was hunted by spearing or stomping on nests and was considered "*bunggan mainmak tjukur mirrir*" (good smell, good food) (Dixon and Huxley 1985). Specht (1964) noted them as an abundant species, recording: "*In small patches of understory that escape the fires, nests and runways of bandicoots can nearly always be found*." (Specht 1964, p.447).

Marrŋu (Common (Northern) Brushtail Possum)

The *marrŋu* is a nocturnal arboreal marsupial that was once distributed across most of the Australian continent and all climactic zones (Bannister 2019). Since colonization, the Common Brushtail Possum's georgraphic range has decreased by more than 50%, mostly across arid and semi-arid regions (Bannister 2019). However, recent research indicates the geographic range of *marrŋu* has also declined by 72% across north-western Australia since 1993 (Stobo-Wilson et al. 2019). Restricted to areas of higher rainfall, *marrŋu* abundance is positively correlated with shrub density and canopy cover (Stobo-Wilson et al. 2019).

Both Thomson and the Smithsonian Expedition recorded this species in the study area in the 1940's and 1950's. Thomson described many *Yolŋu* names for this species including: *marrngo* generally and for females; *kapardi* for males; and *ropo* as a rare collective term. *Marrŋu* were described by Thomson as relished for food and to make string (*bulnyin / burnyinI* in *Wangurr*i, and *bulka* in *Kopapoingo*) (Dixon and Huxley 1985). They were described by *Yolŋu* to be solitary;

however, during *kardai kia* (flower time) the "males and females camp together during the day" (in the same tree hollow) (Dixon and Huxley 1985, p.56). He also noted that strict taboos surrounded the eating of this animal (Dixon and Huxley 1985).

Guthin (Red-cheeked Dunnart)

The *guthin* is a smalll carnivorous marsupial native to tropical regions of Australiasia. Declines have been recently documented in the NT and northern Queensland (Woinarski et al. 2010, Perry et al. 2015), and threats include: predation from feral cats, changes in fire regimes and poisoning from cane toads (Woinarski et al. 2010). However, research has shown this species can rapidly learn and retain toad avoidance behaviour, suggesting their populations have the potential to be resilient against toad invasion and presence (Webb et al. 2011). Preferred habitats for this species include: savanna grasslands, wetland and swamp ecosystems, margins of tropical forest, and agricultural plantations (Woolley 2008). Three subspecies are recognised, *S. v. rufigenis* (New Guinea), *S. v. virginiae* (north Queensland), and *S. v. nitela* (north NT and WA). There is a paucity of research on this species, and it has been suggested that further studies are required to determine if *S. v. nitela* should be considered a separate species as it was previously (*S. nitela)* (Blacket et al. 2001).

Barkuma (Northern Quoll)

The *barkuma* is an endangered endemic species with extensively documented declines across most of its range since European colonization (Oakwood et al. 2016). The disjunct populations that remain represent 25% of its historic range, with regional extinctions reported across the NT, WA and northern Queensland (Burnett 1997, Perry et al. 2015, Oakwood et al. 2016). *Barkuma* are generalist carnivores that consume insects, reptiles, mammals and amphibians (Oakwood 1997, Oakwood et al. 2016). They occur across a wide variety of habitats including eucalyptus woodlands, monsoon rainforest and savanna woodlands, where they prefer rocky habitat and shelters in caves, crevices, tree hollows and hollow logs in higher rainfall areas. The ingestion of cane toads, is considered the most serious current threat to this species, and populations continue to collapse following toad invasion (Burnett 1997, Watson and Woinarski 2003, Woinarski et al. 2014). However, declines are also recorded in regions prior to toad invasion and in toad free regions (Hill and Ward 2010). The main drivers implicit in these declines include predation, largely from native dingoes (*Canis lupus dingo* Meyer 1793), as well as invasive feral cats, which has potentially been enabled by landscape degradation from large scale fires (Jolly et al. 2018). Other threats include: foxes (*Vulpes vulpes,* Frisch 1775), habitat fragmentation and loss, weed invasion,

mining and infrastructure development and changes to fire regimes, the majority of which are largely absent across Arnhem Land (Woinarski et al. 2014).

Whilst it is now considered largely extinct from mainland NT (where it is considered Critically Endangered), attempts to safeguard this species resulted in toad-safe 'insurance populations' being established on Astell and Pobassoo Islands in Arnhem Land in 2003 (Rankmore et al. 2008). Since then, recent studies that have managed to successfully train quolls with toad aversion behaviour, have still seen reintroductions fail due to pre-existing threats aforementioned. However, in some regions of toad infested Queensland, quolls persist, suggesting that they can do so in low, post-invasion toad densities (Woinarski et al. 2008).

Dhuliumbarr (Black-footed Tree-rat)

The *dhuliumbarr* is a large semi-arboreal, nocturnal rodent. Whilst this species is considered to have become restricted to the northern Australian coast since European colonization (Dhal 1897), more recent declines across the NT have been recorded, including regions of Arnhem Land (Woinarski et al. 2010, Ziembicki et al. 2013). *Dhuliumbarr* are generally associated with structurally diverse eucalyptus (*Eucalyptus tetrondonta* and *E. miniata*) woodlands and lowland open forests with thick understory assemblages (Friend and Taylor 1985, Friend 1987). Habitat suitability is positively associated with low intensity fire regimes and complex forest structure that includes dense understory and hollow logs (Friend 1987, Rankmore 2006). It has been known to den in tree hollows and *Pandanus* foliage and buildings, with a diet consisting of fruits, seeds (including *Pandanus spiralis* nut), and some invertebrates (Friend and Taylor 1985, Friend 1987, Rankmore 2006). Threats to its abundance and distribution include: high intensity or frequency fires that diminish the abundance of tree-hollows and complex shrubby understory; and poor wet-season rainfall, which limits food sources (Friend 1987, Price et al. 2005). Predation from feral cats is also thought to be potentially causing declines in this species, although to what extent is unknown. Subspecies include: *M. g. gouldii* (north NT, Kimberley), *M. g. melvillensis* (Melville Island), and *M. g. rattoides* (northern Queensland). The NT subspecies *M. g. gouldii* is listed by the Australian Threatened Species Recovery Hub to as one of the 20 mammal species expected to go extinct in the next 20 years (2018).

Nyiknyik (Grassland Melomys)

The *nyiknyik* is a small (30-120g) widely distributed native Australiasian rodent. Declines in *nyiknyik* populations have been observed in regions of northern Queensland (Perry et al. 2015),

but not in the NT (Woinarski et al. 2010). In Australia, this species is commonly found in the northern and eastearn coastal drainage areas, with a wide range of suitable habitat types, including: open woodlands (specifically: *Melaleuca* and *Acacia* forest/woodland with *Pandanus* understory), tall grasslands, tropical forest, swamps, mangrove and vine thickets (Begg et al. 1983, Kerle 2008, Perry et al. 2015). Grassland Melomys are also considered a pest in sugarcane fields (Kerle 2008). It constructs spherical arboreal nests out of dead foilage, including in *Pandanus* (Begg et al. 1983). And feeds on fruits, seeds, foilage, invertebrates and small amphibians (Kerle 2008, Cabrera-Guzmán et al. 2015). Threats to this species are generally not listed, and it is considered to be one of the native rodent species with stable NT populations. Unlike other CWR mammals, *nyiknyik* are not considered to be threatened by cane toads, individuals have been shown to readily fed on toads with no ill effects, and not develop toad aversion behaviour in experimental trails (Cabrera-Guzmán et al. 2015). This species has also been observed to survive well after fire by burrowing underground, and successfully finding food in post-fire environments (Liedloff et al. 2018). There are no recorded subspecies within this speces.

1.9 Research aims

This thesis details a place-based project that aspired to progress the dual global objectives of biological and cultural conservation to conserve biocultural diversity. Specifically, this thesis presents a synthesis of Western science and *Yolŋu* Indigenous knowledge to enhance the understanding and management of native mammal populations, a key taxonomic group undergoing declines in Australia. In this study, we adopted a collaborative, biocultural approach to investigate the status of CWR mammals in the Laynhapuy IPA. Our aims were:

1) Record *Yolŋu* knowledge of the abundance, distribution and population trends of six CWR mammals (Figure 2) that have previously been recorded across the Laynhapuy IPA;

2) Record *Yolŋu* knowledge of the material use and cultural significance of these CWR mammal species;

3) Intergrate *Yolŋu* knowledge with Western science to gain a better understanding of these CWR mammals within the Laynhapuy IPA; and,

4) Map the distribution of two culturally significant CWR species, the *wan'kurra* and *marrŋu* using species occurrence data and *Yolŋu* knowledge.

2. Methods

2.1 Study area

Between mid-August to late-November 2019, fieldwork was conducted with the Yirralka Rangers in the Laynhapuy IPA, north-east Arnhem Land (Figure 4). During August 2019, the author lived and worked closely with the Yirralka Rangers at their base in Yirrkala to co-design the research project. The Indigenous population of Yirrkala has been recorded to be around 809 people, and the main spoken languages are *Yolŋu matha* dialects including*: Dhuwaya, Djambarrpuyngu, Gumatj, Anindilyakwa* and *Rirratjingu* (Australian Bureau of Statistics 2016).

2.2 Interviews with Yolŋu Kowledge Holders

2.2.1 Interviewees

Across six weeks, between the 24th of September to the 15th of November, 2019, 13 interviews were conducted with 15 Yolŋu knowledge holders (YKH) (5 women, 10 men) from nine different clans (*Dätiwuy, Dhalwaŋu, Djapu, Gupapuyŋu, Madarrpa, Maŋgalili, Marrkula, Wangurri, Wanambi*) (Table 2). YKH were selected by peer selection (Huntington 2000), based on their knowledge of, and/or cultural connection to the study species. The majority of YKH were senior clan members and leaders. Six YKH were also employed (either presently, or previously) by the Yirralka Rangers.

2.2.2 Interview Structure

The purpose and use of the interview data was discussed with participants before the interviews, and written prior informed consent was sought in line with Macquarie University Human Ethics Committee approval (Reference number 5201800178). Interviews focused on the elicitation of knowledge about the six study species (Figure 2), and knowledge and connection to Country. Interviews were semi-structured, with open-ended questions (Table 3). Both English and *Yolŋu matha* were used in the interviews. Three Yirralka Rangers (Gurrundul Marika, Nyemburr Munungurr, and Wesley Ganambarr) assisted with the translation from *Yolŋu matha* to English and *vice versa,* either in real time or post interview. English was the primary language used; however, all interviews incorporated some *Yolŋu matha*. All but one participant agreed to be filmed during the interview. Responses for this participant were transcribed on paper.

Figure 4. Extent and Homelands of the Laynhapuy IPA, north-east Arnhem Land, NT.

Table 2. List of Yolŋu knowledge holders interviewed for this study, their respective clan, age range and affiliation with the Yirralka rangers and community. Two YKH did not consent to their names being used in scientific reports. They are listed below as Participant X and, Y.

Name	Homeland	Clan *	Age range	Role/s	Duration (mins)
Margaret Wanambi	Raymangirr	*Wanambi*	>80	Elder; senior knowledge holder for Raymangirr.	43
Participant Y	Djarrakpi	*Maŋgalili*	>70	Artist; elder; senior knowledge holder; leader of Maŋgalili clan, Djarrakpi.	38
Participant X	Buymarr	*Wangurri*	>70	Elder; senior knowledge holder.	38
Manman Wirrpanda	Gangan/Dhuruputjpi	*Djapu (Dhudi Djapu)*	>60	Elder; senior knowledge holder ; leader of Gangan Homeland.	45
Paul Wununŋmurra	Yalakun	*Dhalwaŋu (Y)*	>60	Senior Ranger; elder; head of Yalakun Homeland.	38
Djambawa Marawili	Yilpara/Baniyala (Blue Mud Bay)	*Madarrpa (Yithuwa) (Y)*	60-70	Artist; senior knowledge holder; ceremonial leader.	50
Naminapu Maymuru White	Djarrakpi (born) / Gurkawuy (briefly) / Yirrkala (current)	*Maŋgalili (Y)*	60-70	Senior member of *Maŋgalili* clan.	45
Jimmy Marrkula	Gapuwiyak (Bapapwuŋumi)	*Marrkula*	60-70	Elder; senior knowledge holder; leader for Gapuwiyak.	47
Banul Munyarryun	Dhalinybuy	*Wangurri (Y)*	50-60	Senior Ranger; senior knowledge holder; clan elder Dhalinbuy.	42
Buwathay (Kevin) Munyarryun	Dhalinybuy	*Wangurri (Y)*	50-60	Artist; minister; senior knowledge holder; clan elder.	29
Susan Ganambarr	Rorrowuy	*Dätiwuy (D)*	50-60	Teacher at Rorrowuy Homeland school; Community Leader.	30
Gurrundul Marika	Yilpara/Yirrkala	*Madarrpa (Y)*	40-50	Ranger Facilitator; artist; senior clan member.	31
Jason Marrkula	Gapuwiyak (Bapapwuŋumi)	*Marrkula*	40-50	Son of Jimmy Marrkula (above); will take over clan leadership from his father.	47
Yinimala Gumana	Gangan	*Dhalwaŋu (Y)*	30-40	Senior Ranger; ceremonial leader: *Dalkarra* (regional ritual specialist).	36
Thomas Marrkula	Burrum / Gapuwiyak	*Gupapuyŋu*	30-40	Ranger; future clan leader.	28

*(Y) = *Yirritja*, (D) = *Dhuwa.*

Table 3. Flow of interview questions asked of YKH.

1. **Identifier questions**			
1.1 What is your name?	**1.2** How old are you?	**1.3** Is this/where is your Country?	**1.4** What is your clan (*bäpurru*)
2. Questions about Country			
2.1 How did you learn about your Country?	**2.2** What things are important to learn about Country?	**2.3** What responsibility do you have for your Country?	**2.4** Do young people share this responsibility?
3. Questions about CWR mammal species			
3.1 Do you know this animal? / Have you seen it before?	**3.2** What is its name?	**3.3** What moiety/ *bäpurru* does it belong too?	**3.4** Where have you seen it? (Past and Present) / Do you know where it can be found (what Country)?
3.5 Have you noticed any change in numbers over time? If so, why?	**3.6** Is this animal connected to any *manikay*, stories or ceremony?	**3.7** Do you have anything you would like to say about this animal?	**3.8** Do you think knowledge about these animals is important? Why?
4. Referral questions			
4.1 Do you know anyone else that you think I should speak to about these animals?		**4.2** Do you have any further questions for me about this project, or is there anything else you would like to say?	

Spatial data was recorded on a large A1 laminated map of the Laynhapuy (Figure 5). Polygons or points where YKH had seen the study species in the past and/or recently, and culturally significant places were drawn on the map. Spatial data recorded on the maps during interviews was photographed and later digitised using ArcGIS Desktop version 10.6.1 (ESRI 2018). As skin and/or taxidermy specimens of the six study species could not be obtained for use in this study (sensu Ziembicki et al. 2013) multiple photographs of each species were printed in colour on A4 sheets of paper and shown to participants to aid identification and familiarisation (sensu Kotschwar et al. 2015, Evangelista et al. 2018). All interviews were recorded using a video camera and microphone and interviews generally lasted about 40 minutes, with some exceptions (Table 2). Participants who were not employed by the Yirralka Rangers were paid $50 for participating in interviews.

Figure 5. TO for Dhalinybuy, Buwathay (Kevin) Munyarryun, pointing out an area where he had seen the *wan'kurra* in the past when he went hunting across the floodplains north of Dhalinybuy.

2.2.3 Interview data analysis

A grounded theory approach (Glaser and Strauss 2006) was used to analyse and interpret interview data. Key themes and patterns were identified and appear in Appendix 3. Spatial data extracted post-hoc from interviews (not transcribed during the interviews on physical maps) was transcribed using ArcGIS Desktop version 10.6.1 (ESRI 2018). Prior to commencing interviews, a participant insisted we inspect the *Buku-Larrnggay Mulka* Art Centre (based at Yirrkala) and its archives so the researcher would have some background of the existing, documented cultural information and symbology of the species and their connection to *Yolŋu* prior to conducting interviews. Artworks, artefacts and transcriptions from the Art Centre that included images or symbology of the study species were analysed with permission from the Art Centre, according to Morphy (1991), to compliment interview findings.

2.3 Species distribution models

2.3.1 Study species

The *wan'kurra* and *marrŋu* were chosen for species distribution modelling (SDM) as they were well known, culturally significant species (Morphy 1991). Due to the taxonomic uncertainty surrounding the Australian subspecies of *I. macrourus* (Figure 6a) (Freedman and Rightmire 1971, Close et al. 1990, Pope et al. 2001), both subspecies were included in the analysis. The status of the Common (Northern Brushtail Possum) as a subspecies of *T. vulpecula* is more certain (Kerle et al. 1991) (Figure 6b), and only data for this subspecies was included in the analysis.

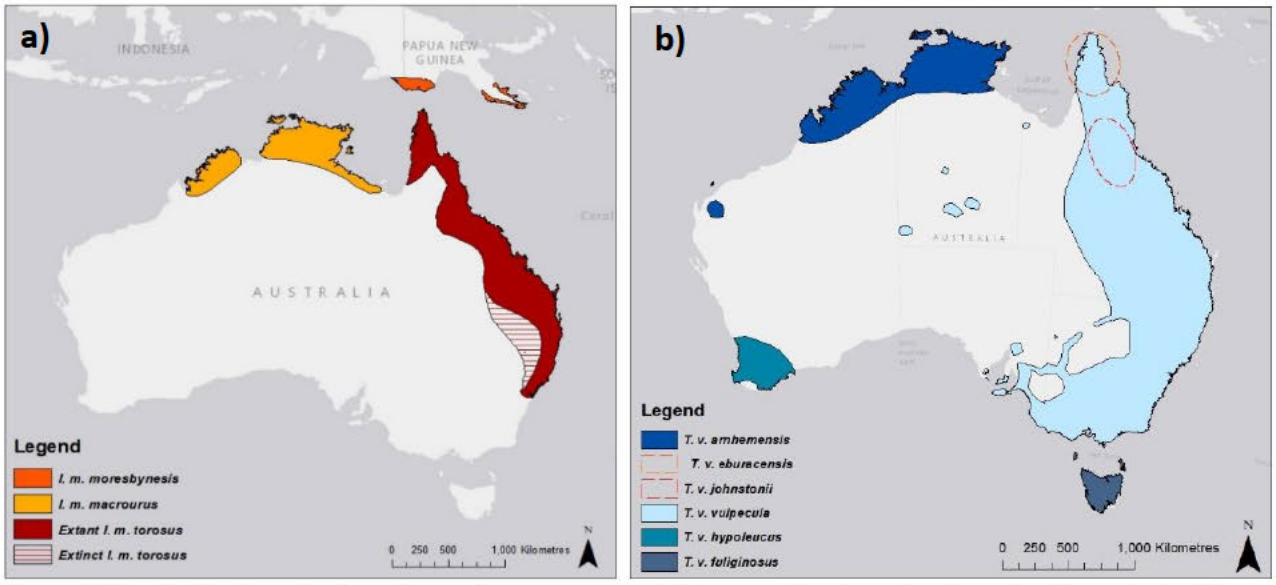

Figure 6. The distribution of, **a)** *wan'kurra, I. macrourus.* and **b)** *marrŋu, T. vulpecula* subspecies. The extent of *T.v. eburacensis* and *T. v. johnstonii* have not been extensively delineated, and so their potential distribution is represented by dashed outlines. Distribution data are from the IUCN website (https://www.iucnredlist.org/, accessed: 10/4/2020) for the *wan'kurra* as well as Kerle and How (2008) for the *marrŋu.*

2.3.2 Occurrence data

Occurrence data was downloaded from the Atlas of Living Australia (Figure 6; ALA; www.ala.org.au; accessed: 3/2/2020). All occurrence records listed for *I. macrourus* on the Australian continent were downloaded for the *wan'kurra* model, and all occurrence records for *T. v. arnhemensis* on the Australian continent were downloaded for the *marrŋu* model. The occurrence data was then cleaned prior to analysis using the following criteria to exclude ambiguous data points/observations: records >50 years old, records without dates, duplicate data, geographical outliers or incorrect records. A total of 4422 occurence records were used for the *wan'kurra.* Due to the overlapping of *marrŋu* occurence points, which lead to model overfitting, a 5km grid was used to filter points. The centre of a 5km grid cell that contained *marrŋu* occurrence records was used as a surrogate for presence data to reduce clumping of points. This reduced the number of *marrŋu* occurence points from 994 to 257 points.

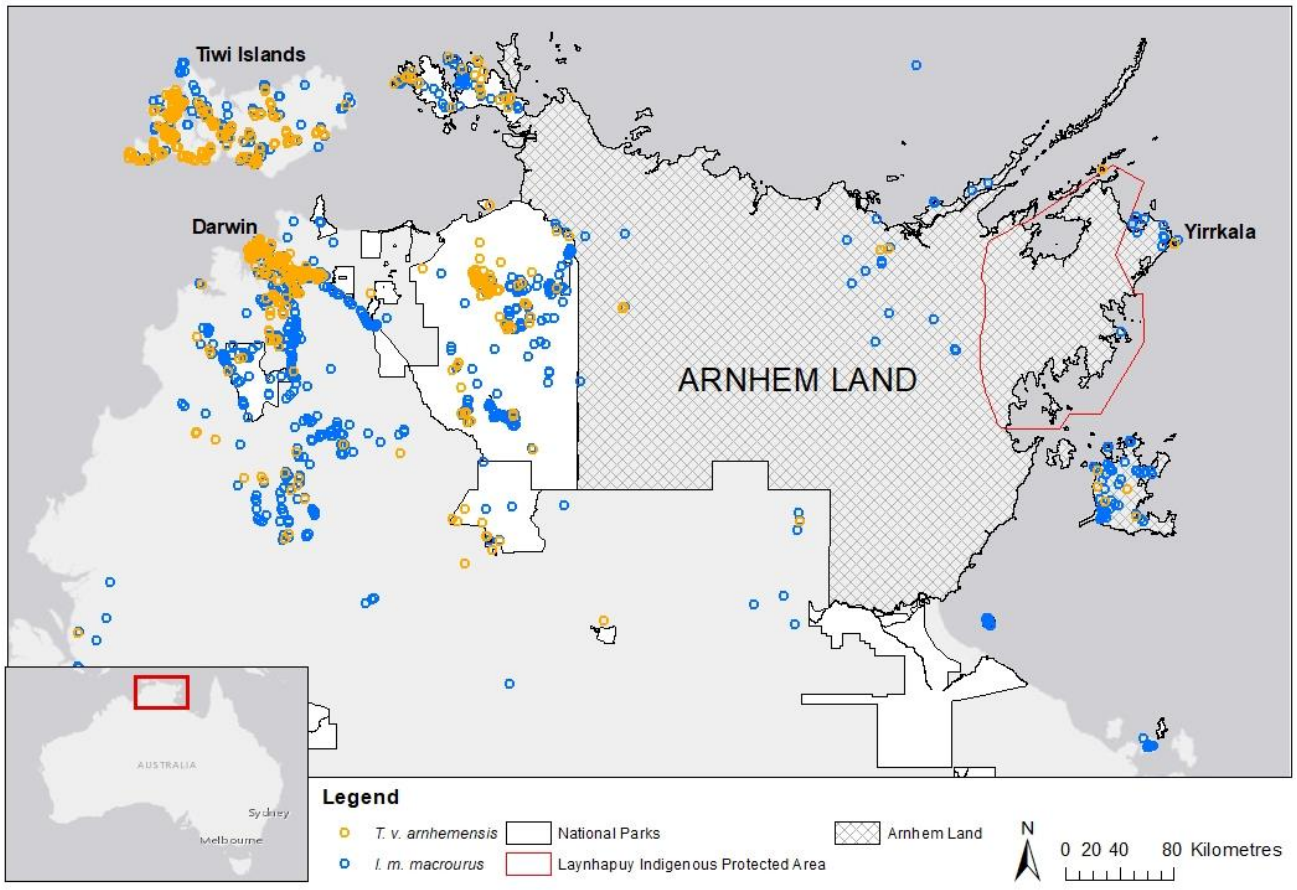

Figure 7. Occurrence points for *marrŋu and wan'kurra* from 1970-2020, downloaded from the Atlas of Living Australia. Only 6.13 % of all occurrences points for *marrŋu* and 0.07% for *wan'kurra* fall within Arnhem Land. In the Laynhapuy IPA, there was only one occurrence point for the *wan'kurra*, and no records for the *marrŋu* (using data selection criteria).

2.3.3 Environmental variables

Twelve environmental variables were selected as potential predictors for *wan'kurra* and *marrŋu* habitat suitability (Appendix 4), including seven climactic variables and five biophysical variables.

The climactic variables were derived from the 'Australia current climate (1976-2005)' layer (VanDerWal 2012): annual mean temperature (B01), maximum temperature of the warmest month (B05), minimum temperature of the coldest month (B06), annual precipitation (B12), precipitation of the wettest month (B13), precipitation of the driest month (B14), and precipitation seasonality (B15). The biophysical variables included: vegetation type (Australian major vegetation groups- present) (Commonwealth of Australia 2018), soil type, soil moisture and soil clay content (National Soil Grids 2012, ACLEP), as well as elevation (9 arcsec Digital Elevation Model (DEM)) (Hutchinson et al. 2008). All environmental data was available on the Biodiversity Climate Change Virtual Laboratory (BCCVL (Hallgren et al. 2016) database (http://bccvl.org.au), except for the DEM, which was downloaded from Geoscience Australia (https://www.ga.gov.au/).

Correlations between the continuous environmental variables were visually inspected using the 'variable correlations' figure produced by BCCVL. Variables were removed from the analysis if they showed a strong pairwise correlation with other variables. The 'permutation importance' of the remaining variables, including categorical environmental variables, was used to assess their relevance to the model. If the percentage permutation importance was very low (<1.0 %), the variable was removed from the model. Following this variable selection process, the remaining five variables for the *wan'kurra* SDM were B01, B05, B06, B12 and elevation, and *marrŋu* SDM were: vegetation type, elevation, B01, B12 and B15.

2.3.5 BCCVL model construction

To generate species distribution models the species occurence data (or modified species occurence data, *marrŋu)* from the ALA was uploaded to the BCCVL. The 'MaxEnt' algorithm (Phillips et al. 2006), one of the options on the BCCVL, was used as it is arguably the most common algorithm used to develop SDMs using presence-only species occurence data (Elith et al. 2011). MaxEnt, standing for 'maximum entropy modelling,' estimates habitat preferences for species using machine learning (Phillips et al. 2006). Background points for the wan'kurra SDM (10,000 points) and marrŋu SDM (2550 points) were generated by BCCVL for the model. By default, the BCCVL generated a 'convex hull' around the species' occurrence points to provide the geographical constraint for the selection of background points and model projection. However, for the marrŋu model a polygon of the IBRA regions that included occurence points for this species was used in lieu of a convex hull for the geographic extent, in attempt to improve the model fit. Default BCCVL

configuration options for MaxEnt were used, and are listed in the Appendix 5. By default, the BCCVL carries out 10-fold cross-validation to evaluate Maxent models.

2.3.6 Model post-processing to include IBK

ArcGIS Desktop 10.6 (ESRI 2018) was used to post-process the SDM models using the digitised *Yolŋu* knowledge of species occurence and significance. *Yolŋu* knowledge of study species occurence (polygons) was overlaid on top of the models. Locations of culturally significant Homeland centres for different species were also added (point) (Figures 14 and 15). *Yolŋu* knowledge of *wan'kurra* seasonal distribution was used to post-process the SDM model output to produce a model of *wan'kurra* distribution during the wet season (Figure 13).

3. Results

3.1 Interviews with *Yolŋu* Knowledge Holders

Yolŋu knowledge of each species is presented below. Occurences of species noted as in the 'past' refers to a period of time >20-60 years, when Yolŋu Knowledge Holders (YKH) noted occurrences of species when they were children/adolescents, or even by their parents' generation (also referred to as the 'old people'). 'Recent/present' was used to describe the occurrence of species <20years ago, or when YKH said they saw this species regularly, or if it was assumed to still be present at a location. All study species were considered to be part of the *Yirritja* moiety.

3.1.1 *Wan'kurra* (Northern Brown Bandicoot)

Nomenclature |*Yäku*

All participants identified and/or recognised the Northern Brown Bandicoot as the *wan'kurra* (n = 15).

Occurrence | *Dirrgiyun*

Many YKH reported seeing *wan'kurra* in the past (n = 9), whilst under half reported recent sightings (n= 6). YKH that reported recent sightings of *wan'kurra* were from Homelands located in the north-west region of the IPA, where they also described the *wan'kurra* as abundant. For example, Margaret Wanambi stated: *"...dhaŋaŋ* [many] *wan'kurra in the bushes around here* [Raymangirr]." However, at other Homelands, *wan'kurra* had not been observed recently, with some participants revealing the last time they observed a *wan'kurra* was during the Homeland movement in the 1970's. Susan Ganambarr stated: *"We don't have wan'kurras here* [Rorrowuy] *at the moment,*" while Djambawa Marawili said that *"…before we used to have a lot of wan'kurra*

here, yo [yes]*, a lot of bandicoot. It lives on this country. In the early 70's we saw a lot of these animals living in the Blue Mud Bay area*…". Knowledge holders whose clan estate overlapped with *wan'kurra* distribution, such as Banul Munyarryun from Dhalinybuy Homeland and Margaret Wanambi from Raymangirr, were the most knowledgeable about *wan'kurra* habitat, seasonality, and hunting. Homelands where *wan'kurra* have been sighted in the past include: Gangan, Baniyala, Djarrakpi, Gurkawuy and Rorrowuy, and present: Mäpuru, Burrum, Raymangirr, Yalakun, Dhalinybuy and Yirrkala (Figure 11a).

Habitat | *Wäŋa*

Floodplains (*ninydjiya*), were identified as the major habitat type of the *wan'kurra* (n = 4). As Banul Munyarryun noted "…*you find them at the floodplain, and right next to Arnhem Bay*." Other YKH described eucalypt woodland (n = 3) or rocky habitat (n = 2) as the preferred habitat type, or associated their distribution with bodies of water (n = 1). Multiple participants observed the *wan'kurra* during night (n=5). Some YKH noted that you can tell when *wan'kurra* have been in an area due to the 'hole' or depression they leave behind on the ground where they built their nest (n= 3). Margaret Wanambi described their nest building behaviour:

"…they make a nest, not in the trees, but in the ground… it's made out of mulmu [grass] *and there is a hole inside, but covered with grasses…Sometimes, wan'kurra make a nest to keep all the kids in that nest."*

Cultural significance | *Mayali'*

Many YKH reported *wan'kurra* as a culturally significant species, being sung in *manikay* (songlines), danced in *buŋgul* (ceremony), and appearing in sacred clan designs. Some participants also described an association between the *wan'kurra* and 'secret men's business' (n= 4). Specifically with male initation *buŋgul* (ceremony), that are currently practicsed "…in the sacred area, for every clan" according to Margaret Wanambi. However, they did not elaborate much about this ceremony, with participants emphasizing that they "… *can't tell the story of men's ceremony to the ladies or to the kids… we can't*" (Jimmy and Jason Marrkula). Some knowledge holders revealed a connection between the *wan'kurra* and *larrakitj* (hollow log/ mortuary pole) (n = 3), which is depicted in the *nuwayak* bark painting below (Figure 8). Banul Munyarryun explained that: *"Sometimes wan'kurra got footprints like in wangurri dhäwu* [story] *it's got footprints, and also its on larrakitj that my marku bapa* [father] *that tells stories about wan'kurra."*

Figure 8. *Nuwayak* (bark painting) by Y.Yunupingu (Date unknown) of the *Gumatj* ancestral *Wan'kurra* entering and leaving a nest. Courtesy of the Buku-Larrnggay Mulka Art Centre (Yirrkala, NT).

The *dhäwu* (story) of the *Gumatj Wan'kurra* (Figure 8), was detailed in a transcription from the archives of the Buku-Larrnggay Mulka Art Centre by M. Yunipingu (date unknown). In this *dhäwu* a fire started by the *Bäru* (the ancestral crocodile), spread from a ceremonial ground at *Ŋalarwwuy* to burn the nest of the *Wan'kurra* (the ancestral bandicoot), "*forcing him to hide in a hollow log larrakitj to save himself. Wan'kurra is thus danced and sang at mortuary ceremony as he is associated with the burial log used to contain the bones of the deceased*...*The wan'kurra travelled through the hollow log with its tail on fire transferring the Gumatj identity to new places".* Many other species are intertwined in this story which describes the connection between the ancestral totems of the *Yirritja Gumatj* people, and also "...*named sites which were burnt as the ancestral fire spread across the land."* Where these marked places exist outside *Gumatj* clan lands, they "..*represent important relationships held between these clans".*

Material value | *Bäki*

Some participants reported that the *wan'kurra* is hunted for meat (n= 4), and that the dry season is the ideal time to hunt for them. As Margaret Wanambi noted,*"...if they see him* [a *wan'kurra*] *in the nest, they will hit him with a big stick... it's a good meat, it's a nice one".* Further, some knowledge holders indicated that the late dry season was the best time to hunt for *wan'kurra "…after the fire work they can* [come out] *in the night, they can walk around, not in the wet – yaka* [no] – *the long wet…"* (Banul Munyarryun). Banul further elaborated on the seasonality and hunting of *wan'kurra:*

"Important part for Yolŋu, when they go out to catch wan'kurra or rupu, that time is called warrk and fire work, that's when Yolŋu goes, this is the good season for it, because wan'kurra- bandicoot,

goanna… what else… echidna, this is the good season for those tucker now for Yolŋu – for Yolŋu ŋatha [food]. *And also sugarbags* [honey], *its the same season, when the first Yolŋu they look at the warrk first, they do fire and they hunt for those species of animals, that's the Yolŋu way, what Yolŋu were doing in the past, eating tucker".*

Some YKH reported that they no longer hunted for *wan'kurra*, revealing that it was only hunted in the past, for meat (n = 7) and its fur which was used to make string (n = 1). Buwuthay Munyarryun revealed that *"…a long time* [ago] *we saw dhaŋaŋ* [many] *wan'kurra…when we used to go camping to the plain site and we ate them, a lot of wan'kurra… I was only young, bäyŋu* [no] *kids, bäyŋu* [not] *married".*

Threats | *Burrakuma*

For those that no longer hunt *wan'kurra*, some hypothesised that the absence of *wan'kurra* could be due to cane toads (*Rhinella marina*) (n=3). As Jason Marrkula described,*"… he was here heaps* [in Gapuwiyak]*, but the cane toads come and just kill all the animals."* Further, Gurrundul Marika (a Yirralka Ranger) affirmed that cane toads do*"...not belong to the NT…when cane toads came in to Arnhem Land,* [they] *got rid of other animals, because scientists told us that cane toads got poison, and get rid of the native animals. We heard about it…from scientists."* Indicating that it was poisoning from cane toads that was causing a decline in numerous animal species, and could also be impacting on *wan'kurra* distribution. Another knowledge holder, Djambawa Marawili, reported that fire might be impacting *wan'kurra* distribution, suggesting that they may have "*...moved to avoid the fire – to hide from it*" in the Blue Mud Bay area, and others noted that fire was dangerous for them, and/or that they have observed *wan'kurra* running from fire (n= 3).

3.1.2 *Marrŋu* (Common (Northern) Brushtail Possum)

Nomenclature | *Yäku*

Many knowledge holders identified the Common (Northern) Brushtail Possum as *rupu* (n =5), whilst others identified it as *marrŋu* (n = 5), and others identified both terms as correct names for this species (n = 3). Thomas Marrkula explained that this was because of dialectual differences: *"...in Yirrkala way they call* [it] *rupu, but we call* [it] *marrŋu – one body but two names."* Nami Maymuru White indicated that: *"This two possum,* [are] *a male and female – one is rupu and one is marrŋu."* Nevertheless, both names were considered common vernacular for 'possum.' Whilst the *marrŋu*, is one of two species of possum which has a distribution in north-east Arnhem Land,

the other, the Sugar Glider (*Petaurus breviceps,* Waterhouse 1839), was identified as *mi̲tiwirri* or *warrawar* by YKH, and noted to be 'related to' but different from *marrŋu.*

Occurrence | *D̲irrgiyun*

All YKH had seen this species before, but few reported seeing it routinely (n = 2). Margaret Wanambi divulged that she sees this species "...*every night- walking around*" Raymangirr. However, others had not seen it in a very long time, or within the IPA (n= 6). Homelands where this species has been observed recently include: Dhalinybuy, Burrum, Yalakun, Yirrkala and, Raymangirr. They have been observed at Djarrakpi, Baniyala, Gangan and Doyndji in the past (Figure 11b).

Habitat | *Wäŋa*

YKH described the habitat of *marrŋu* as eucalypt woodland and/or bushland areas (n = 4). Many suggested that it lives in tree hollows (*l̲arrakitj*), and can be located by claw marks from where the animal has climbed up or down the tree (n= 4). Further, they noted that they can often be found adjacent to mangroves (and in mangroves) or rivers (n= 2). Paul Wunuŋmurra gave a good summary of this species' habitat:

"…I see a lot of them around – when you go forest area – like thick jungle you see them… along mangroves and rivers – you can see the hole [tree hollow] *and scratch*[es]*…Yolŋu knows where they are living – because they see scratches on the trees* [in] *dense forest, near freshwater, and where freshwater and salt water meet."*

Cultural significance | *Mayali'*

All YKH considered the *marrŋu* a culturally important species, associated with *manikay, buŋgul* and sacred clan designs. Specifically, YKH identified this species as part of the *manikay* of the *Wangurri, Madarrpa, Dhalawangu, Maŋgalili, Ritharrŋu, and Munyuku* clans. Further, it is considered especially important for the *Mangalili* clan at Djarrakpi, as it is one of the ancestor *waŋarr* of the Djarrakpi Homeland. Almost all respondents knew details of this story, as Djambawa Marawili acknowledged: *"…they paint this one-it's in their patterns, the Maŋgalili people… The pattern started there* [Djarrakpi]*…that's been passed on from their ancestral beings".* A member of this clan, Nami Maymuru White, explained that the *marrŋu* was a protected totemic species: *"… for us, the Maŋgalili clan, it is a protected animal...we are not allowed to kill or eat it".* The ancestory of the *marrŋu* is immortalised in paintings of the story of the Guwak (*Mangalili* ancestral

bird), in which the *Guwak* bird (Pacific Koel, *Eudynamys orientalis,* Linnaeus 1766) made string out of *marrŋu* fur called *bulkun* (Figure 9; Morphy 1991).

Whilst starting at Djarrakpi, the story connects multiple Homelands and clans, specifically *Yirritja* people, as Banul Munyarryun said: "...*rupu stories travel right up the coast Gangan, Baniyala-Gapuwiyak and further west..."* Further, like the *wan'kurra,* the *marrŋu* plays a prominent role in the morturary rituals of *Yolŋu*. One YKH, Nami Maymuru White provided an indepth description of the significance of the *bulkun* (possum string) in mortuary *buŋgul* (not provided here for cultural reasons).

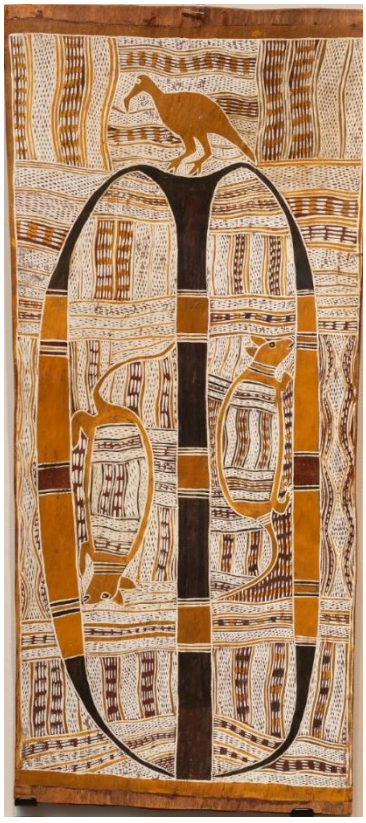

Figure 9. Illustrates a *nuwayak* (bark painting) by master artist and ceremonial leader Narritjin Maymuru. Titled *The Guwak and Possum* (1969), it depicts the events of *Maŋgalili* ancestral *Guwak* and *Marrŋu* at Djarrakpi. (Held in the National Gallery of Australia, copyright of the estate of the artist courtesy of Buku-Larrnggay Mulka Art Centre).

Material value | *Bäki*

Some knowledge holders recorded that this species was previously hunted for food (n =9). As Manman Wirrapanda commented: "*This animal is good tucker, although not hunted for at the moment."* YKH also noted that it was hunted for its fur, which was used to make string (n =3) (*bulkun*) and also 'sacred bags' or dilly bags (n = 3) and ceremonial armbands and headbands (n =2) used for *buŋgul* (specifically *buŋgul* marking male initiation). As Banul Manyurryan recorded *"...when they hunt to eat, they make fur out of it, for dancing."* Further Jimmy and Jason Marrkula explained that *"...they use it for making a sacred bag and for making young men/boys into men."* However, some YKH noted that this current practice, whilst others acknoeledge that this practice was not current, but occured when they were younger, or practiced by their parents' generation (n =5), as summarised by Yinimala Gumana:

"It's a good tucker and Aboriginal people all over the region.... way back, what we've been hearing from our parents and from our people, they used to see those animals, they used to collect it, they used to eat it, they used to use it for cultural protocols activities..."

Some YKH still hunt this species, like Margaret Wanambi's family at Raymangirr, *"...sometimes when you go hunting outside they see the mark scratching with the claws and they know there is a possum in that tree…they hit him and they take him for dinner or breakfast. Manymak* [good] *taste."* When asked if they still hunt for this species, Jimmy and Jason Marrkula replied: *"Bäyŋu! We are scared of the rangers. We cant steal animals, the rangers might cost* [fine] *us..."* aluding that they might be fined by the rangers if they killed this animal. However, no other YKH reported this sentiment. Djambawa Marawili explained that possum fur for *bungul* at Yilpara now had to be purchased and shipped up from suppliers in Tasmania.

Threats | *Burrakuma*

Many YKH considered this species to be abundant in areas of favourablle habitat and weren't aware of changes, or any threats that could negatively impact populations of this species. As Paul Wunuŋmurra stated about Yalakun *"...their numbers are still there, they are cruising, healthy one*."

3.1.3 *Barkuma* (Northern Quoll)

Nomenclature | *Yäku*

Most YKH recognised the Northern Quoll as *barkuma* (n=13). However, some only remembered this name after they were promted (n = 9). Further, some YKH recognised the name, but not the photo of the animal (n =2). Buwathay Munyarryun identified the name for this species as *warral*: "*…we call it warral that one… similar to possum? Yo that one, but that's the warral*."

Occurrence | *Dirrgiyun*

Whilst some respondents had never seen *barkuma* before (n = 5), the majority had heard about them in stories, passed down from older generations. Yinimala Gumana explained that at his Homeland, Gangan, they: *"...never see that animal now, they were there, out in the bush, but we never seen them. Maybe they're there but we don't know… my family, they used to pass the stories to us, you know they seen all these animals in the past".* Further, some YKH reported observing this species in the past 'a long time ago' generally in their youth (>20-40 years ago) (n = 4). Gurundul Marika elaborated that,*"…when I was young, I saw that kind of animal, when we go out look for honey, ga* [and] *wan'kurra, and saw this one – long time, in the past. Never seen them this time".* Even Margaret Wanambi reported that *"…we used to find them a long time ago, but this time we can't find them*". In fact, only two respondents, Banul Munyarryun and Djambawa Marawili recorded observing this species relatively recently (<20yrs).

Habitat | *Wäŋa*

YKH suggested that this species might be found in rocky areas (n = 4) as they can hide themselves well in: "…*good caves, holes, that's where you get the barkuma*..." (Banul Munyarryun). Jason Marrkula described an association with *Pandanus*: *"In the old ages when we saw this… when we used to go out for the pandanus… and cut it down, and it would just fooosh* [fly] *down like that."* Djambawa Marawili described foraging behaviour in mangroves:

"...on the plain country, open area, where the rocks are, barkuma need a place where they can hide themselves on the rocks...this mob always goes into the mangroves and feed[s] *themselves and then walk*[s] *back."*

Cultural significance | *Mayali'*

Only Djambawa Marawili indicated that this species was culturally signifcant, stating that there were songlines for this species, but that he did not maintain that particular one, and it could be connected to *nyiknyik* and *rupu* in *manikay* because *"...they are all living in plain Country, and the fur is all the same, and it is used sometimes for ceremony thing for armbands or you know…"* No artwork of this species was found in searches of the Buku-larrŋgay Mulka Art Centre archives.

Material value | *Bäki*

Some YKH reported that this speices was hunted for meat in the past (n = 6). They indicated this by explaining that only previous generations did this, for example, Jason Marrkula described that:

"Old people used to eat that [*barkuma*]*…my father's father, my grandma, like that you know… but now the new generation came in, and we don't eat that one, we don't hunt for that one, we just hunt for kangaroos, goannas, fish…"*.

Margaret Wanambi explained that previous generations took hunting dogs with them in order to hunt for this species, but that this practice had not continued:

"A long time ago, they were lucky because they used to take the dogs with them. The dogs…A long time ago. [Now] *bäyŋu* [none]*, because they don't go out hunting…They don't go looking for these animals* [anymore]*…*".

Threats | *Burrakuma*

For those YKH who reported not observing this species, and those who don't observe them as often as they used to, cane toads (n =2) and climate change (n=1) were suggested as possible drivers of their absence.

3.1.4 *Nyiknyik/guthin* (Red-cheeked Dunnart)

Nomenclature | Yäku

Like the Grassland Melomys, many YKH identified the Red-cheeked Dunnart as *nyiknyik* (n =8). Some respondents indicated, that *nyinkyik* was a common name used for all small 'rat-like' species, but that there are different names for different types that other YKH might know, as Paul Wunuŋmurra stated: *"There's a lot, small ones, I just call them nyiknyik but there's different names. Jimmy* [Yumutjin Jimmy Wunuŋumurra] *he knows more."* Margaret Wanambi and Jimmy Marrkula identified this species beyond *nyiknyik*, as *guthin* (n= 2). However, other YKH had never seen this species before, and could not identify it (n=4).

Occurrence | *Dirrgiyun*

Few respondents had seen this *nyiknyik* before (n =5): two in the past; one recently; and two did not provide a time frame but suggested multiple locations where they were assumed to be present. Specific locations where this species had been seen included: the Mäpuru floodplains, the Dhalinybuy floodplains, Dhuruputjpi, Garraŋarri, Balma, Ninydjiya (Gurrurmuru) and Baygurrtji.

Habitat | *Wäŋa*

Many respondents associated this species with *ninydjiya* (flood plains) or 'plain country' (n = 7), swamp /billabong habitat (n =1), and sandy areas (n=1). Margaret Wanmabi recorded that this species builds nests underground, where it rears its young. "*He used to make his nest underground. Breeds a lot; famous mice."*

Cultural significance | *Mayali'*

Margaret Wanambi recorded that: *"Dhuwal* [a lot of/big] *manikay. Wangurri…they sing it. That's all the Garmu bäpurru* [clans]*, they are from Dhalinbuy and Warrawar** (near Mäpuru), *yo next to Mäpuru. It's the same songline: Dhalinbuy and Warrawa".* Jason Marrkula also acknowledged that this species had 'dreaming' at, and was 'established' at Mäpuru. However, most YKH were uncertain if the cultural significance was separate from the other species that are also categorised as *nyiknyik*, like Grassland Melomys.

Material value | *Bäki*

Two YKH, Margaret Wanambi and Djambawa Marawili, reported that this species was previously hunted for food/ eaten.

Threats | *Burrakuma*

Most YKH did not indicate if this species had changed in number over time, and as many had only seen them once, so estimating change was not really possible. However, Paul Wunuŋmurra reported that *"…there's still heaps of them around".*

3.1.5 *Dhuliumbarr* (Black-footed Tree-rat)

Nomenclature | *Yäku*

Most YKH were not aware of this species, and had never seen it before (n = 12), and most did not know what it was called, but remarked it resembled *nyiknyik* (n =11), or was possibly related to *marrŋu* (n=1). Djambawa Marawili, recognised this species as *dhuliumbarr,* although no other *Yolŋu* name of this species or record of this word was found.

Occurrence | *Dirrgiyun*

Occurrence of this species was only noted by three respondents: Banul and Buwathay Munyarryun, who noted this species in Dhalinybuy and near Gangan; and Djambawa Marawili said it occured in the Blue Mud Bay area.

Habitat | *Wäŋa*

Banul Munyarryun sighted this species near a fresh water creek in a pandanus tree near Dhalinybuy. Djambawa Marawili described how he chased one through 'mangrove Country,' in Blue Mud Bay, where freshwater and salt water meet, detailing: *"...sometimes they live in mangroves, that's where they can catch a lot of healthy food".*

Cultural significance | *Mayali'*

The cultural significance of this species was not known/ discussed. However, some respondents suggested that it could be associated with *nyinkyik.*

Material value | *Bäki*

Banul Munyarryun recently caught an individual of this species and used it for fishing bait. Otherwise no material use was described/acknowledged.

Threats | *Burrakuma*

Any changes to populations was not commented on by YKH and no knowledge of factors influencing populations of this species were known.

3.1.6 *Nyiknyik* (Grassland Melomys)

Nomenclature | *Yäku*

All respondents identified/recognised Grassland Melomys as *nyiknyik* (n =15). We note that *nyiknyik* is a commonly used *Yolŋu* name for all small rodents.

Occurrence | *Dirrgiyun*

Many respondents recorded recent occurences of Grassland Melomys, or considered them to be present across the landscape (n= 9).

Habitat | *Wäŋa*

Grassland Melomys are considered to be associated with *Pandanus* assembledges*,* where they build their nests (n =5), and prefer areas along creeks, near billabongs and in swampy areas. Djambawa Marawili gave a good summary of their known association with *Pandanus:*

"...when we always go to collect the pandanus tree, they always see these ones, they jump out from the pandanus, they run and go out into the bush, they make their home in the pandanus – maybe easy for them, sometimes they eat the pandanus nut there".

Some respondents also reported they had seen this species in their houses (n= 3), and one of the rangers had seen this species on recent fauna surveys within the Laynhapuy IPA. Homelands where recent sightings were reported include: Baniyala, Dhalinybuy, Gangan, Raymangirr, Ninydjya (Gurrurmuru), Raymangirr, Rorruwuy and past sightings were reported around Gapuwiyak.

Cultural significance | *Mayali'*

Many respondents reported that the Grassland Melomys was a culturally significant animal (n =4). As Djambawa Marawili explained:

"Yo [yes]*, we sing the songline* [in Baniyala], *sometimes it is on the patterns, what I mean by patterns is the artwork, it's really important … you should go back and ask the and look for the ancestral beings… you know… and they can tell you about this, not me, because I just inherit this*

land from my father and my father pickup from his father, handing it over and over until today to me, so I can sing about that one there."

This species is a totemic species for some *Yolŋu*, and has *manikay* and *buŋgul* and clan designs for: *Wangurri, Madarrpa, Dhalwaŋu* and *Maŋgalili.* The *Wangurri nyiknyik* design is depicted in Figure 10. Here the *nyiknyiks* role in cleaning the ceremony ground and carrying stories is depicted (transcription from the Buku-Larrnggay Mulka Art Centre). As Buwathay Munyarryun, a *Wangurri* man, described:

"I've got manikay, and I've got buŋgul for them, and I've got painting… [the *nyiknyik* is] *connected to Dhalinybuy though manikay and buŋgul, and Warrawar – Lake Evella way, right up to Millingimbi way, right up to Maningrida way, connected you know, songlines from here to there…*"

Figure 10. '*Ŋokawu, nyiknyik, watpirrya' Nuwayak* by Gadalminy Munyarryun from the *Wangurri* clan at Dhalinybuy. (Courtesy of Buku-Larrnggay Mulka Art Centre)

Material value | *Bäki*

Grassland Melomys were not reported to be sought out as a food source or for creation of any material goods.

Threats | *Burrakuma*

Many YKH reported that Grassland Melomys were abundant in numerous areas, and gave no indication that the numbers of this species were changing, or declining.

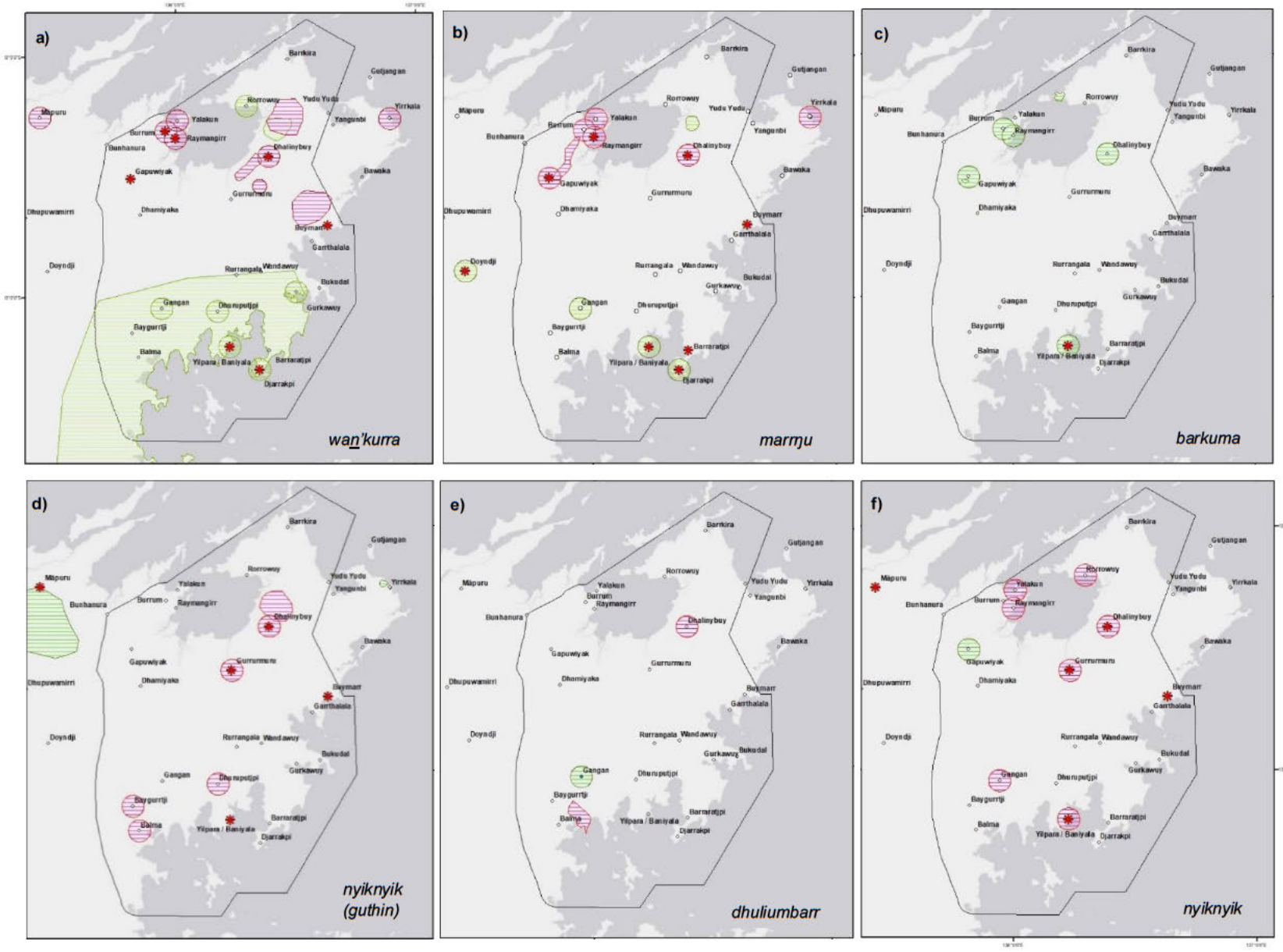

Figure 11. Mapped *Yolŋu* knowledge of study species occurence and locations of cultural significance in the Laynhapuy IPA. Homelands where species occurences were recorded are marked by a circular polygons (5km radius). Other polygons represent approximate regions where species have been seen, or are believed to be present outside immediate Homeland areas.

3.2 Species distribution models

3.2.1 Importance of environmental predictors

Mean annual precipitation (B12) had the highest permutation importance (58.2) for the *wan'kurra* SDM, followed by, maximum temperature of warmest month (B05) (33.2063), annual mean temperature (B01) (4.422), minimum temperature of coldest month (B06) (2.296) and elevation (1.8758). For the *marrŋu* SDM, the permutation importance was also highest for mean annual precipitation (B12) (79.6384), followed by precipitation seasonality B15 (9.8662), elevation (7.7131), vegetation type (2.4768), mean annual temperature (B01) (0.3054).

3.2.2 BCCVL model performance

Models of 30 arcsec ~1km resolution were generated for the *wan'kurra* and *marrŋu.* Both models produced high AUC values (AUC = 0.96), indicating robust model performance. A broad potential distribution was projected for the *wan'kurra,* bot not the *marrŋu.* The projected distribution for the *wan'kurra* extends from the Kimberleys to northern NSW, with a semi-continuous distribution of high habitat suitability along the northern and eastern coatslines, excluding the southern coastline of the Gulf of Carpentaria. Areas of high habitat suitability for the *marrŋu* were restricted to Melville Island and the north-western coast of the NT, with patches along the coast of north-east Arnhem Land.

3.2.3 Model refinement with *Yolŋu* knowledge

Yolŋu knowledge helped refine the SDMs in two ways. Firstly, some YKH indicated *wan'kurra* distribution was seasonal, acknowledging they were commonly found across the flood plains during the dry season, but retreated to surrounding woodland during the wet season. Comparative dry and wet season models were constructed for the *wan'kurra* in response to this (Figure 12 and 13). Secondly, where YKH indicated occurences and cultural significance of these species, this was mapped on top of the models (Figure 14 and 15). Mapping of YKH knowledge of *wan'kurra* aligned with the SDM, suggesting low probablity in the southern regions of the IPA (Figure 14). The *marrŋu* SDM predicted very low probabilities of occurence for the majority of the IPA. This conflicts with *Yolŋu* knowledge that this species was once present throughout the entire region, and is now restricted to north-west regions, similar to the *wan'kurra* (Figure 15).

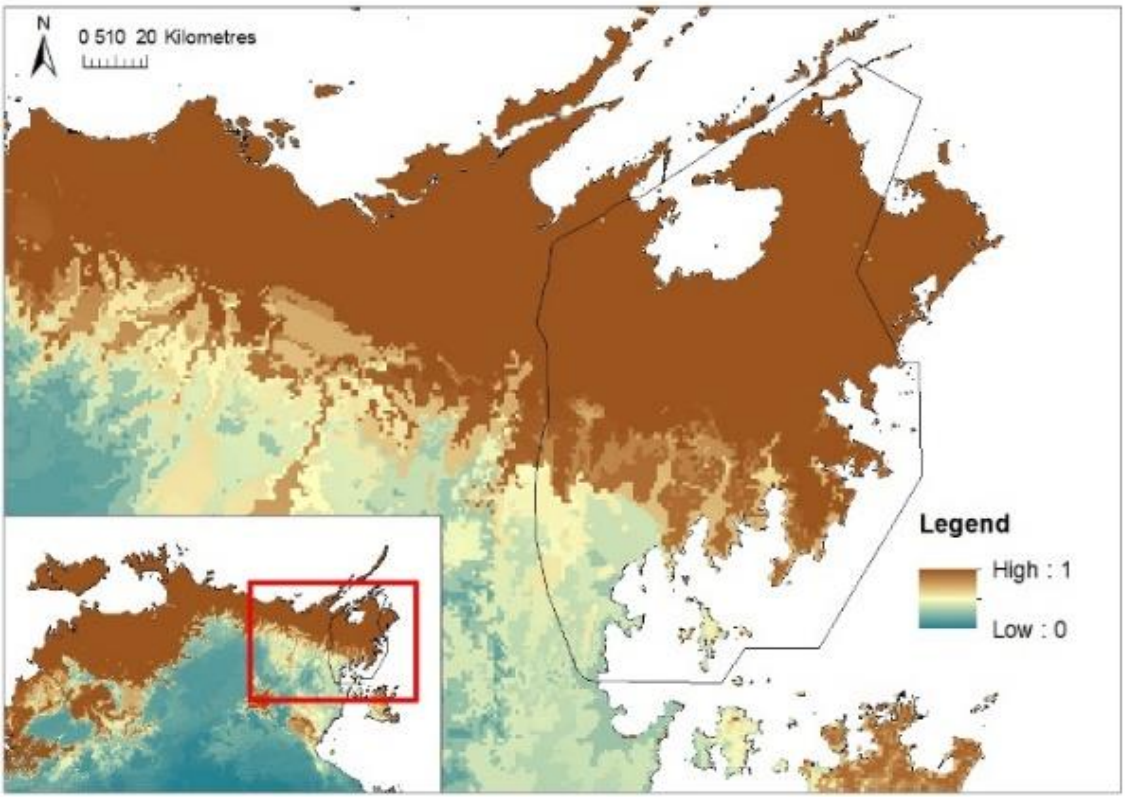

Figure 12. Species distribution model for the *wan'kurra* across north east Arnhem Land and the Top End (inset) in the dry season. Regions of predicted habitat suitability are restricted to coastal regions.

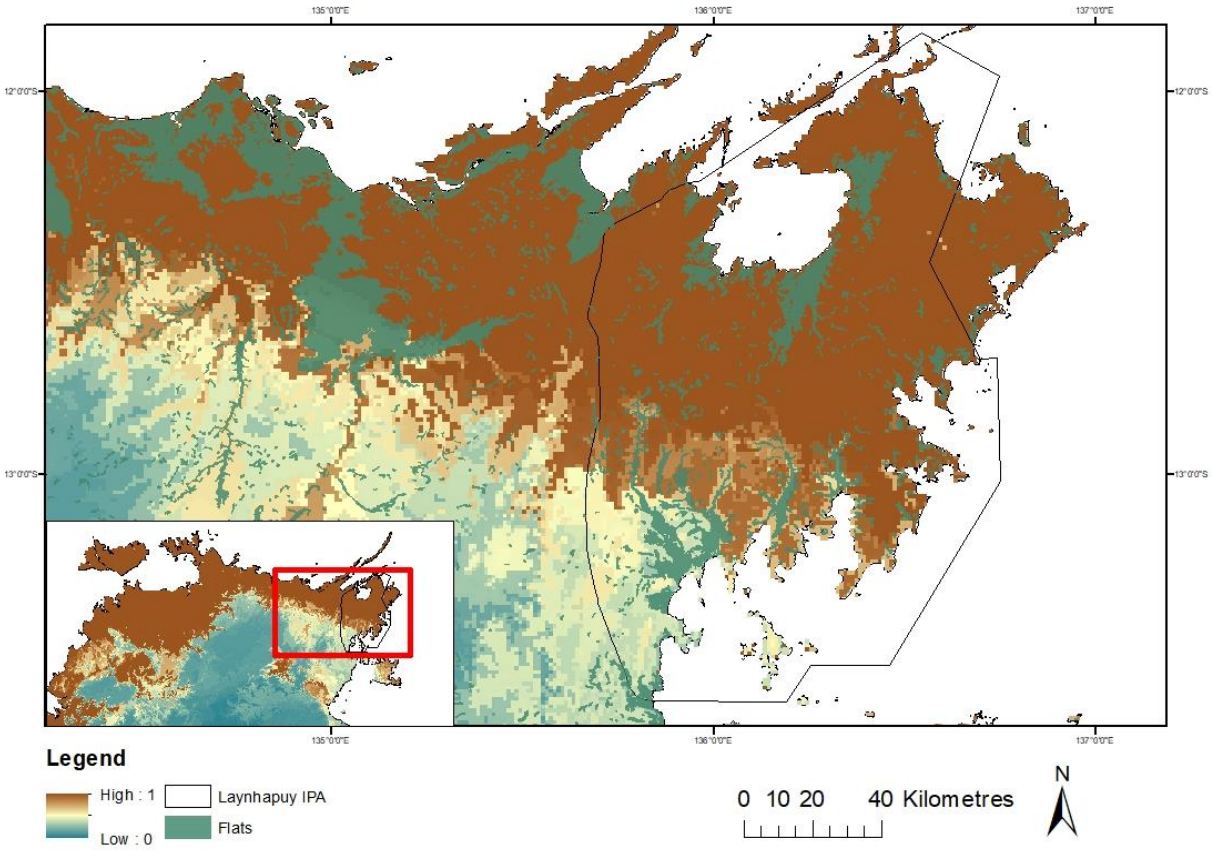

Figure 13. Wet season *wan'kurra* SDM. Data for flats from Geoscience Australia (https://www.ga.gov.au/) was overlayed on the model to indicate wet season distribution of this species.

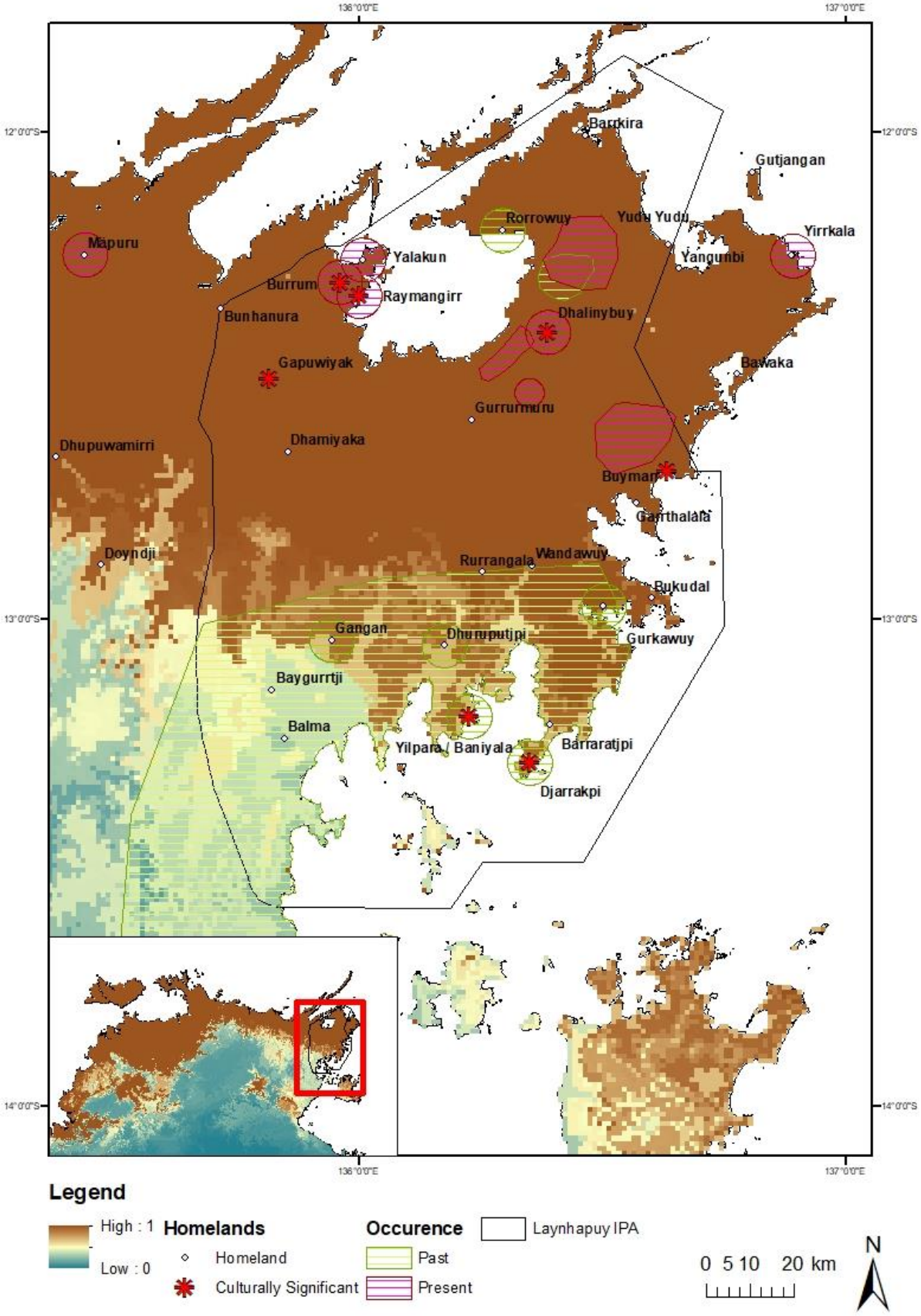

Figure 14. *Wan'kurra* SDM overlaid with *Yolŋu* knowledge of present and past sightings and places of cultural significance. Suitable habitat is prominent within the IPA, especially in the northern coastal regions.

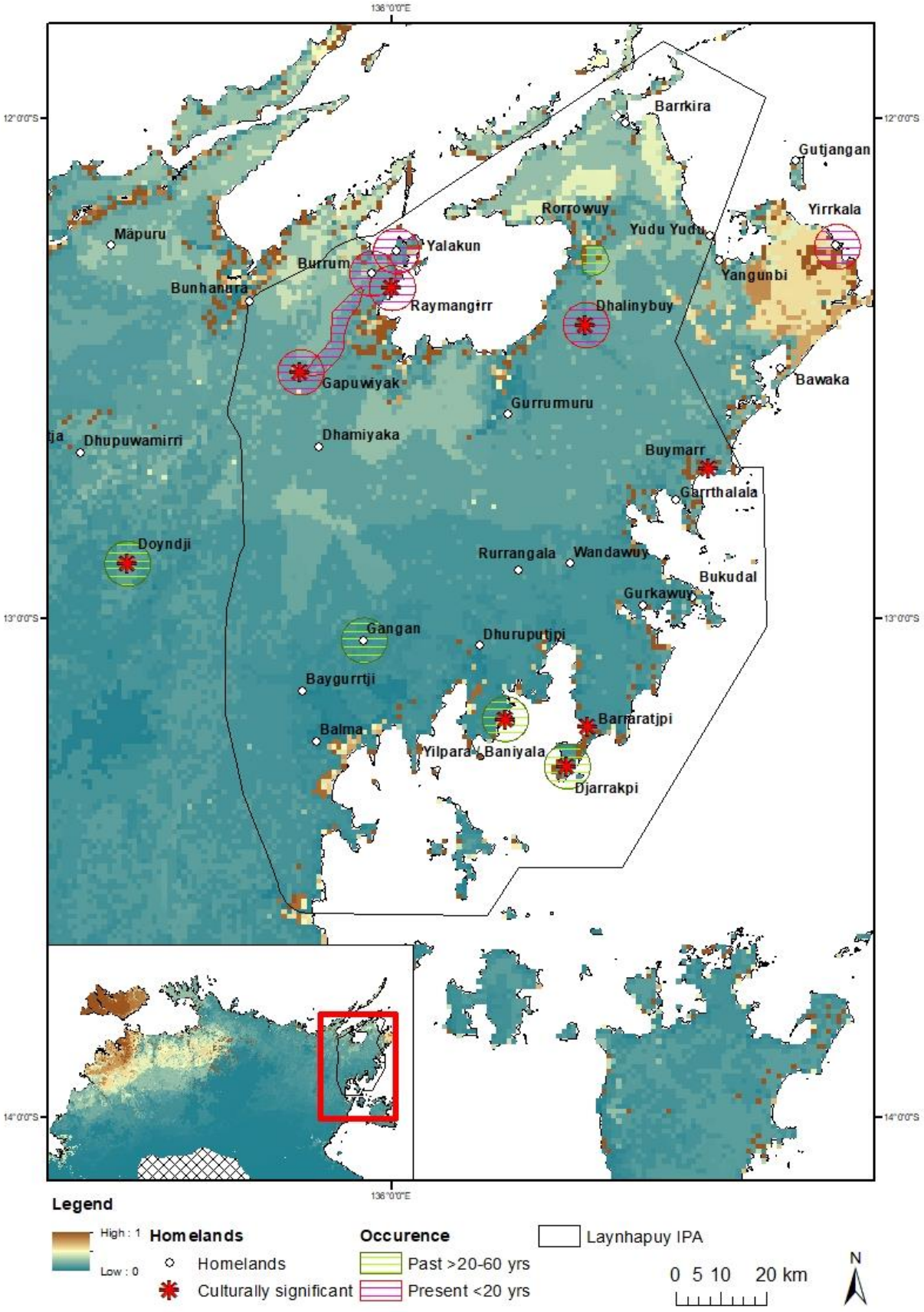

Figure 15. *Marrŋu* model ouptput overlaid with *Yolŋu* knowledge of species occurence and significance. Extent map indicates low habitat suitability over most of the region of the Laynhapuy IPA, excluding the Gove Peninsula where Yirrkala is located, with areas of high habitat suitability in north-west NT.

4. Discussion

Since early 20th Century expeditions by Thomson and the Smithsonian institute, dramatic declines in the study species have occurred. In this study *Yolŋu* senior knowledge holders provided knowledge that presents strong evidence for declines in at least four of the CWR study species: *wan'kurra, marrŋu, barkuma,* and *dhuliumbarr.* Due to the *Yolŋu* taxonomic grouping of the two species identified as *nyiknyik,* further investigation is needed to tease out trends for these individual species. Knowledge of culturally signficant species was better retained than for other species, acknowledging the connection between biological and cultural knowledge. By combining species distribution models and *Yolŋu* knowledge of the probable occurence of two culturally significant species, *wan'kurra* and *marrŋu,* we enhanced current understandings of their distribution in the Laynhapuy IPA. The findings of this study not only align with previous reports of declines across northern Australia that are suggestive of widespread CWR mammal loss (Woinarski et al. 2010, Ziembicki et al. 2013), but by bringing together *Yolŋu* and Western scientific insights, can enhance the local scale and context specific management of these species by the Yirralka Rangers.

This research aligns with with similar research demonstrating declines of CWR species in other parts of northern Australia such as the Kimberley in WA, NT National Parks and regions of Arnhem Land (Ziembicki et al. 2013, Woinarski et al. 2015). The *barkuma* and *dhuliumbarr* have likely undergone the most dramatic declines, probably pre-dating the observed declines in the other study species by YKH. The *wan'kurra* and *marrŋu* appear to have declined relatively recently throughout the southern regions of the IPA, but are still regularly observed in the northern and specifically north-west regions. Although other research has suggested that the Grassland Melomys and Red-cheeked Dunnart are 'safe' in the NT, there is an acknowledged lack of data, especially for the Red-cheeked Dunnart and local scale threats that warrant attention for these species. Furthermore, the majority of these species have purported broad distributions across Australia; however, such studies often dont differentiate subspecies that are limited to northern Australia (such as the *I. macrourus*, *T. vulpecula*, *M. gouldii*, and *S. virginiae*). Due to the homogenisation of subspecies, it is possible that entire subspecies may go extinct un-noticed.

Dhuliumbarr | M. burtonii

For the *dhuliumbarr* the lack of recognition by most YKH, lends support to previous research indicating wide spread historic declines of the WA/NT subspecies (*M. g. gouldii* and *M. g. melvillensis)* (Woinarski et al. 2010, Ziembicki et al. 2013, Davies et al. 2018). Whilst the Black-footed Tree-rat is considered to have a patchy distribution, which could account for the lack of recognition of this species by YKH in the present study, both Thomson (who recorded *Yolŋu* knowledge of this species) and the Smithsonian Expedition recorded this species within the IPA in the early 20th century (Specht 1964, Dixon and Huxley 1985). More recently Ziembicki et al. (2013) reported that TOs observed a significant decline in this species over the past 50 years.

Barkuma | D. hallucatus

The decline and potential local extinction of critically endangered *barkuma* in the Laynhapuy IPA was also reported in this study. Again, this corresponds with similar reports of decline from across northern Australia (Braithwaite and Griffiths 1994, Ziembicki et al. 2013, Woinarski et al. 2014). Even the oldest YKH, Margaret Wanambi (aged 80+), who reported recent observations of most CWR study species reported that *"…we used to find them* [barkuma] *a long time ago, but this time we can't find them*." Whilst the ongoing rapid decline of *barkuma* across the northern Australia has largely been attributed to the invasion of cane toads (Burnett 1997, Watson and Woinarski 2003, Woinarski et al. 2010), the lack of recognition by most YKH suggests this species may have declined prior to toad invasion from 1985 (Urban et al. 2008). Factors that have been linked to pre-toad declines, such as habitat degradation, inappropriate fire regimes, and predation from feral predators, could also explain the decline in the Laynhapuy IPA, although the exact mechanisms are not and may never be understood (Hill and Ward 2010).

The decline of *barkuma* prior to toad invasion in the Laynhapuy IPA is also suggested by the lack of cultural and material significance of this species that was previously recorded by Thomson (Dixon and Huxley 1985). The loss of *Yolŋu* recognition and knowledge of *barkuma* has similarly been recorded, following declines of this species in Indigenous communities of the Pellew Island group (Bradley et al. 2006). In contrast, *barkuma* IBK has been recorded on neighbouring Groote Eylandt (Waddy 1988) which still maintains healthy populations (Heiniger et al. 2020). This suggests that declines in IBK could be connected to species declines, and if so, highlights the connection between biological and cultural diversity.

Marrŋu and wan'kurra | T. vulpecula and I. macourus

Patterns of decline were less pronounced for the *marrŋu* and *wan'kurra,* although the abundance and distribution was noted as contracting, similar to other parts of northern Australia (Woinarski et al. 2010, Ziembicki et al. 2013). Unlike the *dhuliumbarr* and the *barkuma,* the *wan'kurra* and *marrŋu* were readily recognised and discussed by the majority of YKH. YKH responses indicated that both the *wan'kurra* and *marrŋu* have undergone declines throughout the southern regions of the IPA, whilst they remain present across the north-west regions (Figures 14 and 15). In the south of the IPA these species were identified as culturally significant species; however, were no longer reguarly observed or hunted. This pattern of decline reflects observed contractions of CWR species more generally, and specifically both the *wan'kurra* and *marrŋu* populations into the mesic regions of their ranges (Start et al. 2012, Ziembicki et al. 2013, Stobo-Wilson et al. 2019).

SDMs of these species predicted high probabilities (>0.5) of habitat suitability restricted to mesic limits of their ranges. Rainfall (mean annual precipitation) was also the most important environmental predictor (>50 % PI) for both models. The *wan'kurra* SDM predicts areas of high habitat suitability throughout the majority of the Laynhapuy IPA, except the southern reaches. This was affirmed by *Yolŋu* IBK which was juxtaposed over the SDM model (Figure 11) showing an absence or low density of *wan'kurra* across the Blue Mud Bay 44area where they were previously suggested to occur by senior YKH Djambawa Marawilli. Corresponding with previous research, this suggests that *wan'kurra* distribution is not limited by climactic variables alone, but landscape factors are at play. YKH also pointed to seasonality as a key driver of *wan'kurra* presence, and identified that suitable habitat varied between the wet and dry season which further refined the habitat suitability maps produced (Figure 13).

Whilst YKH suggested a similar pattern of decline for *marrŋu,* the model output predicted very low habitat suitability across the majority of the IPA, and entire range of this subspecies. The output was the result of the sampling bias caused by the large amount of data from the north west of the NT, compared to the rest of the subspecies' range within the ALA data set. Despite significant effort to counter sampling bias, it could not be overcome, resulting in poor model performance, and consequently limiting the applicability of of the *marrŋu* SDM to inform species management. No method has been shown to fully correct for sampling bias for presence only data (El-Gabbas and Dormann 2018). This results in SDM outputs that reflect patterns of sampling effort, rather than species' habitat suitability, as is the case in this study (Elith et al. 2011). Here, IBK provided a more extensive and insightful dataset than that available on the ALA to derive *marrŋu* distribution,

especially within the Laynhapuy IPA. This highlights the benefit to including IBK in SDMs, especially where datasets may be limited, or biased, and when modelling certain regions of a species' range for management purposes. Nevertheless, the IBK and the SDM model suggested that *marrŋu* abundance is correlated with higher rainfall areas, and/or regions of suitable habitat. Further, IBK suggested that this species was once widespread throughout the IPA, but now is restricted to certain regions, namely in the north-west, similar to the *wan'kurra*.

Some research exists that describes mechanisms suggested to be driving the decline of *marrŋu* and *wan'kurra* along a rainfall gradient. It has been hypothesised that higher rainfall areas support higher CWR mammal abundances, because they are correlated with: (1) high densities of low lying shrubs which provide a source of food and protection from terrestrial predators such as feral cats (Stobo-Wilson et al. 2019); and (2) low densities of feral cats (Legge et al. 2017). However, other factors (some of which area also correlated with higher rainfall) such as the intensity and frequency of fires, grazing by feral herbivores, and weed presence, can also limit low-lying shrubs, as well as tree hollows and hollow logs that *marrŋu* and *wan'kurra* rely on (Price et al. 2005, Davies et al. 2018). Moreover, regions affected by post-colonial changes to fire and herbivore activity have also been found to support higher activity and abundances of feral cats (Davies et al. 2020). Therefore, multiple 45ainta could be working in concert as stated by Woinarski (2015). Due to a lack of historic records and loss of Indigenous cultural knowledge to what extent these factors explain mammal decline and abundance remains largely speculative (Davies et al. 2018, Stobo-Wilson et al. 2019). Due to the contraction of CWR to the north of the Laynhapuy IPA, comparative research between the southern and northern regions of the IPA could assist with untangling rainfall as a driver of CWR mammals decline as mean annual rainfall does not vary much across the IPA (1200-1600mm (VanDerWal 2012)).

Despite evidence of the decline of both *marrŋu* and *wan'kurra* across the southern reaches of the IPA, indepth knowledge of species occurence, habitat suitability, behavioural ecology, and methods to locate and detect (hunt) *wan'kurra* and *marrŋu* were provided by select YKH. In the 1940s, Thomson recorded more detail on the classification of *marrŋu* and *wan'kurra*, than was recorded in this study, indicating a potential loss of higher order knowledge of this species. Therefore, his notes in (Dixon and Huxley 1985) are a valuable resource for potential revitalisation of cultural knowledge about this, and potetially other species. In some Laynhapuy Homelands, *marrŋu* fur is being ordered from Tasmania so *bulkun* (possum string) can still be used in *buŋgul* (ceremony). This 45action, not only reveals the cultural impacts of ecological decline, but

illuminates *Yolŋu* aspirations to 46maintain traditional cultural practice and uphold *Yolŋu rom* despite ecological change.

Nyiknyik and guthin | M. burtoni and S. virginiae

The *nyiknyik* was identified by all respondents as abundant across multiple Homelands (Figure 11). This aligns with research demonstrating widespread and resilient distributions of Grassland Melomys which are not recorded to be undergoing recent or rapid declines (Woinarski et al. 2010, Cabrera-Guzmán et al. 2015, Liedloff et al. 2018). Recent cross-cultural surveys have also sucessfully trapped this species at many different sites across the Laynhapuy IPA (Ens et al. unpublished survey data). However, as *nyiknyik,* is used as a general term, or common name, for rat or mouse, and even small marsupials, such as the Red-cheeked Dunnart, caution is needed when interpreting and applying insights from *Yolŋu* IBK about these species. Thomson also remarked on this (Dixon and Huxley 1985), as did Jason Marrkula who explained, "*They have one body but different names, but they are one*." Whilst YKH insights on specific habitat associations of different *nyiknyik* species in this study varied and demonstrates species level knowledge, their responses may have been influenced by the photographs of species used in interviews that included images of these habitat types. As stated by YKH in this study, clarification with senior *Yolŋu* knowledge holders who hold the *rom* for these *nyiknyik* species, such as Yumitjin Wunungmurra, is advised.

Benefits and challenges of a biocultural approach

There are many benefits to biocultural research approaches. In this study, the synthesis of IBK and Western science provided increased local scale insights into the population dynamics of CWR mammals in the Laynhapuy IPA. IBK also enhanced the output and interpretation of SDM for two culturally significant species, and overall results from SDM and IBK reveal declines in four CWR mammals. The use of a biocultural approach also enhanced our understanding of and recorded in part the immense, and culturally distinctive value of these species to *Yolŋu,* supporting the need for urgent measures to halt their decline. By paying knowledge holders as experts for their time, we provided a source of income to individuals from remote communities. Further, many younger community members sat in on interviews, and this study was part of a bigger project to record and assist the transfer of *Yolŋu* knowledge. As Buwathay Munyarryun said to me, as I, alongside his children watched his wife carefully separate different cuts of a freshly caught wallaby, that were to each be assigned to different people according to *rom* "...*this is the other way we learn; by doing*." It is thus concerning to consider if, and how, the decline of CWR mammals, alongside other native

species, is impacting processes used by *Yolŋu* to transmit knowledge, and assert their identity, law and soveriegnty.

Whilst the benefits of integrating IBK with Western Science are manifold, it is not without its challenges. Although the western scientific discipline of ecology and IBK are considered complimentary knowledge systems (Berkes et al. 2000, Ens et al. 2016), there are underlying dissonances in the nature of scientific data, and IBK, for example scale (Wohling 2009). Further, to ensure projects ethically engage with Indigenous peoples and ensure Indigenous priorities and knowledges are given equal weighting and respect, time and effort are needed to decolonize western research methods (Smith 2013, Datta 2018). Commitment to building strong, ongoing relationships, and use of multi-disciplinary methods, are also considered key factors that can ensure the mutual benefit sharing of co-created research (Ens et al. 2012). For projects that have strict time limitations, like this Masters thesis, adopting such research approaches are challengnig although necessary for environmental and social justice.

This project built on an ongoing, decade strong partnership with the Yirralka Rangers that focusses on mutually beneficial 'two-way' learning on Country. This ongoing partnership provided the context for the primary researcher to gain previous experience working with, learning from, and building mutually respectful relationships with the Yirralka Rangers. It also allowed for the determination of a common research priority based on both scientific and community concern, namely: the decline of culturally significant CWR species. Voluntary participation in this project allowed the principal author a greater understanding and appreciation of *Yolŋu* knowledge, and basics of *Yolŋu-matha*.

The principal author engaged in a relatively long period of field work (3.5 months). This was to allow for time to expand on past project relationships and avoid unexpected events or logistical constraints that limited connecting with and interviewing YKH. This put limitations on the development of scientific methods used in this study. Specifically the running of species distribution models was caried out using a virtual laboratory (BCCVL) as it is a time and cost effective tool. The SDM models here are a proof of concept of how Western science and IBK can be intergrated, and it needs to be acknowledge that significant time and effort was not chanelled into testing different algorithms or constrains in order to enhance model performance, like in other studies (Skroblin et al. 2019).

In cross-cultural situations, language barriers can hinder the elicitation, or two-way sharing of knowlegde (Skroblin et al. 2019). This can arise in multiple ways. For example, it may hinder attempts to ensure the elicitation of 'reliable' knowledge, or knowledge that equates to quantitative metrics (Kuhnert et al. 2010). Inconsistencies in the taxonomic classification of different species and or types of animals, can also lead to confusion or miscommunication, like in the case of *nyiknyik*. This term is applied widely to small rodents and even some species of marsupials by *Yolŋu*, but has also been recorded as the name for distinct species, such as the Northern Hopping Mouse (*Notomys aquilo*) (Fijn 2013). Further, certain nomenclature recorded previously by Thomson, is not entirely consistent with that recorded from YKH. Perhaps Thomson's notes can help affirm higher order classifcations between species, or relevant groups and bring back some of the detailed knowledge that now appears to be lost.

In general, cultural awareness and care must be used to avoid miscommunications in cross-cultural research (Huntington 2000, Smith 2013, Skroblin et al. 2019). It was challenging to ascertain exact dates and locations from YKH, and most seemed uncomfortable and hesitant to draw on the maps provided. This could reflect the different perceptions of time and place *Yolŋu* use to construct their lives and different means they use to pass on knowledge (Williams 1986, Morphy 1991). Concepts of change in species numbers or 'decline' were also recieved with some confusion by YKH, hence the loose time categories of before (past) or in (present) the last 20 years. Even for YKH who reported observing species in the past and not in the present, in some circumstances, assumed that perhaps there would be more members of that species now, because 20 years had past since they had last observed it. Further, Gurrundul Marika questioned: "*Changed in numbers? Nyiknyik is everywhere. I'm not, what do you call that, a people who count animals – like scientist...".*

In addition, and according to *Yolŋu,* socio-cultural changes which have altered traditional modes of being, could be a factor impacting their observation and knowledge of the study species by some YKH, or in some areas. Specifically a decline in hunting for traditional *ŋatha* (foods) and reliance on grocery stores, and advent of motorised vehicles were discussed by many YKH. As Djambawa Marawili, expressed, *Yolŋu* are not walking across Country as they once did, implicating the change in diet and transportation as the main factors driving knowledge loss. As Djambawa stated: "...*we used to catch them* [*wan'kurra*] *as food, we used to get a lot of animals like this you know in the 70's, 80's and 90's…we don't really go hunting these days...I drive around in a mutika* [vehicle] *I don't go and look for them…".* On top of this, changing sentiment towards feral animals may have

impacted mammal abundance. In the 1930's Thomson recorded that feral cats were hunted for food by *Yolŋu* (Dixon and Huxley 1985); however, now on some Homelands large numbers of cats are kept as pets. The valuation and management of feral water buffalo (*Bubalus bubalis,* Linnaeus 1758) may also have changed with the advent of income generated from safari hunting on some Homelands (Yirralka Rangers 2014).

Implications for management

Whilst, caution must be taken when drawing insights from the SDMs to inform management, due to the impact of sampling bias present in the ALA dataset, when combined with the Indigenous knowledge recorded in this study, they offer strategic insight into where and when CWR species can be located and managed in the Laynhapuy IPA. To enact strategies that mitigate the drivers of CWR decline, urgent research that closely investigates and isolates these drivers is required. Targeted surveying in regions identified by both YKH and SDMs could asist in the location of refugial populations, and provide comparative study sites to investigate threats.

Opportunities for *Yolŋu* to get out on Country and engage in traditional ways of living could also help manage CWR species. As *Yolŋu* revealed themselves, changes to traditional diets, and means of travelling across Country, have inhibited Yolŋu connection and knowledge of Country. Further, it is through these practices that knowledge of species' abundance and distribution, as well as behaviour is learnt and transmited. However, the increasing challenge of hunting for declining species could, although it was specifically stated by YKH, be a driver of, or at least a factor preventing the continuation of related cultural practice in some areas. Further, if declines continue, as is suggested elsewhere, *Yolŋu* could not only loose valuable food sources, and culturally significant species, but experience a disruption in processes through which they generate and acquire other detailed knowledge of their Country.

A growing body of research and policy asserts for the recognition and protection of biocultural diversity (Ens et al. 2016), as do *Yolŋu.* A common *Yolŋu* saying is "*healthy Country, healthy people*" (Yirralka Rangers 2014). This saying recognises the interdependence of people and Country by drawing a direct link between the health of the land and health of *Yolŋu*. It also reflects *Yolŋu* connection with the land, the nature and purpose of traditional land management pratices, and the paradigm of co-becoming with the land (Bawaka Country et al. 2013). By expanding on, and applying lessons learnt in this thesis, we can protect and support the future growth of both the biological and cultural values of the Laynhapuy IPA, and support a future of co-becoming.

Further, we add to the growing literature and projects that endevour to enhance the management of Indigenous land, through Indigenous knowledge, and empower *Yolŋu* to direct management priorities that impact their future.

5. Conclusion

"There have been a lot of changes to Country, and we're not seeing traditional ŋatha anymore..."

~Manman Wirrpanda, 2019~

Urgency is required to address the lack of scientific data and Indigenous knowledge documentation of threatened species across northern Australia. Our study showed that in areas like north east Arnhem Land, where Indigenous knowledge and language is still considered relatively strong (Arthur and Morphy 2019), it can be combined with Western science to enhance the overall understanding of Country. Further, Indigenous knowledge can compliment Western scientific models that often provide general insights, by providing detailed, local scale information. Collaborative research can empower Indigenous communities and strengthen biocultural diversity which is increasingly being threatened worldwide (Maffi 2001, Hill et al. 2011, Bryant 2019).

As a researcher from a Western background, it is paramount to remember that it is not simply enough to recognise the value of IBK without acknowledging the unique way of life and cultural context from which it originated and has been sustained for millenia. If we are to advocate for and support the integration of IBK in biodiversity conservation and NRM, we must also support and advocate for the importance and continuation of Indigenous preferred ways of life and their unique cultural contexts. As *Djambawa Marawili* explained, change in the way researchers engage with Indigenous communities is needed:

"*The university came a long way to get all this information…archaeologists and anthropologists came around* [before] *and collected all those pieces and took it back to their university to store it up, and other people are still coming to get information. I think it is the time to make it a reality. To make it clear for our people, for any, napaki ga yolŋu* [non-Indigenous and Indigenous people]*, to open the way,* [and say] *okay and this is what we've got, we'll give it back to you and share it and make it a resource or whatever. It is time to feedback to the new generation – napaki ga yolŋu world, maynmak* [good]?".

References

Altman, J., and P. J. Whitehead. 2003. Caring for country and sustainable Indigenous development: Opportunities, constraints and innovation. CAEPR Working paper No. 20/2003. Centre for Aboriginal Economic Policy Research (CAEPR), Canberra.

Arthur, B., and F. Morphy. 2019. Macquarie Atlas of Indigenous Australia. Macquarie.

Australian Bureau of Statistics. 2016. 2016 Census QuickStats: Yirrkala.

Australian Federal Government. 2020. Indigenous Protected Areas. Department of Agriculture, Water and the Environment.

Bannister, H. L. 2019. Release protocols and release environment: what influences reintroduction success for the brushtail possum. The University of Adelaide.

Bawaka Country, S. Suchet-Pearson, S. Wright, K. Lloyd, and L. Burarrwanga. 2013. Caring as Country: Towards an ontology of co-becoming in natural resource management. Asia Pacific Viewpoint **54**:185-197.

Begg, R., B. Walsh, F. Woerle, and S. King. 1983. Ecology of Melomys burtoni, the Grassland Melomys (Rodentia : Muridae) at Cobourg Peninsula, N.T. Wildlife Research **10**:259-267.

Berkes, F., J. Colding, and C. Folke. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications **10**:1251-1262.

Berndt, R. M. 1962. An adjustment movement in Arnhem Land Mouton, Paris.

Blacket, M. J., M. Adams, S. J. B. Cooper, C. Krajewski, and M. Westerman. 2001. Systematics and Evolution of the Dasyurid Marsupial Genus Sminthopsis: I. The Macroura Species Group. Journal of Mammalian Evolution **8**:149-170.

Bosso, L., S. Smeraldo, P. Rapuzzi, G. Sama, A. P. Garonna, and D. Russo. 2018. Nature protection areas of Europe are insufficient to preserve the threatened beetle *Rosalia alpina* (Coleoptera: Cerambycidae): evidence from species distribution models and conservation gap analysis. Ecological entomology **43**:192-203.

Bradley, J., M. Holmes, D. N. Marrngawi, J. M. Karrakayan, and I. Ninganga. 2006. Yumbulyumbulmantha ki-Awarawu. All kinds of things from country. Yanyuwa ethnobiological classification. University of Queensland, Brisbane, Australia.

Braithwaite, R. W., and A. D. Griffiths. 1994. Demographic variation and range contraction in the northern quoll, *Dasyurus hallucatus* (Marsupialia: Dasyuridae). Wildlife Research **21**:203-217.

Brennan, K. 2012. Black-footed Tree-rat https://nt.gov.au/__data/assets/pdf_file/0018/205515/black-footet-tree-rat.pdf.

Brook, R. K., and S. M. McLachlan. 2008. Trends and prospects for local knowledge in ecological and conservation research and monitoring. Biodiversity and Conservation **17**:3501-3512.

Bryant, M., Allan, P., Yarina, L. 2019. Applying and communicating indigenous land management knowledge systems and practices to climate change adaptation. Historic Environment **31**:36-48.

Burarrwanga, L., R. Ganambarr, M. Ganambarr-Stubbs, B. Ganambarr, D. Maymuru, S. Wright, S. Suchet-Pearson, and K. Lloyd. 2019. Songspirals: sharing women's wisdom of Country through songlines. Allen and Unwin, Sydney, Australia.

Burbidge, A. A., K. A. Johnson, P. J. Fuller, and R. I. Southgate. 1988. Aboriginal knowledge of the mammals of the central deserts of Australia. Wildlife Research **15**:9-39.

Burbidge, A. A., and N. L. McKenzie. 1989. Patterns in the modern decline of western Australia's vertebrate fauna: Causes and conservation implications. Biological Conservation **50**:143-198.

Burnett, S. 1997. Colonizing cane toads cause population declines in native predators: reliable anecdotal information and management implications. Pacific Conservation Biology **3**:65-72.

Cabrera-Guzmán, E., M. R. Crossland, D. Pearson, J. K. Webb, and R. Shine. 2015. Predation on invasive cane toads (*Rhinella marina*) by native Australian rodents. Journal of Pest Science **88**:143-153.

Calixto-Pérez, E., J. Alarcón-Guerrero, G. Ramos-Fernández, P. A. D. Dias, A. Rangel-Negrín, M. Améndola-Pimenta, C. Domingo, V. Arroyo-Rodríguez, G. Pozo-Montuy, B. Pinacho-Guendulain, T. Urquiza-Haas, P. Koleff, and E. Martínez-Meyer. 2018. Integrating expert knowledge and ecological niche models to estimate Mexican primates' distribution. Primates **59**:451-467.

Ceballos, G., P. R. Ehrlich, and R. Dirzo. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences **114**:E6089-E6096.

Commonwealth of Australia. 2020. EPBC Act Lists of Threatened Flora and Fauna. Department of Water, Agriculture and the Environment. Australia. https://www.environment.gov.au/cgibin/sprat/public/publicthreatenedlist.pl

Close, R. L., J. D. Murray, and D. A. Briscoe, editors. 1990. Electrophoretic and chromosome surveys of the taxa of short-nosed bandicoots within the genus *Isoodon*. Surrey Beatty, Chipping Norton, NSW.

Datta, R. 2018. Decolonizing both researcher and research and its effectiveness in Indigenous research. Research Ethics **14**:1-24.

Davies, H., S. Maier, and B. Murphy. 2020. Feral cats are more abundant under severe disturbance regimes in an Australian tropical savanna. Wildlife Research. Accepted Article.

Davies, H. F., M. A. McCarthy, R. S. C. Firth, J. C. Z. Woinarski, G. R. Gillespie, A. N. Andersen, H. M. Geyle, E. Nicholson, and B. P. Murphy. 2017. Top-down control of species distributions: feral cats driving the regional extinction of a threatened rodent in northern Australia. Diversity and Distributions **23**:272-283.

Davies, H. F., M. A. McCarthy, R. S. C. Firth, J. C. Z. Woinarski, G. R. Gillespie, A. N. Andersen, W. Rioli, J. Puruntatameri, W. Roberts, C. Kerinaiua, V. Kerinauia, K. B. Womatakimi, and B. P. Murphy. 2018. Declining populations in one of the last refuges for threatened mammal species in northern Australia. Austral ecology. **43**:602-612.

Dhal, K. 1897. Biological notes on north-Australian Mammalia. Zoologist **4**:189-216.

Dixon, J. M., and L. Huxley. 1985. Donald Thomson's Mammals and fishes of northern Australia. Nelson, Melbourne, Vic.

Dolrenry, S., L. Hazzah, and L. G. Frank. 2016. Conservation and monitoring of a persecuted African lion population by Maasai warriors. Conservation Biology **30**:467-475.

Draper, D., I. Marques, and J. M. Iriondo. 2019. Species distribution models with field validation, a key approach for successful selection of receptor sites in conservation translocations. Global Ecology and Conservation **19**:e00653.

El-Gabbas, A., and C. F. Dormann. 2018. Improved species-occurrence predictions in data-poor regions: using large-scale data and bias correction with down-weighted Poisson regression and Maxent. Ecography **41**:1161-1172.

Elith, J., and J. R. Leathwick. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution, and Systematics **40**:677-697.

Elith, J., S. J. Phillips, T. Hastie, M. Dudik, Y. E. Chee, and C. J. Yates. 2011. A statistical explanation of MaxEnt for ecologists.(Report). Diversity and Distributions **17**:43.

Ens, E., M. L. Scott, Y. M. Rangers, C. Moritz, and R. Pirzl. 2016. Putting indigenous conservation policy into practice delivers biodiversity and cultural benefits. Biodiversity and Conservation **25**:2889-2906.

Ens, E. J. 2012. Monitoring outcomes of environmental service provision in low socio-economic Indigenous Australia using innovative CyberTracker technology. Conservation and Society **10**:42-52.

Ens, E. J., M. Finlayson, K. Preuss, S. Jackson, and S. Holcombe. 2012. Australian approaches for managing 'country' using Indigenous and non-Indigenous knowledge. Ecological Management & Restoration **13**:100.

Ens, E. J., P. Pert, P. A. Clarke, M. Budden, L. Clubb, B. Doran, C. Douras, J. Gaikwad, B. Gott, and S. Leonard. 2015. Indigenous biocultural knowledge in ecosystem science and management: review and insight from Australia. **181**:133-149.

ESRI. 2018. ArcGIS Desktop: Release 10.6.1 Environmental Systems Research Institute, Redlands, California

Evangelista, P. H., A. M. Mohamed, I. A. Hussein, A. H. Saied, A. H. Mohammed, and N. E. Young. 2018. Integrating indigenous local knowledge and species distribution modeling to detect wildlife in Somaliland. Ecosphere **9**:e02134.

Evangelista, P. H., J. Norman, L. Berhanu, S. Kumar, and N. Alley. 2008. Predicting habitat suitability for the endemic mountain nyala (Tragelaphus buxtoni) in Ethiopia. Wildlife Research **35**:409-416.

Fijn, N. 2013. The nyiknyik or hopping mouse in Arnhem Land. Page https://vimeo.com/70926333.

Filho, R. F., T. Pinto, and B. M. Bezerra. 2018. Using local ecological knowledge to access the distribution of the Endangered Caatinga howler monkey (*Alouatta ululata*). Ethnobiology and Conservation **7**.

Fois, M., A. Cuena-Lombrana, G. Fenu, D. Cogoni, and G. Bacchetta. 2016. The reliability of conservation status assessments at regional level: past, present and future perspectives on *Gentiana lutea L. ssp. lutea* in Sardinia. Journal for Nature Conservation **33**:1-9.

Franklin, D. 2019. Northern Quoll https://bie.ala.org.au/species/urn:lsid:biodiversity.org.au:afd.taxon:5d7aeda8-2ec1-4111-830e-847f34321f88#gallery. Atlas of Living Australia

Freedman, L., and G. P. Rightmire. 1971. Skull and tooth variation in Australian bandicoots (Peramelidae, Marsupiala): the genus *Isoodon* and multivariate comparisons with *Perameles*. Journal of the Royal Society of Western Australia **54**:21-31.

Friend, G. R. 1987. Population Ecology of *Mesembriomys-Gouldii* (Rodentia, Muridae) in the Wet-Dry Tropics of the Northern-Territory. Wildlife Research **14**:293-303.

Friend, G. R., and J. A. Taylor. 1985. Habitat preferences of small mammals in tropical open-forest of the Northern Territory. Australian Journal of Ecology **10**:173-185.

Garnett, S. T., N. D. Burgess, J. E. Fa, Á. Fernández-Llamazares, Z. Molnár, C. J. Robinson, J. E. M. Watson, K. K. Zander, B. Austin, E. S. Brondizio, N. F. Collier, T. Duncan, E. Ellis, H. Geyle, M. V. Jackson, H. Jonas, P. Malmer, B. McGowan, A. Sivongxay, and I. Leiper. 2018. A spatial overview of the global importance of Indigenous lands for conservation. Nature Sustainability **1**:369-374.

Gorenflo, L. J., S. Romaine, R. A. Mittermeier, and K. Walker-Painemilla. 2012. Co-occurrence of linguistic and biological diversity in biodiversity hotspots and high biodiversity wilderness areas. Proceedings of the National Academy of Sciences **109**:8032-8037.

Heiniger, J., H. F. Davies, and G. R. Gillespie. 2020. Status of mammals on Groote Eylandt: Safe haven or slow burn? Austral Ecology **n/a**.

Hill, B., and S. Ward. 2010. National Recovery Plan for the Northern Quoll *Dasyurus hallucatus*. Department of Natural Resources, Environment, The Arts and Sport, Darwin, Asutralia.

Hill, R., L. C. Cullen-Unsworth, L. D. Talbot, and S. McIntyre-Tamwoy. 2011. Empowering Indigenous peoples' biocultural diversity through World Heritage cultural landscapes: a case study from the Australian humid tropical forests. International Journal of Heritage Studies **17**:571-591.

Huntington, H. P. 2000. Using Traditional Ecological Knowledge in science: Methods and applications. Ecological Applications **10**:1270-1274.

ICSU, U. a. 2002. Science, Traditional Knowledge and Sustainable Development. Paris.

IPBES. 2019. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science- Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, Germany.

Jentoft, S., H. Minde, and R. Nilsen. 2003. Indigenous peoples: resource management and global rights. Eburon Uitgeverij BV.

Jolly, C. J., E. Kelly, G. R. Gillespie, B. Phillips, and J. K. Webb. 2018. Out of the frying pan: Reintroduction of toad-smart northern quolls to southern Kakadu National Park. Austral Ecology **43**:139-149.

Kaky, E., and F. Gilbert. 2016. Using species distribution models to assess the importance of Egypt's protected areas for the conservation of medicinal plants. Journal of Arid Environments **135**:140-146.

Kebede, F., A. Bekele, P. D. Moehlman, and P. H. Evangelista. 2012. Endangered Grevy's zebra in the Alledeghi Wildlife Reserve, Ethiopia: species distribution modeling for the determination of optimum habitat. Endangered Species Research **17**:237-244.

Kelly, E., and B. L. Phillips. 2019. Targeted gene flow and rapid adaptation in an endangered marsupial. Conservation Biology **33**:112-121.

Kerins, S. 2010. The future of homelands/outstations [Paper in: The Heartland: Voices from Central Australia: Part 2. Job, Peg (ed).]. Dialogue (Academy of the Social Sciences in Australia) **29**:52.

Kerle, J. A. 2008. Grassland Melomys, Melomys burtoni. .*in* S. Van Dyck and R. Strahan, editors. The mammals of Australia. Reed New Holland, Sydney, Australia.

Kerle, J. A., and R. A. How. 2008. Common brushtail possum, *Trichosurus vulpecula*. Page 887 *in* S. Van Dyck and R. Strahan, editors. The Mammals of Australia. Reed New Holland, Sydney.

Kerle, J. A., G. M. McKay, and G. B. Sharman. 1991. A Systematic Analysis of the Brushtail Possum, *Trichosurus vulpecula* (Kerr, 1792) (Marsupialia, Phalangeridae). Australian Journal of Zoology **39**:313-331.

Kuhnert, P. M., T. G. Martin, and S. P. Griffiths. 2010. A guide to eliciting and using expert knowledge in Bayesian ecological models. Pages 900-914, Oxford, UK.

Lawes, M., D. Fisher, C. Johnson, S. Blomberg, A. Frank, S. Fritz, H. McCallum, J. Vanderwal, B. Abbott, S. Legge, M. Letnic, C. Thomas, N. Thurgate, A. Fisher, I. Gordon, and A. Kutt. 2015. Correlates of Recent Declines of Rodents in Northern and Southern Australia: Habitat Structure Is Critical. PLOS ONE **10**:e0130626.

Le Lay, G., R. Engler, E. Franc, and A. Guisan. 2010. Prospective sampling based on model ensembles improves the detection of rare species. Ecography **33**:1015-1027.

Leahy, L., S. M. Legge, K. Tuft, H. W. McGregor, L. A. Barmuta, M. E. Jones, and C. N. Johnson. 2016. Amplified predation after fire suppresses rodent populations in Australia's tropical savannas. Wildlife Research **42**:705-716.

Legge, S., M. S. Kennedy, R. Lloyd, S. A. Murphy, and A. Fisher. 2011. Rapid recovery of mammal fauna in the central Kimberley, northern Australia, following the removal of introduced herbivores. Austral Ecology **36**:791-799.

Legge, S., B. Murphy, H. McGregor, J. Woinarski, J. Augusteyn, G. Ballard, M. Baseler, T. Buckmaster, C. R. Dickman, and T. Doherty. 2017. Enumerating a continental-scale threat: how many feral cats are in Australia? Biological Conservation **206**:293-303.

Liedloff, A. C., J. C. Wilson, and R. M. Engeman. 2018. The effect of wildfire on population dynamics for two native small mammal species in a coastal heathland in Queensland, Australia. Acta Oecologica **88**:58-64.

Lomolino, M. V., and R. Channell. 1995. Splendid isolation: patterns of geographic range collapse in endangered mammals. Journal of Mammalogy **76**:335-347.

López-Arévalo, H. F., S. Gallina, R. Landgrave, E. Martínez-Meyer, and L. E. Muñoz-Villers. 2011. Local knowledge and species distribution models' contribution towards mammalian conservation. Biological Conservation **144**:1451-1463.

Mackey, B., and D. Claudie. 2015. Points of contact: integrating traditional and scientific knowledge for biocultural conservation. Environmental Ethics **37**:341-357.

Maddock, K. 1972. The Australian Aborigines: A portrait of their society. Allen, London.

Maffi, L. 2001. On biocultural diversity: Linking language, knowledge, and the environment. Smithsonian Inst Pr.

Maffi, L. 2007. Biocultural diversity and sustainability. The Sage handbook of environment and society. London: SLE Pound:267-277.

Maffi, L., and E. Woodley. 2012. Biocultural diversity conservation: a global sourcebook. Routledge.

Mailhot, J. 1994. Traditional Ecological Knowledge: The Diversity of Knowledge Systems and their Study. Great Whale Review, Montreal.

McConvell, P., and N. A. Thieberger. 2006. Keeping track of Indigenous language endangerment in Australia. Language diversity in the Pacific: Endangerment and survival. Multilingual Matters Ltd.

McGregor, H., S. Legge, M. Jones, and C. Johnson. 2015. Feral Cats Are Better Killers in Open Habitats, Revealed by Animal-Borne Video. PLOS ONE **10**:e0133915.

Mckay, L. 2017. A guide to wildlife and protected areas of the top end. The Environment Centre Northern Territory, Darwin, Australia.

McKenzie, N., A. Burbidge, A. Baynes, R. Brereton, C. Dickman, G. Gordon, L. Gibson, P. Menkhorst, A. Robinson, and M. Williams. 2007. Analysis of factors implicated in the recent decline of Australia's mammal fauna. Journal of Biogeography **34**:597-611.

Menkhorst, P., and F. Knight. 2011. A field guide to the mammals of Australia. 3rd edition. Oxford University Press, Oxford.

Miranda, E. B. P., J. F. S. Menezes, C. C. L. Farias, C. Munn, and C. A. Peres. 2019. Species distribution modeling reveals strongholds and potential reintroduction areas for the world's largest eagle. PLOS ONE **14**:e0216323.

Moritz, C., E. J. Ens, S. Potter, and R. A. Catullo. 2013. The Australian monsoonal tropics: an opportunity to protect unique biodiversity and secure benefits for Aboriginal communities. Pacific Conservation Biology **19**:343-355.

Morphy, F., editor. 2017. Australia's Indigenous Protected Areas: Reisstance, Articulaton and Entanglement in the Context of Natural Resource Management University of Toronto Press, Toronto.

Morphy, H. 1983. "Now you understand": An analysis of the way Yolngu have used sacred knowledge to retain their autonomy *in* N. Peterson and M. Langton, editors. Aborigines, land, and land rights. Australian Institute of of Aboriginal Studies, Canberra.

Morphy, H. 1991. Ancestral connections; art and an aboriginal system of knowledge. The University of Chicago Press, Chicago, USA.

Nadasdy, P. 1999. The Politics of Tek: Power and the "Integration" of Knowledge. Arctic Anthropology **36**:1-18.
National Indigenous Australians Agency. 2020. Indigenous Rangers - Working on Country.*in* A. Goverment, editor.
Oakwood, M. 1997. The ecology of the northern quoll, Dasyurus hallucatus.
Oakwood, M., J. Woinarski, and S. Burnett. 2016. *Dasyurus hallucatus*. The IUCN Red List of Threatened Species.
Palmer, C., J. Woinarski, and B. Hill. 2012. Golden Bandicoot: Isoodon aurutus. Darwin, Australia. .
Pardon, L. G., B. W. Brook, A. D. Griffiths, and R. W. Braithwaite. 2003. Determinants of survival for the northern brown bandicoot under a landscape-scale fire experiment. Journal of Animal Ecology **72**:106-115.
Perry, J. J., E. P. Vanderduys, and A. S. Kutt. 2015. More famine than feast: pattern and variation in a potentially degenerating mammal fauna on Cape York Peninsula. Wildlife Research **42**:475-487, 413.
Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological modelling **190**:231-259.
Pierrotti, R. 2011. Indigenous Knowledge, Ecology and Evolutionary Biology. Taylor and Francis, New York.
Pimm, S. L., C. N. Jenkins, R. Abell, T. M. Brooks, J. L. Gittleman, L. N. Joppa, P. H. Raven, C. M. Roberts, and J. O. Sexton. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science **344**:1246752.
Polfus, J. L., K. Heinemeyer, and M. Hebblewhite. 2014. Comparing traditional ecological knowledge and western science woodland caribou habitat models. Journal of Wildlife Management **78**:112-121.
Pope, L., D. Storch, M. Adams, C. Moritz, and G. Gordon. 2001. A phylogeny for the genus *Isoodon* and a range extension for *I. obesulus* peninsulae based on mtDNA control region and morphology. Australian Journal of Zoology **49**:411-434.
Price, O., B. Rankmore, D. Milne, C. Brock, C. Tynan, L. Kean, and L. Roeger. 2005. Regional patterns of mammal abundance and their relationship to landscape variables in eucalypt woodlands near Darwin, northern Australia. Wildlife Research **32**:435-446.
Rankmore, B. 2006. Impacts of habitat fragmentation on the vertebrate fauna of the tropical savannas of northern Australia; with special reference to medium-sized mammals., Charles Darwin University., Darwin, Australia. .
Rankmore, B. R., A. D. Griffiths, J. C. Z. Woinarski, B. L. Ganambarr, R. Taylor, K. Brennan, K. Firestone, and M. and Cardoso. 2008. Island translocation of the northern quoll *Dasyurus hallucatus* as a conservation response to the spread of the cane toad *Chaunus (Bufo) marinus* in the Northern Territory, Australia. Report to the Natural Heritage Trust.
Rose, D., D. Bell, and D. A. Crook. 2016. Restoring habitat and cultural practice in Australia's oldest and largest traditional aquaculture system. Reviews in Fish Biology and Fisheries **26**:589-600.
Russell-Smith, J., C. Yates, A. Edwards, G. E. Allan, G. D. Cook, P. Cooke, R. Craig, B. Heath, and R. Smith. 2003. Contemporary fire regimes of northern Australia, 1997–2001: change since Aboriginal occupancy, challenges for sustainable management. International Journal of Wildland Fire **12**:283-297.
Schecter, G. 2011. Common Brushtail Possum. CC BY 2.0. https://creativecommons.org/licenses/by/2.0/au/. Page GregTheBusker_(1).jpg, WikimediaCommons.
Setterfield, S. A., N. A. Rossiter-Rachor, L. B. Hutley, M. M. Douglas, and R. J. Williams. 2010. BIODIVERSITY RESEARCH: Turning up the heat: the impacts of *Andropogon gayanus* (gamba

grass) invasion on fire behaviour in northern Australian savannas. Diversity and Distributions **16**:854-861.
Simons, G. F. 2019. Two centuries of spreading language loss. 2019 **4(1)**:27-21.
Skroblin, A., T. Carboon, G. Bidu, N. Chapman, M. Miller, K. Taylor, W. Taylor, E. T. Game, and B. A. Wintle. 2019. Including Indigenous knowledge in species distribution modelling for increased ecological insights. Conservation Biology **Accepted Manuscript**.
Smith, L. T. 2013. Decolonizing methodologies: Research and indigenous peoples. Zed Books Ltd.
Soberón, J. 2007. Grinnellian and Eltonian niches and geographic distributions of species. Ecology Letters **10**:1115-1123.
Specht, R. L. 1964. Records of the American-Australian Scientific Expedition to Arnhem Land, Volume 4: Zoology. Melbourne University Press, Melbourne.
Start, A., A. Burbidge, M. McDowell, and N. McKenzie. 2012. The status of non-volant mammals along a rainfall gradient in the south-west Kimberley, Western Australia. Australian Mammalogy **34**:36-48.
Stobo-Wilson, A. M., B. P. Murphy, T. Cremona, and S. M. Carthew. 2019. Contrasting patterns of decline in two arboreal marsupials from Northern Australia. Biodiversity and Conservation **28**:2951-2965.
Sutherland, W. J. 2003. Parallel extinction risk and global distribution of languages and species. Nature **423**:276.
Threatened Species Recovery Hub. 2018. Top 20 Australian mammals and birds at risk of extinction. National Environmentaal Science Programme.
Urban, M., B. Phillips, D. Skelly, and R. Shine. 2008. A Toad More Traveled: The Heterogeneous Invasion Dynamics of Cane Toads in Australia. The American Naturalist **171**:E134-E148.
VanDerWal, J. 2012. All future climate layers for Australia - 5km resolution.*in* J. C. University, editor., Queensland.
Vessella, F., J. López-Tirado, M. C. Simeone, B. Schirone, and P. J. Hidalgo. 2017. A tree species range in the face of climate change: cork oak as a study case for the Mediterranean biome. European Journal of Forest Research **136**:555-569.
Waddy, J. A. 1988. Classification of plants and animals from a Groote Eylandt Aboriginal point of view. Darwin, Australia.
Watson, M., and J. Woinarski. 2003. Vertebrate monitoring and re-sampling in Kakadu National Park, 2002. Report to Parks Australia.Tropical Savannas Cooperative Research Centre, Darwin, NT.
Wayne, A., B. Wilson, and J. Woinarski. 2017. Falling apart? Insights and lessons from three recent studies documenting rapid and severe decline in terrestrial mammal assemblages of northern, south-eastern and south-Western Australia. Wildlife Research **44**.
Webb, J. K., D. Pearson, and R. Shine. 2011. A small dasyurid predator (*Sminthopsis virginiae*) rapidly learns to avoid a toxic invader. Wildlife Research **38**:726-731.
Wilder, B. T., C. O'Meara, L. Monti, and G. P. Nabhan. 2016. The Importance of Indigenous Knowledge in Curbing the Loss of Language and Biodiversity. BioScience **66**:499-509.
Williams, N. 1986. The Yolŋu and their land: A system of land tenure and fight for its recognition. Stanford University Press, Stanford, California.
Wohling, M. 2009. The problem of scale in indigenous knowledge: a perspective from northern Australia. Ecology and Society **14**.
Woinarski, J. C. Z., M. F. Braby, A. A. Burbidge, D. Coates, S. T. Garnett, R. J. Fensham, S. M. Legge, N. L. McKenzie, J. L. Silcock, and B. P. Murphy. 2019. Reading the black book: The number, timing, distribution and causes of listed extinctions in Australia. Biological Conservation **239**:14.

Woinarski, J., A. Burbidge, and P. Harrison. 2014. Action Plan for Australian Mammals 2012. CSIRO Publishing. Collingwood.

Woinarski, J. C., S. Legge, J. A. Fitzsimons, B. J. Traill, A. A. Burbidge, A. Fisher, R. S. Firth, I. J. Gordon, A. D. Griffiths, and C. N. Johnson. 2011. The disappearing mammal fauna of northern Australia: context, cause, and response. Conservation Letters **4**:192-201.

Woinarski, J. C. Z. 2015. Critical-weight-range marsupials in northern Australia are declining: a commentary on Fisher et al. (2014) 'The current decline of tropical marsupials in Australia: is history repeating?'. Global Ecology and Biogeography **24**:118-122.

Woinarski, J. C. Z., M. Armstrong, K. Brennan, A. Fisher, A. D. Griffiths, B. Hill, D. J. Milne, C. Palmer, S. Ward, M. Watson, S. Winderlich, and S. Young. 2010. Monitoring indicates rapid and severe decline of native small mammals in Kakadu National Park, northern Australia. Wildlife Research **37**:116-126.

Woinarski, J. C. Z., A. A. Burbidge, and P. L. Harrison. 2015. Ongoing unraveling of a continental fauna: Decline and extinction of Australian mammals since European settlement. Proceedings of the National Academy of Sciences of the United States of America **112**:4531-4540.

Woinarski, J. C. Z., D. J. Milne, and G. Wanganeen. 2001. Changes in mammal populations in relatively intact landscapes of Kakadu National Park, Northern Territory, Australia. Austral Ecology **26**:360-370.

Woinarski, J. C. Z., M. Oakwood, J. Winter, S. Burnett, D. Milne, P. Foster, H. Myles, and B. Holmes. 2008. Surviving the toads: patterns of persistence of the northern quoll *Dasyurus hallucatus* in Queensland. Report to the Australian Government's Natural Heritage Trust.

Woolley, P. A. 2008. Red-cheeked Dunnart, *Sminthopsis virginiae*. Pages 158-159 *in* S. Van Dyck and R. Strahan, editors. The mammals of Australia. Reed New Holland, Sydney, Australia.

Yirralka Rangers. 2014. Keeping Country: Putting both wasy culture into practice. em PRESS Publishing, Victoria, Australia.

Yirralka Rangers. 2017. Laynhapuy Indigenous Protected Area Management Plan (2017-2022).

Ziembicki, M. R., J. C. Z. Woinarski, and B. Mackey. 2013. Evaluating the status of species using Indigenous knowledge: Novel evidence for major native mammal declines in northern Australia. Biological Conservation **157**:78-92.

Appendices

Appendix 1 - *Yolŋu-matha* Orthography

The following pronunciation guide was adopted from the Yirralka Rangers Management Plan 2017-2022 (Yirralka Rangers 2017), to assist those who are not familiar with *Yolŋu-matha.*

ŋ Pronounced like the 'ng' in ring

ng Pronounce the 'n' and 'g' separately

th, nh, dh Don't pronounce the 'h' but place the tip of the tongue between the front teeth to pronounce the 'd', 't' or 'n'

r, d, n, l, t Pronounced with the tip of the tongue backwards toward the roof of the mouth

rr Pronounced by rolling the 'r'

ny Pronounced like the first 'n' sound in onion

dj, tj Don't pronounce the j, and pronounce the 'd' or 't' with the tongue in the same position as for 'ny' above

ä (Long) pronounced like the 'a' in father

a (Short) pronounced like the 'u' in but

e (Long) pronounced like the 'ee' in feet

i (Short) pronounced like the 'i' in hit

o (Long) pronounced like the 'aw' in dawn

u (Short) pronounced like the 'u' in put

Appendix 2 - Glossary of *Yolŋu-matha* terms featured in this thesis. Most spellings where multiple versions existed, are taken from the online Charles Darwin University *Yolŋu Matha Dictionary* (http://yolngudictionary.cdu.edu.au/). Words that were recorded during this study, that were not found in this dictionary or elsewhere are signified by an * where they first appear.

Yolŋu	**English**
Yolŋu	Human beings. All speakers of Yolŋu matha dialects / the term used by these speakers to refer to themselves.
Matha	Lit. Tougue, speech. Language (or dialect).
Dhuwa/ Yirritja	Complementary patrimoieties. Everything in the Yolŋu universe fits into one of these two moieties. (inherited patrilinearly).
Bäpurru	Clan; group of people linked through patrilineal descent, and have shared estates.
Dalkarra	Regional ritual specialist.
Waŋarr	Spiritual ancestors, now embodied in the landscape.
Rom	Yolŋu law, passed down from spiritual ancestors.
Yo	Yes
Yaka	No
Ga	And
Bäyŋu	None / nothing
Balanda /ŋapaki	Non-indigenous Australian
Mulmu	grass
Nuwayak	bark painting
Larrakitj	Mortuaray/ funerary pole
Dharpa	Wood sculptures / log/ stick
Bulkun	Possum fur string
Buŋgul	Ceremony /dance
Warrk	Traditional time of hunting using fire.

Appendix -3 Summary table of IBK of the study species recorded in interviews with *Yolŋu* knowledge holders.

Scientific name	***I. macrourus***	***T. vulpecula***	***D. hallucatus***	***S. virginae***	***M. burtoni***	***M. gouldii***
***Yolŋu* name**	***wan'kurra***	***marrŋu / rupu***	***barkuma / warral***	***nyiknyik / guthin***	***nyiknyik***	***dhuliumbarr***
Observed <20yrs/>20-40	6/9	7/6	2/6	3/2	9/6	3/0
Never seen /no comment	0	3	7	10	0	12
Associated habitat	Flood plains, eucalypt woodland, rocky habitat.	Wood/ bushland areas, jungle, forages in mangroves. Near water bodies.	Rocky areas, plains, flood plains, *Pandanus* sp. assemblages.	Flood plains. Swamps.	Pandanus assembledges along creek lines. Fresh water assemblages.	Creek lines, *Pandanus* sp. assemblages.
Behavioural ecology	Builds nest out of long grass on the ground in a slight depression. Weans young in nest.	Lives in tree hollows, can be detected via scratch marks on tree trunks.	Forages for food in the mangroves. Hides in rocky areas.	Digs burrows underground.	Creates nests in pandanus trees.	Largely unknown. Forages in mangroves, lives in *Pandanus* sp.
Threats	Cane toads, fire, pythons.	Not identified.	Cane toads, climate change.	Not identified.	Not identified.	Not identified.
Material use	Hunted for food (present and past) and fur (past).	Hunted for food and fur (past and potentially present).	Hunted for food (past).	Few respondents reported consumption of this species. (past)	Not identified.	Used as fishing bait (isolated event).
Cultural significance	**Associated with:** *Wangurri, Maḏarrpa Dhalawaŋu, Maŋgalili, Gumatj.* **Connected to:** Djarrakpi, Dhalinybuy, Baniyala, Burrum.	**Associated with:** *Maŋgalili, Rhittarrŋu, Munyuku, Dhalawaŋu, Maḏarrpa.* **Connected to:** Djarakpi, Doyndjii.	Largely unknown. Could have been connected to Baniyala.	Potentially same as the *nyiknyik*. **Connected to**: Dhalinbuy and Mäpuru.	**Associated with:** *Wangurri,Maḏarrpa, Maŋgalili, Dhalawaŋu.* **Connected to**: Dhalinbuy, Baniyala, Warrawar (near Mäpuru).	Largely unknown. Could be connected to *nyiknyik.*

Appendix 4 - Environmental variables used as predictors in the species distribution models.

Variable	Description	Source type	Source	Resolution
B01	Annual mean temperature	Continuous	Australia, current climate (1976-2005) (VanDerWal 2012)	30 arcsec (~1 km)
B05	Maximum temperature of warmest month	Continuous	"	30 arcsec (~1 km)
B06	Minimum temperature of the coldest month	Continuous	"	30 arcsec (~1 km)
B012	Annual precipitation	Continuous	"	30 arcsec (~1 km)
B013	Precipitation of the wettest month	Continuous	"	30 arcsec (~1 km)
B014	precipitation of the driest month	Continuous	"	30 arcsec (~1 km)
B015	Precipitation Seasonality	Continuous	"	30 arcsec (~1 km)
Elevation	9 arcsec (~250m) DEM	Continuous	(Hutchinson et al. 2008)	9 arcsec (~250m)
Vegetation	Australia, Major Vegetation Groups – present (2016)	Categorical	NVIS v 5.1 (Commonwealth of Australia, Department of Environment and Energy, 2008)	3 arcsec (~90 m)
Soil type	Australian Soil Classification	Categorical	Australia, National Soil Grids (2012) (ACLEP, endorsed by NCST)	9 arcsec (~250 m)
Soil clay content	Clay content percentage (0-30cm)	Continuous	"	9 arcsec (~250 m)
Soil moisture	Plant available water capacity (0-1m)	Continuous	"	9 arcsec (~250 m)

Appendix – 5 Table of Maxent default configuration settings on the BCCVL used for the *wan'kurra* and *marrŋu* models.

Maxent configurations	**Value**
Maximum number of iterations	200
Product/threshold feature threshold	80
Quadratic feature threshold	10
Hinge feature threshold	15
Threshold feature regularization (beta_threshold)	-1.0
Categorical feature regularization (beta_categorical)	-1.0
Linear/quadratic/product feature regularization (beta_lqp)	-1.0
Hinge feature regularization (beta_hinge)	-1.0
Regularization multiplier (betamultiplier)	1.0
Prevalence	0.5

Appendix -6 Human ethics approval granted by Macquarie University Human Research Ethics Committee (HREC).

Office of the Deputy Vice-Chancellor
(Research)

Research Services
Research Hub, Building C5C East
Macquarie University
NSW 2109 Australia
T: +61 (2) 9850 4459
http://www.research.mq.edu.au/
ABN 90 952 801 237

MACQUARIE University
SYDNEY·AUSTRALIA

17 April 2018

Dear Dr. Ens

Reference No: 5201800178

Title: *Cross-cultural biodiversity surveys in eastern Arnhem Land*

Thank you for submitting the above application for ethical and scientific review. Macquarie University Human Research Ethics Committee (HREC) (Human Sciences & Humanities) considered your application.

I am pleased to advise that ethical and scientific approval has been granted for this project to be conducted by Mr Ben Kitchener, Ms Bridget Campbell and Ms Rukshana Sultana under the supervision of Dr. Emilie Ens.

Approval Date: 17 April 2018

This research meets the requirements set out in the *National Statement on Ethical Conduct in Human Research* (2007 – Updated May 2015) (the *National Statement*).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the *National Statement,* which is available at the following website:

http://www.nhmrc.gov.au/book/national-statement-ethical-conduct-human-research

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol.

3. All adverse events, including events which might affect the continued ethical and scientific acceptability of the project, must be reported to the HREC within 72 hours.

4. Proposed changes to the protocol and associated documents must be submitted to the Committee for approval before implementation.

It is the responsibility of the Chief investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Ethics Secretariat on 9850 4194 or by email ethics.secretariat@mq.edu.au

The HREC (Human Sciences and Humanities) Terms of Reference and Standard Operating Procedures are available from the Research Office website at:

https://www.mq.edu.au/research/ethics-integrity-and-policies/ethics/human-ethics

The HREC (Human Sciences and Humanities) wishes you every success in your research.

Yours sincerely

[redacted]

Dr Karolyn White
Director, Research Ethics & Integrity,
Chair, Human Research Ethics Committee (Human Sciences and Humanities)

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research* (2007) and the *CPMP/ICH Note for Guidance on Good Clinical Practice*.