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The ecology and conservation of the water mouse (*Xeromys myoides*) along the Maroochy River Catchment in southeast Queensland.

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Abstract

The water mouse is one of Australia's most enigmatic, intriguing and little-known vertebrate species. It is also in decline and confronted with a wide range of threats. Locally, the demise of one water mouse population along the Coomera River was documented in 2006 within an area where urban and industrial development pressures are paramount for this species and their associated habitat. Improvement of its conservation status is supported by a National Recovery Plan aimed at habitat protection. However, direct human actions threatening water mouse recovery are poorly monitored and inhibit conservation efforts. Therefore, new research methods are required that include an understanding of population dynamics, gestation cycles, but most importantly, the life span of this elusive species as the additional knowledge on this species association to habitat is critical to its survival.

In order to address these deficiencies, logically developed research projects form the framework of this thesis that link new locality records of the species distribution and density across southeast Queensland. The exhausted survey efforts located 352 nests in coastal wetlands between Eurimbula National Park and the Pumicestone Passage to determine the species nest structure and association with plant presence. Consistent monitoring of individual water mouse nests investigated nest building and seasonal behavior; movements and habitat use of the water mouse; impacts and management of foxes, pigs and cats within water mouse territory. Demonstrating that long-term monitoring shows evidence of adverse effects to water mouse nests and presence, by exploring the species behavioral response to changing weather events in its natural environment. Finally, the results confirm the primary factors that are contributing to this species' decline through poor adjacent land management.

This thesis is the first comprehensive research that addresses the '*conservation and ecology of the water mouse in southeast Queensland'*.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in this thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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Publications included in this thesis

The following information identifies the publication included as a chapter in this thesis and provides an overview of the contributions made by others to these publications. Additional description of those who assisted in the collaborative works can be found in the 'Acknowledgements' section of the published article.

Publication citation – incorporated as Chapter 3.

Kaluza, J, Donald, RL, Gynther, IC, Leung, LK-P and Allen, BL 2016, The Distribution and Density of Water Mice (*Xeromys myoides*) in the Maroochy River of Southeast Queensland, Australia. PLoS ONE 11(1): e0146133. https://doi.org/10.1371/journal.pone.0146133

Contributor	Statement of contribution
Kaluza J (Candidate)	Conceived/designed study 100% Conducted field work 80% Conducted statistical analysis 60% Wrote the paper 70%
Allen B Allen B Gynther I Leung L	Conducted statistical analysis 40% Edited the paper (10%) Edited the paper (10%) Edited the paper (10%)
Donald R	Conducted field work 20%

Manuscripts included in this thesis

The following information identifies the draft publications included as chapters in this thesis and provides an overview of the contributions made by others to these publications. Additional description of those who assisted in the collaborative works can be found in the 'Acknowledgements' section.

Chapter 4

Kaluza, J, Howden, C, Allen, BL & McCallum, AB Characteristics of water mouse nest structures in southeast Queensland, Australia: vegetation associations and physical dimensions. Pending publication

Contributor	*Statement of contribution*
Kaluza J (Candidate)	Conceived/designed the study (100%) Conducted field work (100%) Conducted statistical analysis (60%) Wrote the paper (70%)
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Chapter 5

Kaluza, J, Gramotnev, G, Gramotnev, D, Leung, LK-P & McCallum, AB A longitudinal study of water mice activity and behavior: interrelated to atmospheric conditions. In review.

Contributor	*Statement of contribution*
Kaluza J (Candidate)	Conceived/designed the study (100%) Conducted the field work (100%) Conducted statistical analysis (50%) Wrote the paper (55%)
Leung K-L McCallum AB Gramotnev G Gramotnev D	Edited and wrote the paper (5%) Edited and wrote the paper (15%) Conducted statistical analysis (50%) Wrote the paper (25%)

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Conference presentations during candidature

1. Kaluza, J, Donald, RL, Gynther, I, Leung, LK-P & Allen, BL 2014, The distribution and density of water mice in the Maroochy River system of southeast Queensland, Australia. ***Proceedings of the Australasian Wildlife Mammal Society Conference***, Brisbane.

2. Kaluza, J, Donald, RL, Gynther, I, Leung, LK-P & Allen, BL 2016, Nests, Mounds and Middens – a tale of water mouse survival along the coastal wetlands of southeast Queensland, Australia. ***Proceedings of the Australasian Wildlife Mammal Society Conference***, Auckland, New Zealand.

3. Kaluza, J, Gynther, I, Allen BL & McGrath, T 2017, A revised water mouse National Recovery Plan to assist in the development of Threatened Species Recovery Fund. Held 23 March 2017 at the Queensland Herbarium; by the Department of Environment and Energy, Canberra: Commonwealth Government of Australia.

Media release

1. Totally Wild Season 25 Episode 65: Air Date: Thu 21 Jun 2018: https://tenplay.com.au/channel-eleven/totally-wild

2. ABC Radio: http://www.abc.net.au/news/2017-12-14/foxes-prey-on-vulnerable-water-mouse/9259190

Technical reports

1. Kaluza, J 2012, A survey report for *Xeromys myoides* at Bells Creek. Sunshine Coast Regional Council and WetlandCare Australia (WetlandCare Australia, Ballina, NSW).

2. Kaluza, J 2012, A survey report for *Xeromys myoides* at Hussey Creek. Sunshine Coast Regional Council and WetlandCare Australia (WetlandCare Australia, Ballina, NSW).

3. Kaluza, J 2012, A survey report for *Xeromys myoides* at Glasshouse Mountain. Sunshine Coast Regional Council and WetlandCare Australia (WetlandCare Australia, Ballina, NSW).

4. Kaluza, J 2013, A report on *Xeromys myoides* for Sunshine Coast Regional Council; Pelican Waters: A survey, with recommendations for SCRC (Sunshine Coast, Queensland).

5. Kaluza, J 2014, Bli Bli Boardwalk Waigani Street, Wetlands Restoration Advice Feasibility Assessment, Maroochy River: habitat assessment with recommendations (Sunshine Coast Regional Council, Queensland).

6. Kaluza, J & Bolzenius C 2015 Nest distribution of *Xeromys myoides* on Russell Island: A survey, with recommendations for WetlandCare Australia and Redland City Council Conservation Initiative. (WetlandCare Australia, Ballina, NSW).

7. Kaluza, J 2015, Wetlands Australia, National Wetlands Update August 2015 - Issue No 27, Commonwealth of Australia 2015. (EHP, Canberra).

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9. McGrath, T & Kaluza, J, et al. 2015, Referral guideline for the vulnerable water mouse, Commonwealth of Australia 2015. Contributing third party of data on adverse effects for the water mouse. (EPBC Act Policy Statement, Canberra).

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11. Kaluza, J & Bolzenius, C 2016, Gold Coast City Council water mouse survey. Absence or presence findings. (Gold Coast City Council, Gold Coast and WetlandCare Australia, Ballina NSW).

12. Kaluza, J 2016, Logan City Council water mouse survey. Absence or presence findings. (Logan City Council, Brisbane and WetlandCare Australia, Ballina NSW).

Contributions by others to the thesis

All contributions to this thesis are identified below for chapters four to six and in the 'Acknowledgements' section of chapter three, included and associated with this thesis. No additional contributions were made beyond these.

Statement of parts of the thesis submitted to qualify for the award of another degree

None.

Research Involving Human or Animal Subjects

Ethics statement

Water mice are protected and presently listed as 'vulnerable' under the Federal Environment Protection and Biodiversity Conservation Act (1999) and are supported by a National Recovery Plan (DERM 2010). Permission to enter the study sites was granted by the Queensland Parks and Wildlife Service (QPWS) and Marine Parks Authority, and private landholders (MPP QS2015/GS033; WISP15971115; TWB/12/2015; WITK16035715; WITK16215415). The project was approved by the Animal Ethics Committee of Agriculture, Forestry and Fisheries (DAFF) (AEC permit number: CA 2014/08/797), and the project was undertaken in accordance with this approval. As seen in Appendixes 1 to 6.

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Xeromys myoides, water mouse, false water rat, Yirkoo, National Recovery Plan, behaviour, climate, nest activity, camera trapping, conservation status.

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Table of Contents

List of Figures

Chapter 1.

Chapter 2.

Chapter 3.

Chapter 4.

Chapter 5.

Chapter 6.

List of tables

List of abbreviations used in this thesis

AEC – Animal Ethics Committee

ANZSRC - Australian and New Zealand Standard Research Classification

ArcGIS - Aeronautical Reconnaissance Coverage Geographic Information System

ANZECC/ARMCANZ 2000 - Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand 2000

BOM – Bureau of Meteorology

BMRG – Burnett Mary Regional Group

DoEE – Department of Energy and Environment

DAFF - Department of Agriculture, Fisheries and Forestry

DEHP – Department of Environment and Heritage Protection

DEPA – Department of Environmental Protection Agency

DERM – Department of Environment and Resource Management

DES - Department of Environment and Sciences

DNA - Deoxyribonucleic acid

DSITI - Department of Science, Information Technology and Innovation

EILs - Environmental Investigation Levels

EPBC Act – Environment, Protection, Biodiversity and Conservation Act

ESRI - Environmental Systems Research Institute

GIS – Geographic Information System

GSEM - Generalised Structural Equation Modelling

GSS – Great Sandy Strait

MR – Maroochy River

MPP – Marine Park Permit

MNES - Matters of National Environmental Significance

NCA – Nature Conservation Act 1992

NRP – National Recovery Plan 2010

PP – Pumicestone Passage

QPWS – Queensland Parks and Wildlife Service

RE – Regional Ecosystem

SEM - Structural Equation Modelling

SEQ – South East Queensland Catchments Ltd

SCRC – Sunshine Coast Regional Council

TPWC - Territory Parks and Wildlife Conservation Act

WCA – WetlandCare Australia

WM – Water Mouse

WMN – Water Mouse Nest

Chapter 1

1.0 Introduction

Native to coastal wetlands in the Northern Territory, Queensland and Papua New Guinea, the water mouse was listed as a threatened species of concern in 1990, supported by the Queensland Nature Conservation Act (1992). The species is protected and listed as vulnerable under the Environment Protection Biodiversity and Conservation Act (1999) and its recovery is reinforced by Commonwealth Department of Environment, Resource Management in a National Recovery Plan (DERM 2010). However, little has been done to identify the threat since then. A population of water mouse occurs in the Maroochy River wetlands, but little is known of the ecology or threats to this population. Threats to the water mouse are thought to be associated with human activities and disturbance and are predicted to have intensified in the region over the last few years as the human population has grown (Higgins et al. 2006; Lee et al. 2006). Development to cater for this human population growth is taking place on the edge of intertidal zones (Rayment 2003; McDonald et al. 2006; Smith 2008), the water mouse's preferred habitat. A sound understanding of the distribution, population abundance and important factors affecting water mouse populations is useful to develop strategies for conserving the local water mouse population (Russell & Hale 2009; DERM 2010).

1.1 Water Mouse Biology

The biology of the water mouse was first documented during the discovery of the species in 1889 by Thomas, who found and collected specimens in freshwater wetlands of Beerwah State Forest in Southeast Queensland (THOMAS 1889). Redhead and McKean (1975) and Magnussen et al. (1976) located the species inhabiting saline wetlands along the coastline of the Northern Territory with additional new localities being recorded in Queensland (Van Dyck et al.1979; Van Dyck & Durbidge 1992) and Papua New Guinea (Hitchcock 1998). The water mouse forages nocturnally between low and high tides at night. Its diet consists mainly of crustacean, mollusk and flatworm. The species has unique nesting behavior, constructing nests above the elevated high tide mark in suitable nesting sites in saltmarsh and mangrove systems.

Little is known about their reproduction cycle; it is assumed to be similar to other members of the family Muridae. The water mouse may produce a litter of several (2-3) offspring twice a year with an approximate life expectancy of 3 years (Van Dyck & Gynther 2003). An adult water mouse is approximately 10.5 cm in total head, body and tail length with the tail slightly shorter than the head and body. The average body weight is 40 g. The eyes are small, and the ears are rounded and small (Van Dyck et al*.* 2006; Van Dyck & Gynther 2003; Benfer et al. 2014 and Kaluza et al. 2016). Their unique silky pelt is water and mud resistant with characteristic markings of a white underbelly and steel grey dorsal (Redhead & McKean 1975). White flecking can be found on the dorsal fur of mature adult mice. Human activities and development have been implicated as the cause for the decline in the distribution range of the species in the Southeast Queensland region (Van Dyck et al. 2006; Van Dyck & Gynther 2003; Benfer et al. 2014 and Kaluza et al. 2016) and prior to the present study, little was known of the species habitat. Camera traps have recently become a cost-effective method to observe the behavior of wildlife and these were deployed to study the behaviour of the water mouse.

1.2 Water Mouse Behavior

A wide range of nest structures are found in mammals (Van Dyke & Strahan 2008), indicating the evolutionary importance of nesting strategy in mammals. Many small mammals such as rodents, bandicoots, rabbits, and ground squirrels construct burrows in the ground for protection against the weather, flood, fire and predators. Prairie dogs excavate an elaborate system of tunnels over a large area spanning up to many thousand square kilometers with hundreds of millions of individuals living in it (Sierra–Corona 2015). Beavers are well known for their engineering ability to build dams, canals, and lodges with underwater entries; this is possibly the most elaborate nesting structure observed in mammals (Law et al. 2016).

In Australia, the most elaborate mammalian nest structure is constructed by the water mouse. This terrestrial rodent is considered unique because of its ability to adapt and utilize the entirety of a wetland system to its advantage. Primarily, the animal uses mud and plant material to build a termite style mound that is freestanding in intertidal areas of coastal saltmarsh and mangrove communities (Van Dyck & Gynther 2003). Several nest variations are constructed by the water mouse including mounds built around and/or inside a hollow trunk of the grey mangrove (*Avicennia marina var. australasica)*, internal use of tidal banks found typically beneath swamp oak (*Casuarina glauca*), or man-made or soil heap structures, typically located on the terrestrial fringe, resulting directly from adjacent land use practices. A distinctive mud daubing technique is used to construct and bind the nest (Van Dyck et al. 2006; Van Dyck & Gynther 2003; Benfer et al*.* 2014 and Kaluza et al. 2016). The construction method is time consuming and constant maintenance of the mound is required, by means of daubing mud. A nest typically consists of several internal chambers with external access holes that are convex and elliptical with smooth edges. Access points are typically (approximately) 5 cm in basal circumference with notable presence of fresh mud daubing. The positioning of these openings is possibly influenced by tidal occurrence and habitat.

Figure 1.1 Nest access points (top left), mud nest void of marine couch; height 650mm x basal circumference1.2m (top right), mud nest covered by marine couch; height 1.2m x 3.4m basal circumference (centre left), tree nest; height ≥500mm (centre right), bank nest (bottom left), inter-tidal bank nest; height 800mm x length 5m (bottom right). (Photos: Kaluza 2014).

1.3 Thesis aims and structure

In 2011, the Queensland, Northern Territory and Australian Governments collaborated to make a National Recovery Plan (NRP) for the species under the EPBC Act (1999). The NRP (DERM 2010) describes the research and management actions necessary to stop the decline of, and support the recovery of, the water mouse, so that its chances of long term survival in nature are maximised. Furthermore, the recommendations within the NRP (DERM 2010) play an important role in water mouse protection. This is because proposals to remove or degrade habitat for a nationally listed species must be considered by the Federal Minister for the Environment and must be consistent with the species' recovery plan.

In this thesis I therefore focus on the ecology and conservation of the water mouse (*Xeromys myoides*) in areas aligned with the EPBC act (1999). I will attempt to address the Key Actions of the National Recovery Plan (NRP: DERM 2010) for the water mouse by determining the distribution, abundance and ecology of the species in Southeast Queensland to address the following specific aims:

1. Has the management Plan (NRP: DERM 2010) for water mouse recovery proven to be successful;

2. Were the desired outcomes achieved, and

3. Did the management unit (Commonwealth Government) provide sufficient resources to successfully implement the plan?

This knowledge is useful for developing improved strategies for conserving the population and valuable for extension work such as establishing voluntary conservation agreements with relevant land owners. In order to examine these aims, I conducted a series of surveys of water mouse populations and their nesting structures across coastal wetlands of southeast Queensland, including the Maroochy River, over the period 2012 to 2017. A preliminary survey revealed the existence of nine water mouse nests, suggesting a 'hot spot' in the local distribution of water mice along the Maroochy River (Kaluza et al. 2016). The Maroochy River begins at the ocean inlet of Mudjimba Beach on the Sunshine Coast of southeast Queensland.

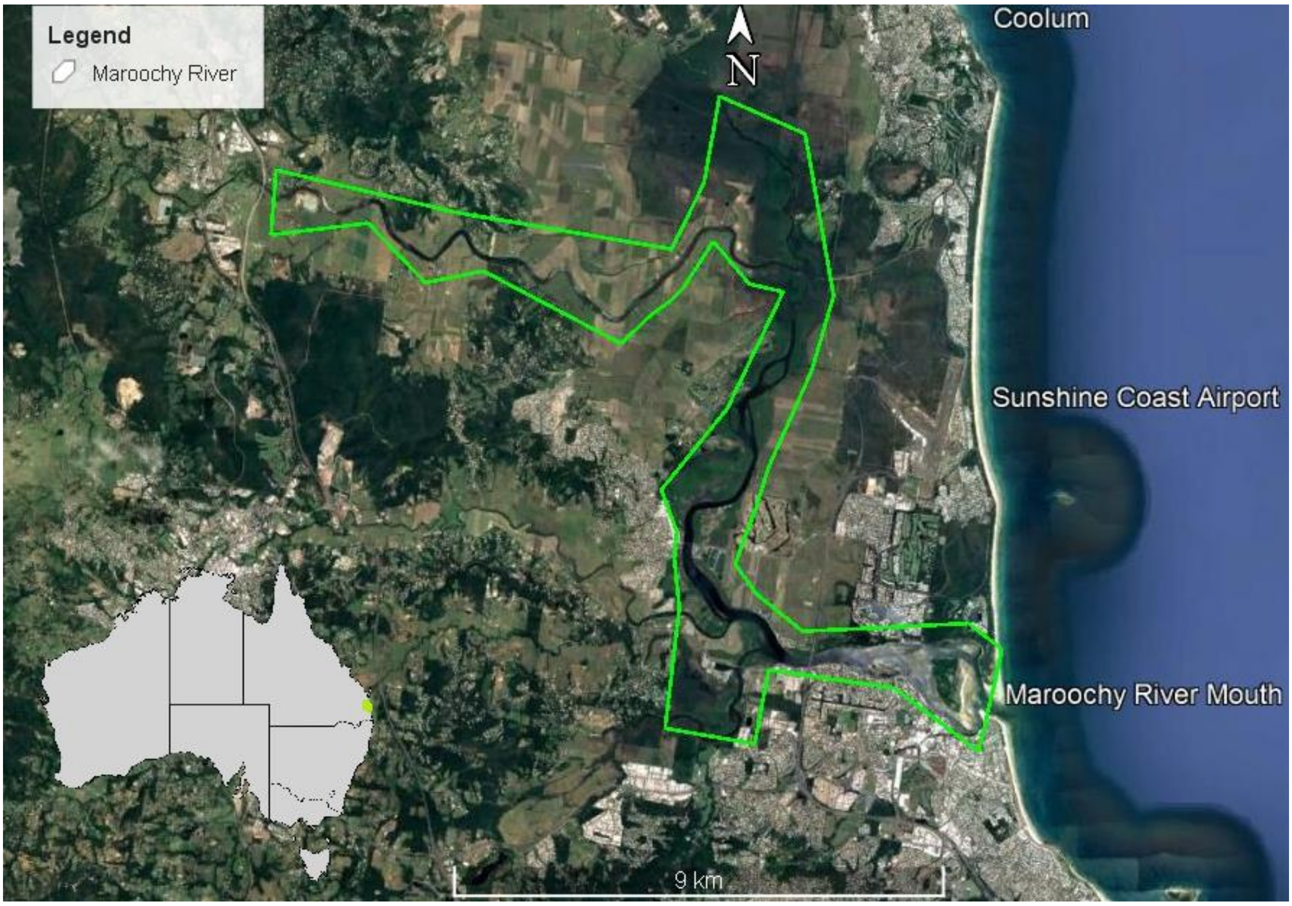

Figure 1.2 Depicts the surveyed area along the Maroochy River, the catchment is situated in the middle of existing agricultural land and growing urban development. (Map created in Google Earth Pro: Kaluza 2018).

Part of this river system was gazetted in 1992 as a Conservation Park that stretches over 174 hectares. Also, the saltmarsh and mangrove communities were zoned as potential water mouse habitat to protect the species. An extensive survey for this local population along the Maroochy River was commenced in 2011 in response to a request by Wetland Care Australia and Queensland Parks & Wildlife Service.

In Chapter 2 of this thesis I review the scientific literature to provide an overview of the ecology and conservation of the water mouse in south-east Queensland and identify gaps in ecological knowledge required for developing improved strategies for conserving this species. My intention was to examine particular research questions that when considered collectively, examine whether the management plan of one single nationally important species, (*Xeromys myoides*) is sufficient for its recovery or if a new plan of action is required.

In Chapter 3, I examine the current distribution of the species in the Maroochy River region and identify known/potential threatening processes.

In Chapter 4, I present an investigation into how water mouse nests vary in structure and type in response to the plant community in which the animal inhabits, across three extensive study sites in southeast Queensland.

In Chapter 5, I examine important factors affecting water mouse nesting behavior and use the results to predict behavioral response to the risk of flooding.

In Chapter 6, in response to the recommendations of the National Recovery Plan for the water mouse I investigate the persistence of the local population and land use practices along Hussey Creek of the Pumicestone Passage, Queensland. Survey data of nest sites within preferred water mouse habitats are presented and the most likely population threat identified.

In Chapter 7, I provide a synopsis of the research, including a brief discussion of results emerging from the integration of the preceding chapters, and present additional strategies based on these chapters to conserve the species.

1.4 References

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Chapter 2

2.0 Literature review

2.1 Introduction

Over 270 mammals have experienced declines in Australia over the last two hundred years, resulting in the extinction of seventeen of those mammals, with an accelerated proportion in the last 100 years (Australian Bureau of Statistics 2007); 41% of the losses were native rodents. Australia is accountable for 68% of global mammal extinctions. In 2007 a further fifty-three Australian native mammals were listed as 'vulnerable' under the Environment Protection Biodiversity and Conservation Act (1999). Rodents are an important food source for top order mammals, birds, reptiles and feral pests, but are often displaced by introduced species and human activity. They also play other important ecological roles such as changing the soil structure through burrowing activities (Dickman et al. 2000). Their ecological roles require further investigation but with substantial extinctions time may be limited (Lee 1999; Woinarski et al. 2014; Woinarski et al. 2015). The latest extinction example was the Bramble Cay melomys (*Melomys rubicola*), that became extinct due to habitat loss caused by climate change (Waller et al. 2014; Gynther et al 2016). This species was endemic to the Great Barrier Reef because it was found only on the Bramble Cay (Latch 2008; Dennis 2012; Woinarski et al. 2014).

The nest structure of Australian rodents is an adaptation to their local environment (Meek 2002). An open sclerophyll forest with broad moist gullies is the prime habitat of the endangered Hasting River Mouse (*Pseudomys oralis*). Their nest is found in fallen logs (Meek 2002) or rock hollows (Tweedie and York 1993) that are commonly available in this habitat. In the arid outback the dusky hopping mouse (*Notomys fuscus*) or spinifex hopping mouse (*Notomys alexis*) construct deep burrows to avoid heat (Watts & Aslin 1981; Moseby & Brandle 1999; Owens et al. 2008). Other rodents such as the desert mouse (*P. desertor*), delicate mouse (*P. delicatulus*) and the eastern chestnut mouse (*P. gracilicaudatus*) use various grasses as material for nest construction (Watts & Aslin 1981; Fox 1995).

Xeromys myoides (from here forth referred to as: water mouse) is a unique, poorly known species limited to coastal wetlands of Queensland, the Northern Territory and Papua New Guinea. Water mouse prove difficult to examine due to their nocturnal behavior, geographical presence, various nest styles and data gaps on the biology of the species.

The aim of this review is to examine potential survey methods to assist the conservation status of the water mouse. As the species is a nationally important population, its rarity leads to periodic gaps in literature, such as; identification of new localities or additional threats impacting its habitat. Additionally, I will examine methods used to monitor the species and discuss the potential of new monitoring methods. Consequently, this will be used to update the management of this threatened species to aid in habitat recovery.

2.2 Nesting Behavior

Water mouse nests are a distinct permanent structure (Van Dyck 1996; Gynther 2001; Van Dyck & Gynther 2003; Kaluza et al. 2016). Their nests are found in intertidal wetlands, both saline and freshwater, and are considered extraordinary because the species is not aquatic or arboreal (Van Dyck 1996). The intertidal zone is not a typical habitat for a terrestrial mammal, yet the water mouse is strongly associated with this harsh environment. Several types of water mouse nests have been recorded: free standing mound, mound associated with hollow trees, and underground nest in tidal banks (Redhead & McKean 1975; Magnusson et al. 1976; Van Dyck et al. 1979, Van Dyck & Durbidge 1992; Woinarski et al. 2000; Van Dyck & Gynther 2003; Ball 2004 and Kaluza et al. 2016). The main construction material used for nest building by the water mouse is mud (Redhead & McKean 1975; Magnusson et al. 1976). After transporting the mud from the base of the mound, the material is then daubed onto various sections of the nest. The water mouse will also use surrounding materials such as marine couch, mangrove leaf and food remnants to reinforce the structure (Van Dyck & Gynther 2003). Each nest is built in response to the local wetland hydrology (Magnusson et al.1976).

To minimize energy expenditure (Geiser & Turbill 2009), the water mouse employs torpor inside the nest during the day. However, little is known about the nest characteristics, and the physical endurance it takes to build and maintain a nest. Nest numbers are used as an index of the population of water mice, but the detection probability of nests varies greatly between nest types (Ball 2004). In 2002 Burnham completed a 2-year survey on water mouse presence across coastal communities of the Great Sandy Strait (GSS). Based on survey methods used by Van Dyck and Gynther (2003), Burnham tallied 207 nests covering 32 survey sites in six localities. Using the same methodology, a repeated survey along the GSS (2014-2017) indicated a decline in nest numbers and an increase in pest animal activity (Kaluza unpublished data).

2.3 Diet and foraging activity

Based on observation, the diet of water mice in a healthy wetland system consists mostly of crustaceans such as *Parasesarma erythodactyla,* gastropods*,* bi-valve and flat worm (Redhead & McKean 1975; Van Dyck 1996). Leaving their protected dwelling, the water mouse will use the receding night tide to hunt prey among intertidal mangroves. Foraging behavior by the water mouse can be identified through left-over meal remains otherwise known as middens. These remnants can be located at the base of or used to reinforce a nest; they can also be located at feeding stations used to traverse the intertidal system. However, there is little understanding of water mouse diet and the nutritional value it provides them (Van Dyck1996). Also, no records exist on the mammal's drinking water nor if their saline diet of invertebrates is substantial. Investigation on their diet dependency would prove worthwhile in determining key habitat values for the water mouse.

2.4 Reproductive biology

Although the water mouse has been held in captivity (Van Dyck pers. comm. 2007) there is still minimal evidence on their breeding cycle or on their interaction with successive generations. Data on water mouse gestation and life cycle is sparse with only one extended study documenting its genetics (Benfer et al. 2014). This study confirmed its diversity as being very low across their known range, suggesting that water mouse populations may have experienced recent expansion. If this knowledge is applied carefully, Benfer (2014) depicts the water mouse as a single population that could be translocated to areas of local decline or extinction. Benfer (2014) also identified population substructure in the Mackay region of Central Queensland, suggesting isolated origins for the species had occurred. Essential gaps also remain in the broader population of the water mouse found in Papua New Guinea. This information would be important for linking the species' range to preferred habitat and diet. As outlined by Benfer (et al. 2014), further understanding of this species' genetic distribution and its immune response may aid its recovery.

2.5 Critical Habitat

Coastal wetlands are a critical point of connectivity between terrestrial and marine ecosystems and their health is important to the proper functioning role of both (Erwin 2009; Lee et al. 2006). Worldwide, there are consistent threats to wetland habitat such as adjacent land change, pollution, introduced species and climate change (Robertson & Duke 1987; Saintilan & Williams 2000; Mimura et al. 2007; Smith 2008). These processes can create a change in species distribution, abundance and behavior (Woinarski et al. 2007). Determining these adverse threats requires consistent data collection that is useful for best management practices in the conservation of species.

Primary water mouse habitat consists of intertidal wetlands containing common salt marsh, ruby saltbush (*Enchylaena tomentose* var. *glabra)*, bead weed (*Sarcocornia quinqueflora*), marine couch (*Sporobolus virginicus*), sedgelands, knobby club rush (*Isolepis nodosa*) and jointed rush (*Juncus kraussii*), as well as mangrove forests dominated by grey mangrove (*Avicennia marina* var. a*ustralasica*), orange mangrove (*Bruguiera gymnorhiza*), stilted mangrove (*Rhizophora apiculata*) and milky mangrove (*Excoecaria agallocha*) (adapted from Van Dyck and Gynther (2003)). Inclusive of freshwater wetlands of Beerwah State Forest where the species was first known to occur (Thomas 1889).

Vegetation communities and associated landforms are well documented in various studies on water mouse populations (Woinarski et al. 2000; Burnham 2002; Van Dyck & Gynther 2003; Ball 2004 and Kaluza et al. 2016). Determining the presence and absence of nesting structures has been the basis of some previous surveys for water mice (Magnussen et al. 1973; Redhead & McKean 1975). Earlier work by Van Dyck and Gynther (2003) examined the characteristics of nest structures in southeast Queensland. They also described nest types, appearance of each type and their occurrence in different vegetation communities and plant species associated with each nest structure. Van Dyck and Gynther (2003) also identified that nest position within the intertidal zone, erosion impact and tidal tolerance were relevant in understanding the ecology of this specialist rodent.

Considering this earlier work, Kaluza et al*.* (2016) estimated the distribution and density of water mice along the Maroochy River (southeast Queensland) by comprehensively surveying their nest structures (Chapter 3; Figure 1). The evaluation at these sites produced GIS habitat models noting a high correlation of key habitat characteristics related to plant presence, stable hydrology and mud type. Notably, bank nests were located at or just below ground level in solid muddy banks situated at the intertidal, terrestrial boundary, and typically were not inundated with water during most high tides. Also, tree nests sometimes resembled mound nests, although they were typically supported structurally by a large hollowed tree, allowing nest heights to exceed 2 m (limited only by the height of the hollow part of the tree). During the Maroochy River survey, mound nests were frequently found in exposed tidal areas of saltmarsh or sedgelands in a clustered format, particularly at sites considered to be under severe threat from habitat degradation associated to adjacent land change. By implementing NRP (DERM 2010) objectives and survey guidelines (DSEWPaC 2011j), extension of their known range was determined in areas of increased human activity in southeast Queensland.

2.6 Water mouse populations

According to the NRP (DERM 2010) current habitat models, water mouse populations are fragmented between localities, occurring mainly in protected areas (Figure 1).

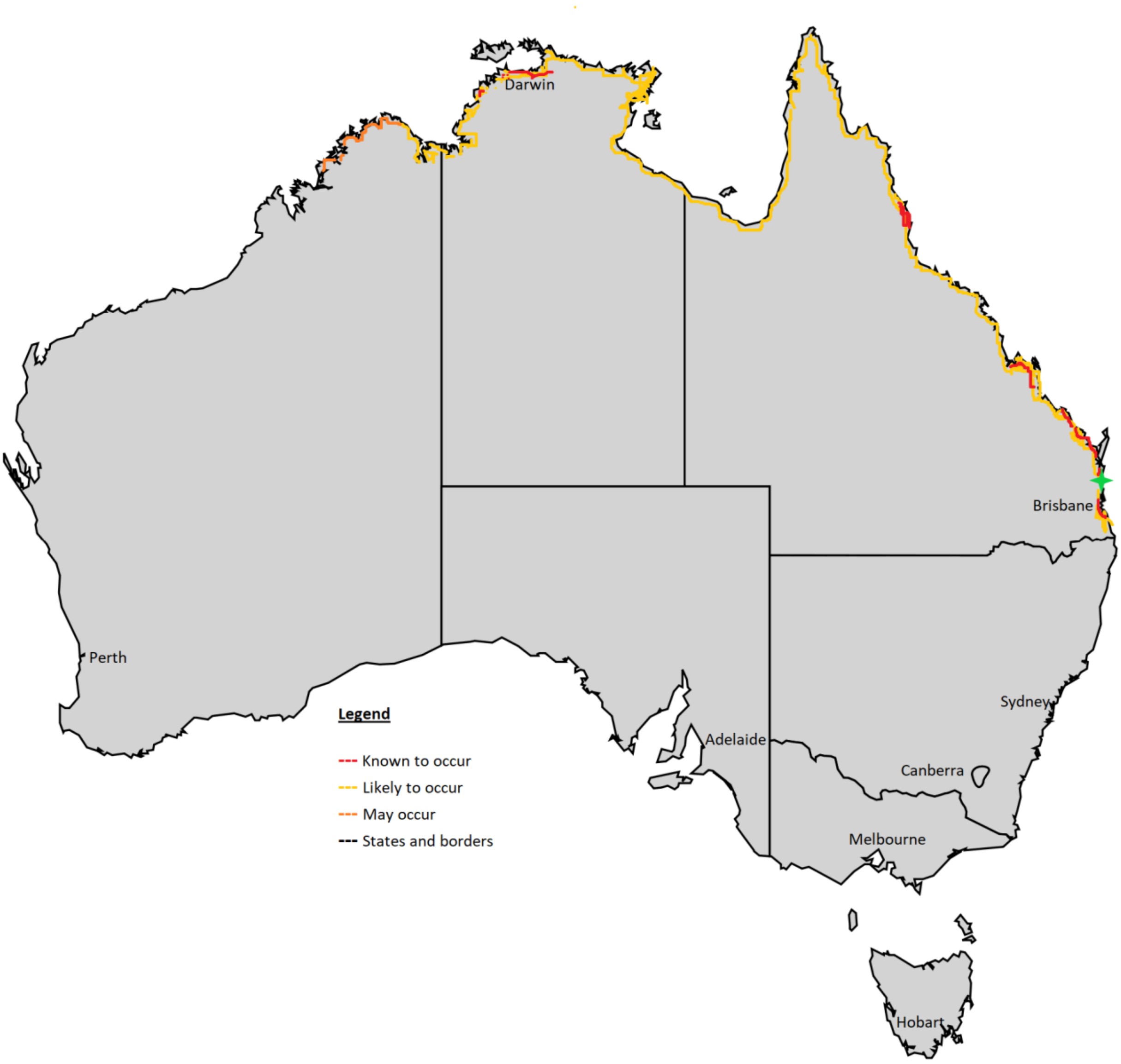

Figure 2.1 Known current distribution and historical records for *Xeromys myoides* in Australia. Map image from frhttps://www.drodd.com/images16/blank-australia-map1.png (Wikimedia Commons 2018) and enhanced using Microsoft Office Program in Paint (Kaluza 2018).

They are known to occur in central and southeast Queensland (inclusive of island communities) with a population estimate of between 1001 – 10000 individuals, an area occupancy between 101 per 1000 km² (Dickman et al. 2000; ICUN 2016). Areas of the Northern Territory are data deficient for water mouse localities (Magnusson et al. 1976; Redhead & McKean 1975; Woinarski et al. 2000; DERM 2010) in comparison to Queensland where records are currently under review by the Commonwealth Government Threatened Species Unit, Department of Environment and Energy. Monitoring the species has been highly successful with credited insight based on observation alone. Live trapping by Van Dyck and Gynther (2003), Woinarski et al. (2000), Gynther and Janetzki (2008) and Ball (2004) yielded positive confirmation and biological characteristics of the water mouse. Resulting knowledge, particularly DNA extraction allowed Benfer (2014) to implement NRP Key Action 2.1 and conduct genetic analysis on subpopulations of the species generating significant results. However, behavioral studies on the species remains lacking and further investigation is required to measure trends in species abundance, nesting and social activity. Camera trapping is an effective tool for small mammal studies (Meek et al. 2015) and less invasive for the animal than live trapping. This monitoring method has been deployed for the entirety of this study focusing on sites across the species' range in southeast and central Queensland (Kaluza unpublished data) enabling new insight on population dynamics, nesting behavior and threats.

2.7 Potential threats to the species

Water mouse are listed as `vulnerable' under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the Queensland Nature Conservation Act 1992 (NCA; listed as false water-rat). Likely threats to the water mouse are primarily associated with increased human disturbances and predation from feral animals such as pig, fox and cat (EPBC 1999; DERM 2010). Their distribution is wide but patchy with evidence of decline in some regions (Van Dyck et al. 2006). Extensive surveys were undertaken between 1990-2008 in their preferred habitat of southeast Queensland (Van Dyck 1996; Van Dyck 1997; Burnham 2002; Van Dyck & Gynther 2003; Van Dyck, Janetzki & Gynther 2003; Van Dyck et al. 2006; Gynther & Janetzki 2008) the Northern Territory (Woinarski 2000; Woinarski et al. 2000; Woinarski 2003; Woinarski et al. 2007) and some areas of central Queensland (Ball 2004), and within one locality in Papua New Guinea (Hitchcock 1998). However, although exhaustive efforts were applied, there remains large gaps in the species known-localities, substantiating ongoing concerns for population decline. Their status is recorded as 'data deficient' in the Northern Territory under the

Territory Parks and Wildlife Conservation Act 2000 (TPWC). A National Recovery Plan (NRP; DERM 2010) and Referral Guidelines (2015) for the water mouse identifies Key Actions required for the recovery of the species. Relevant actions include: confirming and documenting current distribution of the species and mapping known populations and their habitat by assessing the adverse impacts of known threatening processes.

In March 2017 a workshop was held with the Department of Environment and Energy (DEE) in Brisbane, where a review of the NRP for the water mouse was drafted. The current condition of the water mouse was determined as `good', but its conservation trajectory was determined to be probably deteriorating. The level of confidence in this assessment is considered high given the species' broad distribution and the large extent of unsurveyed, undeveloped and likely occupied habitat (Figure 1). However, evidence of damaging new threats and localized extinctions in the southern parts of their habitat range has led to vital policy development and mapping updates. Future studies should investigate sediment and water quality, diet, community composition and threatening processes. The information would assist in a revised National Recovery Plan (NRP) for the conservation of the vulnerable water mouse.

2.8 Populations under threat

Various research over the last 30 years has produced significant findings on the local decline of water mouse populations. For example, Van Dyck et al. (2006) studied the species over a 5-year period in wetlands along the Coomera River, particularly noting the accelerated changes to water mouse habitat during urban development. Water mouse population was determined by monthly live trapping over the study period. However, a decline in the species numbers eventually lead to a local extinction of the rodent. This demise, although difficult to pin point exactly, coincided with the development of Coomera Waters Estate, Gold Coast.

This type of ongoing disturbance has the potential to degrade existing habitat, diet and nest preference of the water mouse. Table 1 indicates the extent of water mouse habitat removed since the time pre-clearing commenced and 2005, inclusive only of saline wetlands (EPA 2007). Furthermore, in 2002 Burnham reported water mouse populations along the GSS as under high threat from adjacent land management (Kauri Creek section) and urban development at Booral and River Heads (Burnham 2002). Other prime sites most likely at risk from urban sprawl include Mc Coys Creek on the Gold Coast and Turtle Cove at River Heads (Kaluza unpublished 2017) as well as Maroochy River (Kaluza et al. 2016).

Table 1. Regional Ecosystem (RE) data (EPA 2007) estimates the area of Water Mouse habitat cleared in Queensland since pre-clearing times.

Description (EPA 2007)	**Pre-clearing extent (ha)**	**Extent remaining in 2005 (ha)**	**Estimate of clearing (pre-clearing-to 2005) (ha)**
Mangrove vegetation of marine clay plains and estuaries.	41 024	40 248	776
Sporobolus virginicus grassland on marine clay plains.	35 008	17 633	17 375
Samphire foreland or bare mud-flats on Quaternary estuarine deposits.	11 3110	104 073	9037
Mangrove low forest on Quaternary estuarine deposits.	85 291	84 282	1009
Mangrove shrubland to low closed forest on marine clay plains and estuaries.	53 499	50 483	3016

Using regional ecosystems considered essential habitat in Queensland resulted in an estimate that 31 213 ha of water mouse habitat had been cleared between pre-clearing times and 2005 (EPA 2007). Along with the increased loss of preferred habitat, adjacent land removal and global warming there is little opportunity for nest variation by the water mouse. As a terrestrial rodent they have successfully adapted to a semi-aquatic environment but has this come at a cost to the species longevity. Additional understanding of this species' ecology and habitat association are required to determine their response to new threats such as rising sea levels linked to global climate change. A consistent monitoring program to measure the direct and indirect implications on water mouse populations is urgently required and of paramount importance to manage such threats. Therefore, future research should focus on an array of pressures placed on the water mouse including: gestation cycles, hydrology changes, sediment and water quality testing, diet abundance, predation and avoidance, internal nest structure and increased habitat boundary. Such research would improve habitat quality and aid in species recovery.

2.9 Conclusion

The purpose of this review was to gain insight on threatened species studies over the last 35 years and to understand how conservation practices for small mammals have changed and continue to evolve. It is apparent that population monitoring is widely practiced and that such research provides valuable insight into species ecology. Additionally, it is also clear that the volume of research evident for particular rodents facing a high risk of extinction in the wild in the medium-term future is limited. This deficiency is significant, considering the recent and local extinction of a water mouse population within the south east Queensland region, occurring amidst a contemporary trend of mammal decline in Australia. Future extinctions of water mouse populations in southeast Queensland and elsewhere across the species' range must be avoided.

In order to address these deficiencies, that appear to exist for both water mouse populations and threatened species more generally, it seems additional resources must be directed towards longer-term research programs that assist in better understanding of the species' behaviour and habitat characteristics, so that identification of threats and causes of local water mouse decline can be identified, potentially enabling the arrest of population decline. Additionally, such research may also enhance our capacity to manage water mouse habitat such as coastal wetlands more effectively and identify practices that can be implemented more broadly to address nationwide conservation practices for threatened species. The establishment of these longer-term population monitoring, and additional research programmes appears essential to supplant shorter term reactive research support that primarily addresses a species in rapid decline at too late a stage, precluding the identification of longer-term preferred management strategies.

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Contributor	Statement of contribution
Kaluza J (Candidate)	Conceived/designed study 100% Conducted field work 80% Conducted statistical analysis 60% Wrote the paper 70%
Allen B Allen B Gynther I Leung L	Conducted statistical analysis 40% Edited the paper (10%) Edited the paper (10%) Edited the paper (10%)
Donald R	Conducted field work 20%

Chapter 3

3.0 The distribution and density of water mice in the Maroochy River system of southeast Queensland, Australia.

3.1 Abstract

The water mouse is a small and vulnerable rodent present in coastal areas of south-west Papua New Guinea, and eastern Queensland and the Northern Territory of Australia. Current knowledge regarding the distribution of the water mouse is incomplete and the loss of one local population has been documented in southeast Queensland, a region where pressures from urban and industrial development are increasing. Water mouse populations have not been studied intensively enough to enable the primary factors responsible for the local decline to be identified. We surveyed the distribution and density of the water mouse along the Maroochy River of southeast Queensland, near the southern extent of the species' range, to gather baseline data that may prove valuable for detecting any future decline in this population's size or health. All areas of suitable habitat were surveyed on foot or by kayak or boat over a three-year period. We found 180 water mouse nests, of which ~94% were active. Permanent camera monitoring of one nest and limited supplementary live trapping suggested that up to three individual mice occupied active nests. Water mouse density was estimated to be 0.44 per hectare of suitable habitat along the Maroochy River. Should future monitoring reveal an adverse change in the water mouse population on the Maroochy River, a concerted effort should be made to identify contributing factors and address proximate reasons for the decline.

Key words: absolute abundance, density estimation, false water rat, intertidal zone, mangrove, population census, small mammal, *Xeromys myoides*

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3.2 Introduction

Coastal wetlands are critical points of connectivity between terrestrial and marine ecosystems, and their environmental health is important for the proper functioning of both. Worldwide, coastal wetlands are threatened by a variety of factors including land use change, increasing human presence, invasive species and climate change Erwin 2009; Eslami-Andargoli et al. 2009). These processes can manifest themselves as changes in species distribution, abundance and/or behaviour (Hughes 2003). Mitigating the effects of these threatening processes on wetland species requires the ongoing collection of information useful for enabling best-practice management of species of conservation concern.

The east coast of Queensland, north-eastern Australia, is ~7,000 km long and is bordered by the Great Barrier Reef marine ecosystem and the tropical and subtropical terrestrial ecosystems of the Great Dividing Range. Along the coast, approximately 36 major rivers flow east into the Pacific Ocean from this Range. These contribute to a substantial number of coastal wetlands, which provide breeding grounds for many marine microorganisms, crustaceans, birds, fish and other species (Robertson and Duke 1987) Queensland is home to over 4.7 million people, 85% of whom live within 50 km of the coast along many of these rivers (www.abs.gov.au). This human presence may have previously altered any balance between natural ecosystem processes and extant fauna at wetland sites. As we continue to explore the types of impacts humans may have on the environment, consistent research is required to determine any declining range of coastal fauna since European occupation of Australia in the late 1700s.

The water mouse (*Xeromys myoides*; also known as the false water rat or 'yirrkoo') is a small carnivorous rodent (~40 g) that builds and occupies elaborate nest structures in intertidal zones dominated by mangrove (e.g. *Avicennia marina* var. *australasica*, *Bruguiera gymnorhiza*, *Aegiceras corniculatum, Rhizophora stylosa*, *Excoecaria agallocha*) and saltmarsh (e.g. *Enchylaena tomentose* var. *glabra*, *Sarcocornia quinqueflora*, *Sporobolus virginicus*, *Isolepis nodosa*, *Juncus kraussii)* vegetation communities (Fig. 1; Van Dyck and Gynther 2012; 2003), which are preferred habitat for this species. The distribution of the water mouse is currently known to extend from Papua New Guinea to the north coast of Australia and in eastern coastal wetlands as far south as the Gold Coast in southeast Queensland (Benfer et al. 2014; Gynther and Janetzki 2008). The Maroochy River is approximately 135 km from the southern edge of the species' known range. Water mouse populations are believed to have become locally extinct from the Coomera River over the last few decades (Benfer et al. 2014; Van Dyck et al. 2006). The ecological roles of the water mouse are not clear. However, as one of the few native terrestrial mammals occupying these wetlands, it is likely to be an important predator of molluscs and crustaceans, prey for nocturnal raptors, reptiles and other species (Van Dyck 1997), and potentially provides ecosystem services for other native animals through the construction of mud nests that represent small islands in the intertidal zone.

In this study, we describe the distribution and density of water mice in the Maroochy River system of southeast Queensland. Our aim was to generate baseline population data that may be useful for determining trends in distribution and abundance following future monitoring of the species.

Figure 1. Two water mice maintaining a mound-style nest in a mangrove vegetation community of Sector 3 of the Maroochy River system, 8th March 2012 (Photo: Janina Kaluza).

3.3 Methods

Ethics statement

Water mice are protected and presently listed as 'vulnerable' under the Federal *Environment Protection and Biodiversity Conservation Act (1999)* and are supported by a national recovery plan (NRP 2010) Permission to enter the study site was granted by the Queensland Parks and Wildlife Service and Marine Parks Authority. The Animal Ethics Committee of the

Department of Agriculture, Forestry and Fisheries (DAFF) approved this study (permit approval number: CA 2014/08/797), and the project was carried out in accordance with this approval.

3.4 Study site

The Maroochy River is located on the Sunshine Coast of southeast Queensland. It is a popular and growing residential area with >250,000 people (Higgins et al 2009). The area is subtropical, with a warm and humid climate, and receives an average of ~1,550 mm of rainfall annually, which peaks in summer (www.bom.gov.au). The area surrounding the Maroochy River supports both natural and human-modified areas (Fig. 2). The former includes paperbark (*Melaleuca* spp.) swampland, open forest communities and small fragments of subtropical rainforest, with mangrove and saltmarsh fragments adjoining the river's edge in many places. Human land use around the river is predominantly agricultural (sugar cane crops and ex-sugar cane areas now supporting grassland) and urban residential (Fig. 2). The area is undergoing substantial development, including new golf courses, industrial areas, residential areas and an extension to a local major airport.

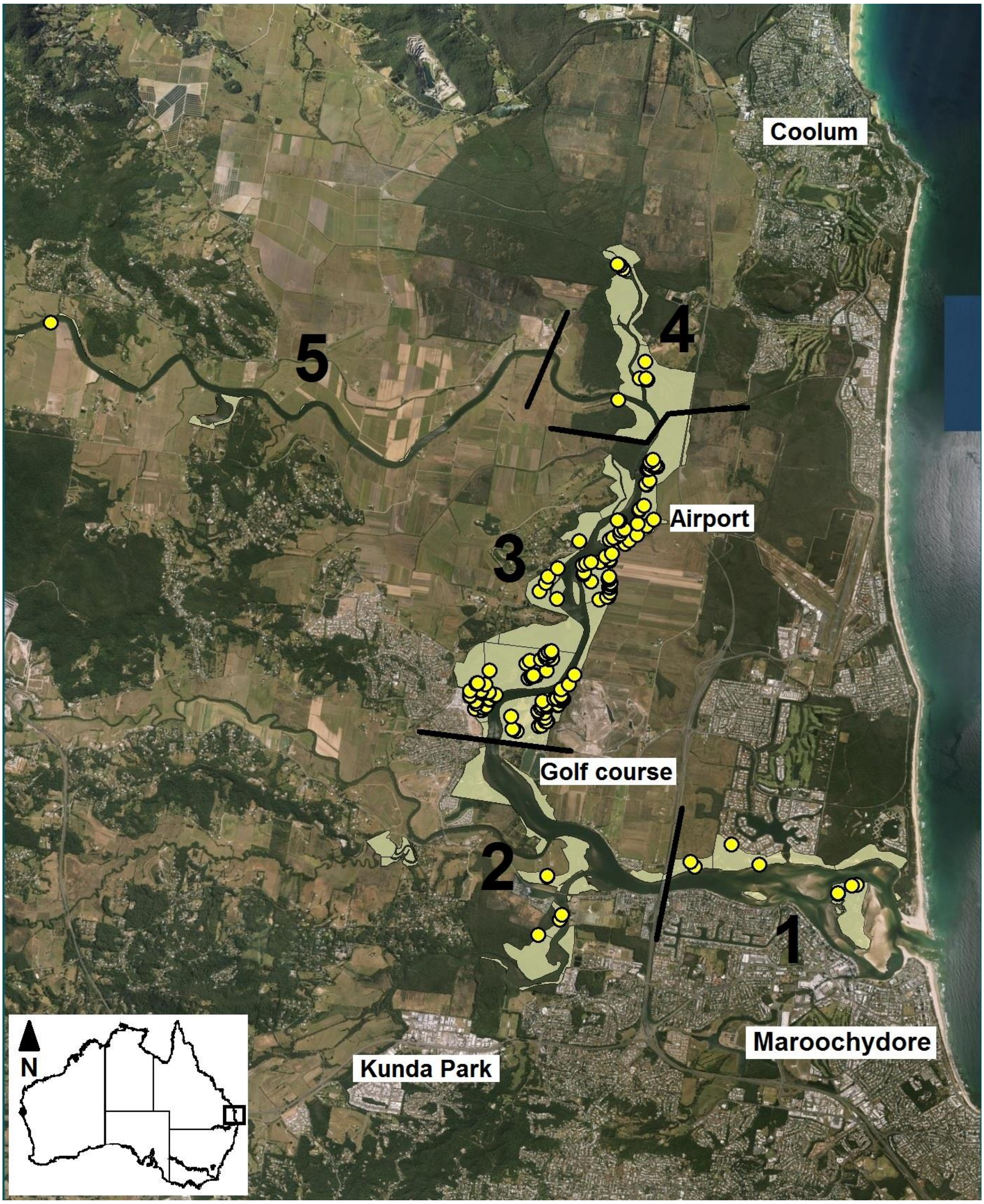

Figure 2. The study site on the lower Maroochy River of Queensland’s Sunshine Coast, showing the location of 180 water mouse nests (yellow circles) and areas of suitable water mouse habitat (shaded areas). Numbering indicates survey sectors. Map was created new by the authors in ArcGIS v10.1 (ESRI Inc.).

3.4 Water mouse distribution and abundance

For the purposes of our surveys, the lower Maroochy River was arbitrarily divided into five adjoining sectors based on unique features of the river system, such as bends and tributaries. We then systematically identified all suitable water mouse habitat in each sector using high-resolution aerial photography and GIS vegetation datasets maintained by the Queensland Herbarium. We then undertook extensive ground surveys for water mouse nests within these sectors between September 2011 and December 2014. All suitable habitats were surveyed by boat, kayak, or typically on foot during low tide, on multiple occasions for some areas, to minimise the possibility of overlooking nests. Nests were classified as 'active' or 'inactive' based on sign of recent water mouse activity (e.g. fresh foot prints, mud daubing, or the presence of fresh prey remains). Absolute density of nests was calculated as the number of nests per hectare of suitable habitat.

Three automated trail cameras (Pixcontroller trail cameras, Digital Eye TM, CAMO60 6.0, Digital Trail Camera) were deployed between March 2012 and December 2014 at one mound-style nest (Fig. 1) in Sector 3 in a longitudinal study designed to determine the number of individual water mice occupying the nest. Mound-style nests are the most common form of water mouse nests at this site, and this nest was of broadly similar construction to the others (J. Kaluza, unpublished data). Live trapping (under Queensland Department of Agriculture and Fisheries Animal Ethics Committee approval number SA 2013/12/452 to IG) was undertaken on one occasion on the night of the 4th June 2014, using a total of 75 Elliott traps (for more information on Elliot trapping, see (Tasker and Dickman 2002) set around this nest and two nearby nests on a supralittoral bank (i.e. a low bank at the boundary between the intertidal and terrestrial communities) less than 100 m away. We used a barricade trapping approach, whereby the nests were first completely surrounded by a flywire mesh fence installed at least 50 mm below ground level and 250 mm above ground. Multiple Elliott traps were then placed both inside (N = 16–18) and outside (N = 8–9) the barricade with the aim of catching water mice that were inside the nest and those that were absent from the nest at the time the barricade was established. Each trap was baited with a piece of blue pilchard (*Sardinops sagax*) approximately 3 cm in length.

Traps were checked multiple times throughout the night to ensure they were not inundated as the tide rose. Captured animals were removed from traps, sexed, measured and then released at the point of capture at midnight and/or dawn. Captured animals were temporarily marked by clipping a small patch of hair on the crown with scissors; individual identification was based on the unique patterns of white spots on the dorsal pelage. A small ear snip and a saliva sample were collected, and body weight, head length, head and body length, tail length, ear length and hindfoot length were measured. Ear and saliva samples were given to the Queensland Museum for specimen cataloguing and keeping. Age and reproductive condition were also assessed. At no time were animals anaesthetised. Trapping results were used to attempt to verify the number of individuals within an active nest, as recorded by camera.

3.5 Results

We identified a total of 765 ha of suitable water mouse habitat in the lower Maroochy River, most of which was in Sector 3 (Fig. 2). Approximately 600 ha of land along the river system is designated and managed by state and local governments as conservation reserves; ~23% of water mouse habitat (~175 ha) occurred within these reserves. We located a total of 169 active and 11 inactive water mouse nests. Most of the active and all the inactive nests were in Sector 3 (Fig. 2, Table 1), and 53 nests occurred within reserves. The absolute density of active nests across all five survey sectors was 0.22 nests per hectare of suitable habitat (Fig. 3).

Table 1. The number of water mice nests in the lower Maroochy River.

Sector	**No. of active nests**	**No. of inactive nests**	**Total no. of nests**
1	11	0	11
2	3	0	3
3	140	11	151
4	14	0	14
5	1	0	1
Total	**169**	**11**	**180**

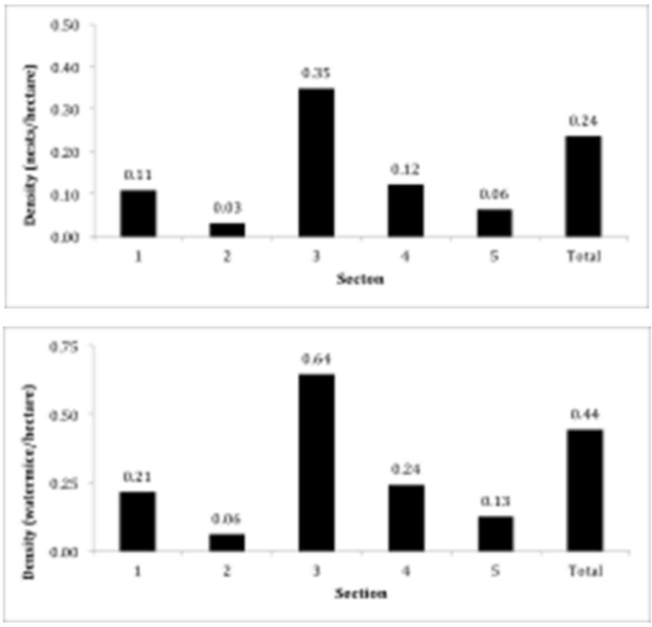

Figure 3 – The density of active and inactive water mouse nests (top) and water mouse individuals (assuming an occupancy rate of two mice per nest; bottom) in suitable habitat across all survey sectors along the lower Maroochy River.

The trail cameras recorded c. 10,000 photos. Of these, c. 8,000 photos captured water mice. No more than two individual water mice were observed in any one photo. However, body size, pelage, and the sequence and timing of behaviours observed in some photos suggested that up to three individual water mice (two adults and a juvenile) used the nest under surveillance at any one time during the course of the study.

Live trapping yielded five individual water mice from two nests – three individuals were captured inside the barricade fence at one of the supralittoral bank nests and two individuals (one inside the barricade fence and one outside) were caught at the nest that was monitored by the trail cameras (Fig. 1); no water mice were captured at the third nest (Table 2). Despite these trapping results, we cannot be sure that any individual captured inside the barricade fence at a particular nest had occupied the nest in question because of the possibility that water mice may have traversed the fence barrier via subterranean tunnels. This reduces the reliability of any conclusions drawn about numbers of individual occupying nests based solely on the trapping data. Nevertheless, assuming that two individuals occupy an active nest, water mouse density in the study area was 0.44 individuals per hectare of suitable habitat (Fig. 2), suggesting a local population size of ~340 individuals. Assuming that three individuals occupy each active nest, water mouse density would be as high as 0.66 individuals per hectare, or ~500 individuals in the lower Maroochy River.

Table 2 – The number of individual water mice trapped around nest sites at midnight and dawn on 4–5 June 2014, in the Maroochy River system (^captured inside the barricade, *captured outside the barricade).

	Midnight	**Dawn**		**Combined**
Nest	**New captures**	**New captures**	**Recaptures**	**Total no. of individuals**
1	3^	0	3^	3
2	0	0	0	0
3	1^	1*	1^	2

3.6 Discussion

This study is the first to report the distribution and density of water mice in the Maroochy River. Given that the species has become locally extinct from one site in a similar river system in southeast Queensland (Van Dyck et al. 2006), the 180 nests we located (Fig. 2, Table 1) and the ~340–500 individuals likely to be present in this estuarine system represent a population of considerable conservation significance. By comparison, our nest tally is equivalent to the total number of nests found during an intensive, two-year survey of the full extent of the Great Sandy Strait (Burnham 2000) – a Ramsar and Marine Park site recognised as supporting a water mouse population of national importance (DERM 2010) - even though we surveyed a much smaller area along the Maroochy River. No other detailed studies of this species has identified such high numbers or densities of nesting structures associated with any water mouse population (e.g. (Van Dyck and Gynther 2003; Van Dyck 1997; Ball 2004).

Although a large range of threats to the water mouse across the species' range has been identified (e.g. (Van Dyck and Gynther 2012; Benfer et al. 2014; Gynther and Janetzki 2008; DERM 2010), precise threats to the wetland communities along the Maroochy River are yet to be established. Nevertheless, they are likely to include the direct and indirect effects of rapid land use change from natural ecosystems to agricultural, residential and industrial areas. Extant mangrove habitats are highly fragmented (McDonald et al 2006); Fig. 2), and for over 100 years the adjacent crop farms have used substantial quantities of pesticide, herbicide and fertilizer (Smith 2008). Minimal buffer zones exist between wetlands and agricultural areas, which are typically located side by side (Fig. 2). Historically, major earthworks (to improve drainage for agriculture) have allowed runoff to be directed straight into the adjacent wetlands (Rayment 2003). Draining of wetlands and land reclamation for agriculture and development have also occurred. This alteration of the environment not only removes wetlands completely but is also likely to have affected remaining wetlands through changes to salinity and sediment levels (Saintilan and Williams 2000) which, in turn, affect the abundance of crustaceans and other prey species for water mice (DERM 2010; Ball et al. 2006).

Results of the current study imply that the water mouse has persisted along the Maroochy River despite these historical changes brought about by the conversion of natural areas to agricultural land. However, as current land use undergoes further rapid change from agricultural to residential with much higher human densities, the nutrient-enriched soils of the former cropping land become disturbed and exposed to runoff during construction, and increased stormwater flows and pollutants after construction (Ball et al. 2006; Lee et al. 2006). Little is known about the chemical and physical composition of mud required to bind water mouse nests (DERM 2010; Burnham 2000; Russell and Hale 2009), the resources required to sustain water mouse populations, the processes that negatively affect those resources, or threshold levels of environmental change that water mice (or their prey) may be able to withstand (Erwin 2009; DERM 2010).

Water mouse nests were not evenly distributed throughout the suitable habitat available to them but were instead clumped (Figs. 2 and 3), suggesting that factors other than habitat availability per se may influence the species' local distribution and density. A very cautious approach to land use change in this area is warranted to protect the water mouse and other species from local extinction (Higgins et al. 2009; Smith 2008; Lee et al. 2006; Duke et al. 2005).

We can be confident that our figure for absolute nest density accurately reflects the true situation given the extensive surveys that were conducted. We cannot dismiss the possibility that some additional water mice nests may be present, although we believe there is unlikely to be a substantial number of nests not detected by our surveys. We are also confident in our population estimate of ~340–500 individual water mice in the lower Maroochy River. However, we acknowledge the limited data we have on the number of individuals occupying nests, and whether or not multiple nests are shared by individuals or groups – factors that contribute to accurately assessing the abundance and density of individuals. Van Dyck

(1997) previously recorded up to eight individuals per nest on Stradbroke Island; if this were the case in our study area, then water mouse density would be as high as 1.76 mice per hectare, or as many as ~1,350 mice in the lower Maroochy River. Alternatively, if the same individuals or groups use multiple nests, water mouse abundance and density will be lower than our estimates. A greater understanding of nest occupancy, demography, and reproductive and movement behaviour is logically the next step for assessing the true conservation status of the water mouse population in this area.

The recent and local extinction of a water mouse population within the region (Van Dyck et al. 2006) is a part of the current trend of mammal declines in Australia (Benfer et al. 2014; Woinarski et al. 2015). Further such extinctions of water mouse populations in southeast Queensland and elsewhere across the species' range must be avoided. If robust population monitoring practices can be successfully implemented and maintained, researchers may be able to identify the threats and causes of any local water mouse decline, potentially allowing the species to be recovered. In turn, this may lead to a greater understanding of how to better manage and conserve other coastal wetlands and their constituent wildlife in the face of increasing global threats and species declines.

3.7 Acknowledgements

This project was supported by funds provided by the Commonwealth Government program 'Caring for Our Country' and also the 'Coastal 20' funding program by Wetland Care Australia, which was facilitated by Cheryl Bolzenius. Kerry Jones and Sean Fleischfresser of Bunya Bunya Country Aboriginal Corporation provided assistance and gave permission for access to their land in search of 'yirrkoo' (the indigenous name for the water mouse). Lee Allen kindly provided the use of his private boat to conduct surveys. Steve Van Dyck also contributed to helpful discussions and much direction on the life history and local distribution and ecology of water mice. Countless volunteers provided project support and contributed many hours wading through mud, while fending off biting midges and intolerable mosquitoes, to hunt down every water mouse nest we located; they included Amber Kaluza, Delphinia Kaluza, Taryn Kaluza and Lachlan Woithe. Many additional volunteers from the following organisations also contributed to the project for which we are extremely grateful: Queensland Parks and Wildlife Service, Landcare Australia, Green Army Corporation, Noosa Parks Association, Maroochy Wetland Sanctuary, Coolum District Coast Care, SEQ Catchments Ltd, Sunshine Coast Regional Council and Sunshine Beach State High School.

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Chapter 4.

4.0 Characteristics of water mouse nest structures in southeast Queensland, Australia: vegetation associations and physical dimensions.

4.1 Abstract

The water mouse is a rare terrestrial mammal that resides in coastal wetlands. Their distribution is wide but sporadic with evidence of decline in some areas. Water mouse nests are permanent and important features, contributing to the stability of water mouse populations. However, little is known about nest characteristics and why this harsh environment is critical to their survival. We studied 352 nests across three large areas of south east Queensland to determine physical characteristics of nest structure. We found mound nests were an average height of 50 cm ranging between 25 cm and 100 cm; mound basal circumference averaged 200 cm, ranging between 90 cm and 550 cm, for all three sites. Identified nest types included: free standing mounds, hollow trees (*Avicennia marina*) and supralittoral hollow banks. On average, important vegetation coverage included *Sporobolus. viginicus* 79%, *Avicennia. marina* 94% and *Casuarina. glauca* 81% within a 5 m radius of each mound. Recorded pH levels suggest water mice like a saline environment with 301 out of 352 nests determined as active. Our results provide evidence of crucial nest characteristics, confirming mud quality as a defining key requirement to enable nest construction. Future studies should investigate sediment and water quality, diet, community composition and threatening processes. The information is valuable for any future National Recovery Plan, drafted for the vulnerable water mouse.

4.2 Introduction

Determining the presence and absence of nesting structures has been the basis of numerous water mouse surveys (Magnussen et al. 1973; Redhead & McKean 1975). Earlier work by Van Dyck and Gynther (2003) examined the characteristics of water mouse nest structures in southeast Queensland. The authors described nest types, their appearances and the vegetation communities and plant species associated with each type. Kaluza et al. (2016) estimated the distribution and density of water mice along the Maroochy River (southeast Queensland) by detecting their nests. The authors found that bank nests were located at or just below the ground level in solid muddy banks situated at the intertidal-terrestrial boundary and were not inundated with water during most high tides. Mound nests were free-standing and frequently found in exposed tidal areas of saltmarsh or sedgelands in a clustered format. Tree nests resembled mound nests, but were supported structurally by a large hollowed tree, allowing nest heights to exceed 2 m (limited only by the height of the hollow part of the tree).

Animal-plant associations are common in nature and a sound knowledge of these are useful for conservation. For example, knowledge that certain species of birds rely on tree hollows for nesting helps prioritise the retention of trees with hollows in forests subject to logging (Gibbons 1994). Another example is koalas (*Phascolarctos cinereus*) preferring to browse only a selected range of eucalypts (Wu et. al 2012). Many invertebrates are also heavily reliant on specific plant species for food and breeding (Abrantes & Sheaves 2009). However, Dickman (1999) has identified the ability of many rodents to engineer local environments biotically and non-biotically.

The water mouse inhabits coastal wetland systems consisting of woodland, saltmarsh, sedgelands, and mangrove communities (Gynther & Janetzki 2008). Although other species of rodent traverse and use all these zones, only the water mouse resides within the intertidal area (Watts & Aslin 1981). The water mouse is recorded in southeast Queensland, (Van Dyck & Gynther 2003; Kaluza et al. 2016) central Queensland (McDougall 1944; Ball 2004), the Northern Territory (Redhead & McKean 1975; Magnusson et al. 1976) and Papua New Guinea (Hitchcock 1998). Active at night, the water mouse builds various nest types in response to local tidal and vegetation conditions (Van Dyck 1997; Van Dyck & Gynther 2003). Nests are distinct, permanent, engineered structures, enabling the water mouse to inhabit one of the harshest eco-systems (Van Dyck 1996; Gynther 2001; Van Dyck & Gynther 2003).

The water mouse is listed as “Vulnerable’ under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the Queensland Nature Conservation Act 1992 (NCA; listed as false water-rat). Likely threats to the water mouse are associated with increased human disturbances and predation by feral animals such as the introduced pig, fox and cat (EPBC 2015; DERM 2010). Their known distribution is wide but patchy with evidence of decline in some regions (Van Dyck et al. 2006). Furthermore, the species conservation status in the Northern Territory is listed as ‘Data deficient’ under the Territory Parks and Wildlife Conservation Act 2000 (TPWC). A National Recovery Plan (DERM 2010) and Referral guidelines (DoEE 2015) identified Key Actions required for the recovery of the species.

This study examines the nest structural characteristics of the water mouse and the association between nest types and vegetation communities across three south east Queensland regions: the Great Sandy Strait, Maroochy River and Pumicestone Passage. This knowledge may lead to improved strategies for conserving this species.

4.3 Methods

Ethics statement

Permission to enter the study sites was granted by the Queensland Parks and Wildlife Service (QPWS), the Marine Parks Authority, and private landholders (MPP QS2015/GS033; WISP15971115; TWB/12/2015; WITK16035715; WITK16215415). The project was approved by the Animal Ethics Committee of Agriculture, Forestry and Fisheries (DAFF) (AEC permit number: CA 2014/08/797) and the project was undertaken in accordance with this approval.

4.4 Study sites

The study was conducted in coastal areas of the Great Sandy Strait (GSS), Pumicestone Passage (PP) and the Maroochy River (MR) in southeast Queensland, Australia (Fig. 1). Southeast Queensland is near the most southern extent of the water mouse's range. It is approximately 400 km south of the Tropic of Capricorn and has a subtropical climate. The GSS and PP represent two of the five RAMSAR sites located in Queensland (RAMSAR) and includes both extensive and relatively unaltered marine and freshwater systems of great conservation value. The MR is a relatively small river system located between these two other sites; it is extensively altered by agriculture and urbanisation (Kaluza et al. 2016).

We identified all potential water mouse habitat in each site using high-resolution aerial photography and GIS vegetation datasets maintained by the Queensland Herbarium. These habitats primarily consisted of intertidal wetlands containing common salt marsh, ruby saltbush (*Enchylaena tomentose* var. *glabra)*, bead weed (*Sarcocornia quinqueflora*), marine couch (*Sporobolus virginicus*), sedgelands, knobby club rush (*Isolepis nodosa*) and jointed rush (*Juncus kraussii*), as well as mangrove forests dominated by grey mangrove (*Avicennia marina* var. a*ustralasica*), orange mangrove (*Bruguiera gymnorhiza*), stilted mangrove (*Rhizophora apiculata*) and milky mangrove (*Excoecaria agallocha*).

4.5 Nest characteristics

We undertook extensive ground surveys for water mouse nests within the identified habitat at each site between September 2011 and September 2016. Surveys were undertaken by boat, canoe or typically by foot during low tide. Some areas were surveyed on multiple occasions to minimise the possibility of overlooking nests during surveys. All areas of suitable habitat were surveyed at the small MR site (Kaluza et al. 2016), but there remains much area to survey at the other two large sites. Once found, nests were categorised as either active or inactive based on sign of recent water mouse activity (e.g. fresh foot prints, mud daubing, vegetation disturbance, or the presence of fresh prey remains). The type of nest was recorded (i.e. mound nest, tree nest, or bank nest; Fig. 1), along with physical characteristics including nest height, basal circumference, the pH of the surrounding mud, and vegetation species present within 5 m of the nest. The number of entrance holes was also recorded for a random selection of 15 nests at GSS. We recorded evidence of nest damage by predators and identified the presence of any remains of water mouse food items or prey (e.g. shells of marine molluscs). Surveys were assisted by many different staff and volunteers over the study period, resulting in missing and incomplete data for some nest characteristics of interest. Sample sizes therefore varied between analyses, which utilised as much relevant data as possible.

4.6 Analysis

Analysis was undertaken using R (R Core Team 2002). Logistic regression using the function glm with a binomial distribution (logit link function) was used to assess associations between plant presence and nest type. Over (and under) dispersion was evaluated using Pearson residuals to ensure the dispersion parameter was approximately 1. Pearson residuals were used as it has much less bias than using the deviance (Venables and Ripley 2013). Post hoc multiple comparisons were accounted for using Tukeys to test all pairwise comparisons. The calculated R-squared equivalent was the percentage deviance explained from the null model. The ordination was an MDS map made using the function metaMDS.

95% confidence intervals showing plant effects on mound size were calculated using an ANOVA-style linear model analysis using the function lm, where a statistically ‘significant’ effect ($P<0.05$) was deemed to occur if the confidence interval doesn’t encompass 0 i.e. we are 95% sure the effect is different to 0 if it does not lie within the 95% CI. Confidence intervals were used (rather than p-values) because CIs also give an understanding of the likely effect size. The standard graphical assumptions were also tested (i.e. error was normal and random about zero).

The association between site and nest was tested using Fishers Exact test using the function Cross (Table 1), as the assumption that expected values must be >5 for all cells was not met.

4.7 Results

We found a total of 352 water mouse nests at GSS (n = 95; 76% active), MR (n = 185; 90% active) and PP (n = 72; 85% active). Three nest types were identified: mound, bank and tree types (Fig. 1). Mound nests were a free-standing dome or mound of mud that often occurred with minor structural support from pneumatophores and ground vegetation (e.g. marine couch, *Sporobolus virginicus*). Bank nests were located at or just below ground level in solid muddy banks typically not inundated with water during most high tides. Tree nests resembled mound nests, although were supported structurally by a large hollowed tree, allowing nest heights to exceed 2 m (limited only by the height of the hollow part of the tree). Given the obvious influence of tree hollows and bank size on the physical dimensions of the nest, analyses of nest height and circumference were performed only on mound nests.

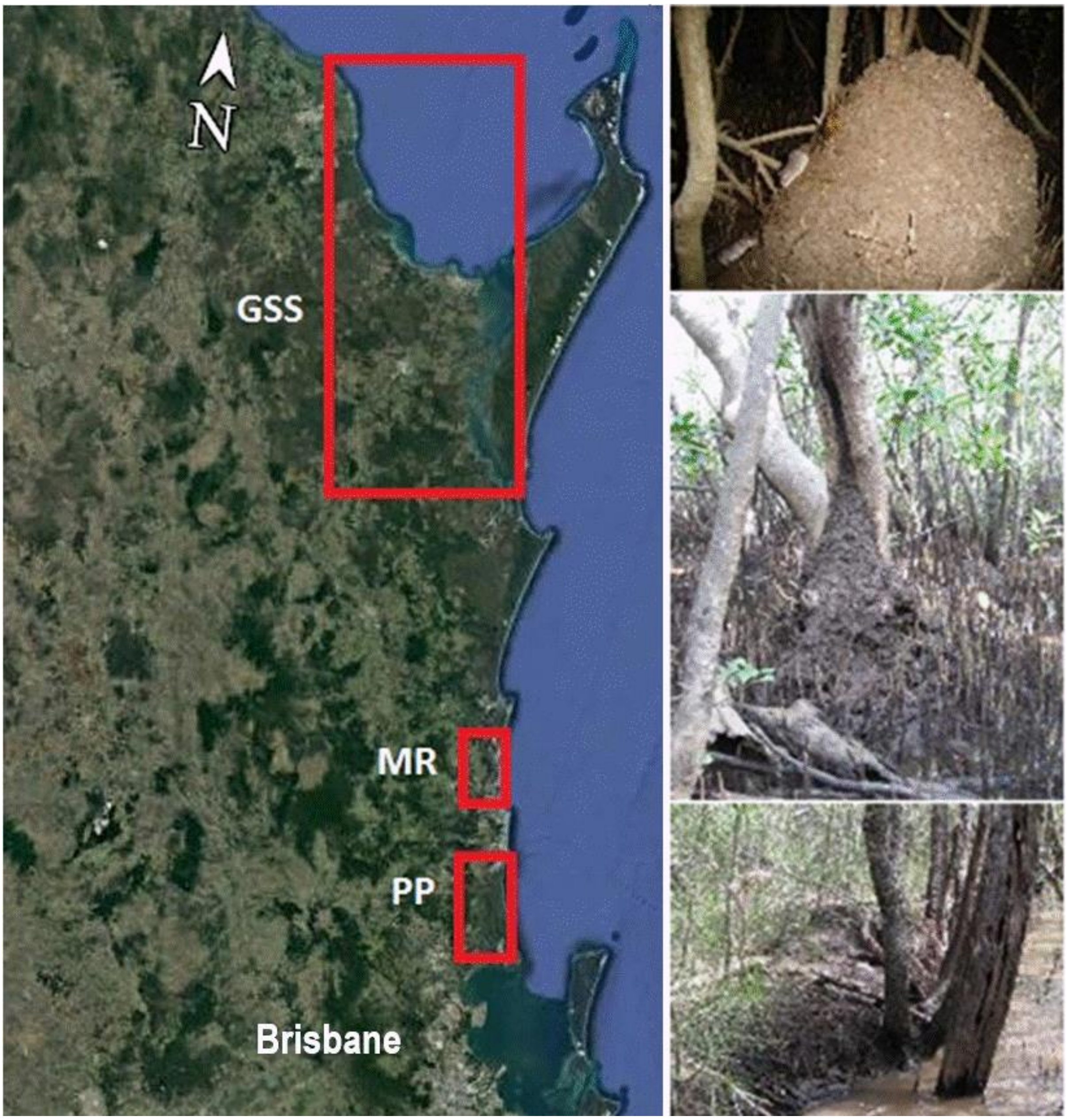

Figure 1. Location of the three study sites at the Great Sandy Strait (GSS), Maroochy River (MR), and the Pumicestone Passage (PP), with examples of water mouse mound (top right), tree (center right) and bank (bottom right) nest types (Photos Kaluza 2017).

The mean height of mound nests was approximately 50 cm (n = 223; range: 211 - 80 cm) and did not differ between sites (Fig. 2). The mean basal circumference of mound nests varied between 170 cm at PP and 270 cm at GSS, with a mean of 211 cm across all sites (Fig. 2). Mean mud pH was 6.1 at GSS (N = 23) and 5.6 at MR (N = 16). A mean of 5.8 entrance holes was observed from 15 nests at GSS. Snails, and crabs (e.g., *Glauconome* sp., and *Helice leachi*) were among the identifiable prey remains found around 272 active nests across all sites.

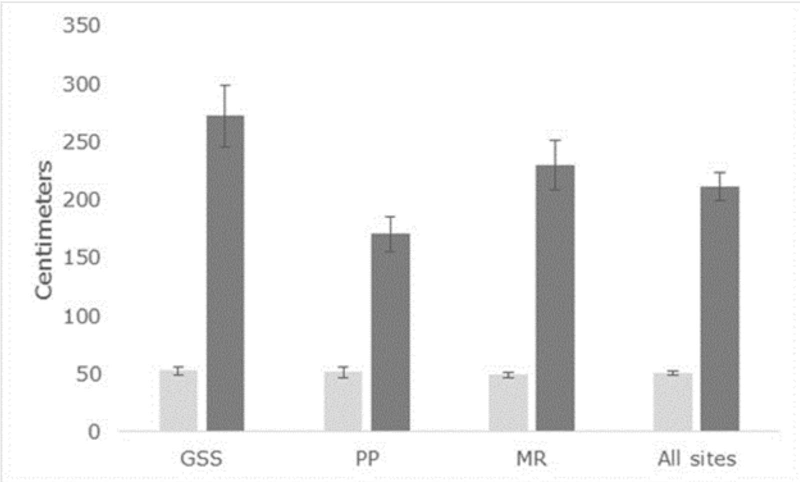

Figure 2. Mean nest height (pale columns) and circumference (dark columns) of free-standing mound nests at the Great Sandy Strait (GSS; N = 95), Pumicestone Passage (PP; N = 72) and Maroochy River (MR; N = 185) sites in southeast Queensland. The vertical lines at the top of each bar denote standard errors.

The presence of (*Excoecaria dulcis)* was associated with significantly greater mound heights than other plant species; where this plant species was present, mounds were on average 50cm higher, with the true difference being between 20-80cm (P(Ho: no effect) $p<0.05$ since the CI does not encompass 0) (Fig. 3). The presence of marine couch (*Sporobolus virginicus)*, jointed rush (*Juncus kraussii)* and knobby club rush (*Isolepis nodosa)* were each associated with significantly greater average mound circumferences of (80 cm, 110 cm, and 160cm, respectively).

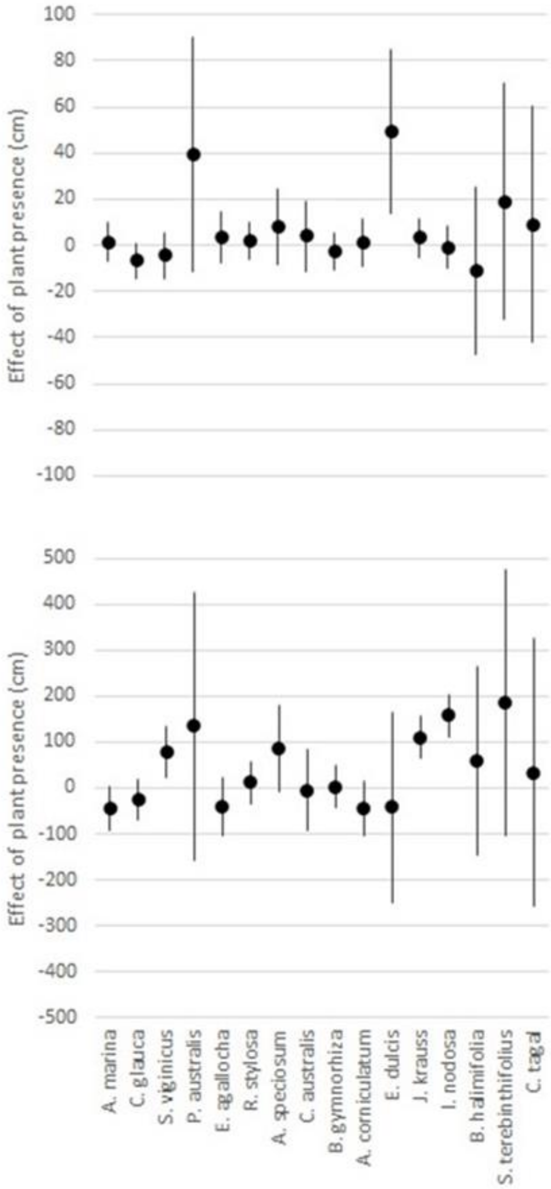

Figure 3. Effect of plant presence on mound height (top) and circumference (bottom) at all three sites combined.

There was a strong relationship between tree nests and grey mangroves (*Avicennia marina* var. *australasica*), which was expected given that all tree nests were inside these trees (Fig. 4; Table 1). The presence *of grey mangroves* was associated more often with tree nests (*Avicennia marina* was present with them 94% of the time) than mound nests (74% of the time) ($z = 3.937$, $p<0.001$), but not between mound nests (74%) or bank nests (69%; $z = -0.417$, $p=0.905$). Marine couch was more associated with mound nests at 79% of the time ; for tests on associations with the other two nest types, p = <0.03 on both occasions. *Casuarina glauca* was more associated with bank nests at 81% than the other 2 nest types (both p <0.04), and mangrove fern was more associated with bank nests at 56% (both p < 0.001).

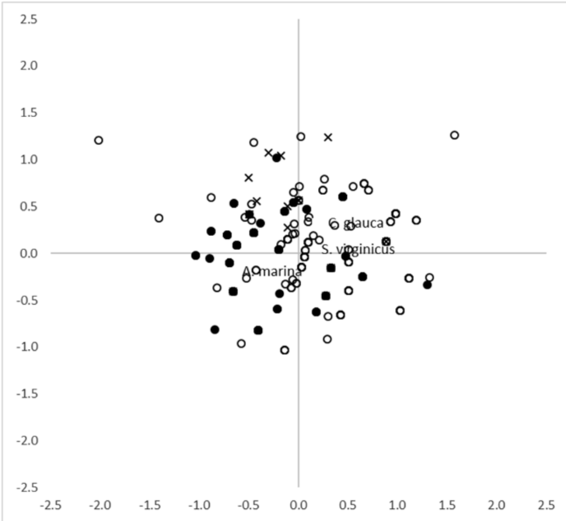

Figure. 4. Relationship between water mouse nest types (mound nests = hollow marks, tree nests = solid marks, bank nests = x) and three main plant species across all sites. Clustering of a given nest type around one of the plant species would indicate a strong relationship between that nest type and plant species.

Table 1. Relationship between plant presence and water mouse nest type at three sites in southeast Queensland, Australia. Score shown is the difference in the model coefficients between the 2 nest types (p-value). **This means association between bank nests and Swamp she-oak; salt couch and mound nests as relevant habitat for nest detection.

		Presence of plants near nest type			Coefficient (z)			
Species	**Common name**	**Mound**	**Bank**	**Tree**	**Bank - Mound**	**Tree - Mound**	**Tree - Bank**	**% Deviance explained**
A. marina	Grey mangrove tree	74%	69%	94%	-0.23 (0.91)	1.76 (<0.00)	1.99 (0.01)	6.7%
C. glauca **	Swamp she-oak	47%	81%	15%	1.58 (0.04)	-1.65 (<0.00)	-3.26 (<0.00)	10.4%
S. virginicus **	Salt couch	79%	50%	18%	-1.32 (0.03)	-2.81 (<0.00)	-1.49 (0.02)	24.2%
E. agallocha	Blind your eye mangrove	12%	25%	8%	0.88 (0.30)	-0.49 (0.46)	-1.38 (0.11)	1.7%
R. stylosa	Stilted mangrove	39%	50%	62%	0.43 (0.68)	0.92 (0.00)	0.50 (0.62)	3.2%
A. speciosum **	Mangrove fern	4%	56%	9%	3.31 (<0.00)	0.71 (0.30)	-2.60 (<0.00)	15.0%
B. gymnorhiza	Orange mangrove	37%	69%	68%	1.31 (0.04)	1.27 (<0.00)	-0.04 (1.00)	6.3%
A. corniculatum	River mangrove	14%	19%	13%	0.36 (0.85)	-0.11 (0.95)	-0.47 (0.78)	0.2%
C. australis	Yellow mangrove	5%	25%	8%	1.77 (0.02)	0.39 (0.68)	-1.38 (0.11)	3.5%

4.8 Discussion

The vegetation community surrounding a water mouse nest appears to have an important influence on nest structure. Our study found a strong association between mound nests and saltmarsh vegetation; this is consistent with previous findings by Van Dyck and Gynther, (2003). However, our study is the first to quantify these findings. We determined that habitat suitability is essential to water mouse survival, requiring the mosaic pattern of wetland communities. Across three sites, mound nests were clustered along the intertidal fringe with direct access to mangrove species (5 m circ.) of grey mangrove, orange mangrove and milky mangrove (Kaluza et al. 2016). We found the mean height (50 cm) of mound nests was uniform across sites whilst significant variation existed in mound base diameter (170 cm at PP and 270 cm at GSS). This is probably because saltmarsh has lower exposure to incoming tides as it is situated in the upper limits of the inter-tidal area, therefore, the risk of nests being flooded during medium/high tide events is infrequent. For the water mouse, nest foundation may be more important than nest height. The dominant presence of marine couch was found to influence the characteristic of the mound's base across three sites (79%). As described by Johns (2006) marine couch is a salt tolerant, low lying vegetation (height ≤30 cm) found in saltmarsh areas. In our study, closed grassland consisted of the matted marine couch and upon observation, the plant's presence seemed to stabilize sediment erosion in upper tidal areas.

Mud is the single most important element of a water mouse nest and is used to construct and maintain the structure, possibly over many lifespans (Redhead & McKean 1975; Magnusson et al. 1976). Therefore, it is understandable that the removal of mud caused by sediment erosion would prove problematic for nest construction and may explain the correlation with greater mound circumference (p=80 cm). Examination of sediment consistency at two sites revealed that pH levels (GSS 6.1; MR 5.6) taken at the mound base were slightly acidic but within the tolerable range (5 to 7) for soils in higher rainfall regions (DES 2018). Further observations of nest characteristics indicated each entrance hole to be approximately 5 cm in basal circumference. But the positioning of the nest access points varied between mounds (GSS) at either above or below the high tide mark; we do not have a strong understanding on the significance of this nesting activity and this requires further investigation.

Along the tidal flats we noted mostly a treeless vegetation consisting of low lying grasses that formed continuous groundcover in saltmarsh areas; some scattered emergent juvenile grey or milky mangrove trees were observed. In this study we found that mound nests were ~50 cm higher when *E. dulcis* was present, as opposed to areas where the species of plant did not occur. Apart from the effect of tidal influence and zonation, we do not know why the association occurs. However, previous studies by Van Dyck (1996) demonstrated that the water mouse uses the entirety of intertidal areas for various night-time activities. It is reasonable to suggest that nests are preferentially constructed on areas of higher ground near available food sources, to minimize the risk of tidal impacts. Therefore, this vegetation may occur near high points in the inter-tidal zone.

The composition of vegetation communities altered between sites with areas of predominant sedgelands being noted at GSS and PP. We identified that the presence of jointed rush and knobby club rush (p= 110 cm and p= 160 cm) influenced the basal characteristics of mound nests for combined sites. The role of each plant in determining the increase in nest circumference is unclear. However, in the upper tidal areas, it is plausible to suggest that water mouse nesting behaviour was dictated by the plants presence. Why the water mouse utilises this type of flora to construct its mound requires further investigation.

A strong relationship was identified between tree nests and grey mangroves (*Avicennia marina* var. *australasica*) along the tidal fringe. 94% of tree nests were found in or near grey mangroves; this is a stronger relationship then for banks (69% found near grey mangroves, p=0.01) and mounds (74%, p<0.01). There was no evidence of a difference between bank and mounds in terms of their association with grey mangroves (Fig. 4; Table 1). This is expected given that virtually all tree nests were inside these trees. In table 1 we test to see if there is a difference in vegetation association between the 3 different nest types using the "« « coefficients (z)" which is the difference in model coefficients between 2 nest types. In this instance we show that grey mangrove is seen more often with trees than mounds (p<0.001) or banks (p=0.01). However, there is no evidence of a difference between grey mangrove presence between mounds or banks (p=0.00). The strong association between tree nest type and grey mangroves was not unexpected as this nest type is characteristically found in grey mangrove (Van Dyck & Gynther, 2003).

Overall, we determined that 85% of the combined nest count (n= 352) were active for the three sites, with most of the mound nests (n= 223) being associated with saltmarsh (79%). Because of the vast difference between coastal landscape of the north and south sectors (Ball 2004; Van Dyck & Gynther 2003), our nest detection methods varied across the three survey sites (Van Dyck & Gynther 2003). The Great Sandy Strait was by far the largest and most challenging survey site due to periodic extremes of tidal movement. Across entire surveys, we noted a distinct zonation between salt tolerant species in mangrove communities: Swamp Oak (*Casuarina glauca;* freshwater woodlands*)*, Jointed rush *(Juncus kraussii and* Knobby club rush *(Isolepis nodosa;* sedgelands*)* Marine couch *(Sporobolus virginicus;* closed grassland*)* and Grey mangrove *(Avicennia marina),* Stilted mangrove *(Rhizophora stylosa),* Yellow mangrove *(Ceriops australis),* Orange mangrove *(Bruguiera* *gymnorhiza),* River mangrove *(Aegiceras corniculatum)* and Blind Your Eye mangrove *(Excoecaria agallocha).*

We observed that the absence of marine couch in areas badly degraded by roaming cattle or feral pig resulted in lower water mouse presence. Within the supralittoral zone, pig wallows and cattle trampling (also reported by Burnham (2000)), removed plant cover and prevented plant recovery, compromising water mouse habitat suitability. During the survey period, the Maroochy River was the only site with no trace of such disturbances. However, scats of the European red fox (*Vulpes vulpes*) were found along supralittoral banks and in some areas of saltmarsh on the western side of the river (Kaluza et al. 2016). The adjacent woodland area had been cleared to accommodate commercial and housing development. Future studies in these habitats should utilise camera traps to investigate if these vertebrate pests are threats to water mouse survival.

4.9 Conclusion

In this study, we have quantified a strong association between mound nests and saltmarsh vegetation. This is consistent with findings of previous qualitative studies (Van Dyck & Gynther 2003). During the three-year survey, two new water mouse localities in southeast Queensland were examined. We also demonstrated that suitable water mouse habitat is dependent on local ecosystem characteristics such as tide level and vegetation type. This knowledge is useful to focus future survey efforts for water mouse nesting sites. If used cautiously, the quantitative relationship that we have identified will inform future surveys for this species. As such, surveys are urgently needed for monitoring of water mouse distribution and to further refine habitat preference. We recommend that future studies compare soil characteristics between nested and non-nested areas to further define water mouse habitat.

4.9.1 Acknowledgements

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Chapter 5.

5.0 A longitudinal study of water mice activity and behaviour in response to meteorological events.

5.1 Abstract

This ecological study examines water mouse (*Xeromys myoides*) nest maintenance activity in response to meteorological events. Consistent camera monitoring recorded the species' nocturnal behaviour from a single mud mound at Maroochy River, southeast Queensland over the period February 2012 to September 2015. Overall, a network of direct and indirect effects of numerous predictor variables was tested identifying the most important factors affecting water mouse behaviour in its natural habitat. Nesting activities were established then characterised using Generalised Structural Equation Modelling (GSEM) and time series modelling to determine if water mouse increase nest productivity in response to significant measures. Models indicated summer nest maintenance peaked during the first four hours after sunset. Furthermore, the prediction of future tide levels (in about four hours) was strongly suggested when testing the behavioural response by the water mouse to these variable patterns. This study will aid recovery of this vulnerable species by filling gaps on its adaptation to critical habitat.

5.2 Introduction

Various small mammals construct underground nests for protection from predators, food storage, and shelter from environmental elements (Watts & Aslin 1981; Reichman and Smith 1990). Burrowing adaptations generate suitable microclimates in extreme environmental conditions (Bethge et al*.* 2004; McCafferty et al. 2003). Most underground nest chambers are deep and lined with plant material or fur, acting as insulation against fluctuating ambient temperatures (Casey 1981). However, the insulation quality of nests can be reduced by exposure to moisture (Gedeon et al. 2010), therefore the selection of nesting material is vital to reduce such affects as seen by the European ground squirrel (*Spermophilus citellus*) during nest preparation (Gedeon et al*.* 2010). Also, thermoregulation in mammals depends on available resources to construct dwellings, for example, the nest of a long-tailed tit, (*Aegithalos caudatus)* is no bigger than a tennis ball, yet the structure can house up to sixteen offspring in one season (McGowen et al*.* 2004). This is a prevalent trait in various small mammals; huddling at low temperatures is known to occur in the nesting chambers of the deer mouse (Howard 1951), taiga vole (Wolff & Lidicker 1981), and the brown rat (Alberts

1978). These are group behavioural mechanisms that enable body temperature regulation whilst conserving energy.

Nesting behaviour of the water mouse (*Xeromys myoides*), also known as Yirkoo, inhabiting intertidal zones, sometimes involves a family group constructing a large mound to provide refuge above the high tide level. The mound is regularly maintained by the mice daubing mud onto the exterior surface. Tidal surges and rainfall events caused by low pressure systems may inundate and damage the mound, although, inside the mound, the mice excavate nesting chambers that can withstand inundation (Van Dyck 2002).

Previous studies suggest the size of a nest may determine the number of mice inhabiting the mound (Van Dyck 1997; Van Dyck & Gynther 2003; Gynther et al*.* 2006). The water mouse's diet consists mainly of crustacean such as red-fingered marsh crab (*Parasesarma erythrodactyla)*, the purple and cream shore crab (*Helice leachii)* and molluscs (Van Dyck 2002). Likely threats to the water mouse are associated with increased human disturbances (Van Dyck et al. 2006; Kaluza et al*.* 2016), climate change and predation from introduced species such as pig (*Sus scrofa*), roaming cattle (*Bos taurus*), fox (*Vulpes vulpes*) and cat (*Felis catus*) (Burnham 2002; DERM 2010). Apart from findings from the Coomera River (Van Dyck et al. 2006) and the nature of the species' genetic structure (Benfer et al*.* 2014), there has been little emphasis placed on the driving forces behind the water mouse's decline or persistence in the habitats on which it depends. Furthermore, gaps in long-term monitoring on habitat association and water mouse behaviour remain (Dickman, et al*.* 2000; Burnham 2002; DERM 2010; Woinarski, et al. 2014; DoEE 2015; Worley & Parsons 2016; Kaluza et al*.* 2016). Therefore, its response to weather events has not been investigated for any length of time nor tested to enable better ecological management of the species. The focus of this study is to examine the nesting behaviour of the water mouse and its response to atmospheric and tidal conditions.

5.3 Methods

Ethics statement

Water mice are protected and presently listed as 'vulnerable' under the Federal Environment Protection and Biodiversity Conservation Act (1999) and are supported by a National Recovery Plan (2010). Permission to enter the study sites was granted by the Queensland Parks and Wildlife Service (QPWS) and Marine Parks Authority, and private landholders (MPP QS2015/GS033; WISP15971115; TWB/12/2015; WITK16035715; WITK16215415).

The project was approved by the Animal Ethics Committee of Agriculture, Forestry and Fisheries (DAFF) (AEC permit number: CA 2014/08/797), and the project was undertaken in accordance with this approval.

5.4 Study Design and Data Collection

This study focussed on a single mounded water mouse nest, situated in coastal wetlands at Bli Bli along the Maroochy River of south east Queensland (Kaluza et al*.* 2016). The nest is considered unusual as mud mounds are typically associated with saltmarsh communities, whereas this mound was located within a tidal mangrove forest and was devoid of marine couch. This allowed various aspects of the mud mound to be monitored by remote cameras, providing clear vision of water mouse activity. A total of three automated trail cameras (Pixcontroller trail cameras, Digital Eye TM, CAMO60 6.0, Digital Trail Camera) were deployed between March 2012 and July 2015. Considering the animals' size, movement and initial trigger activation, each camera was placed within two metres of the mud mound. Each camera was checked and serviced at seven-day intervals during data retrieval. Two cameras were replaced due to mechanical failure after being submerged during a king tide event. Kaluza et al*.* (2016) stated that 8000 images of water mouse behaviour were recorded, however, only 3500 were usable due to a technical failure in the time setting.

To ensure correct monitoring methods were used, a further 50 nests were camera-trapped during and after the same monitoring period in coastal wetlands of the Maroochy River, Pumicestone Passage, the Great Sandy Strait and Eurimbula National Park of south-east Queensland (Table 2). Although not used in the analysis of this study, visual observations confirmed matching nesting behaviour of the water mouse, irrespective of nest style or location (Figs. 1 & 2). For the practical purpose of this paper the water mouse will henceforth be referred to as WM.

5.5 Predictor and Response Variables

The predictor variables used in the analysis included tide levels measured every hour, lowest and highest daily tide, total daily rainfall, maximum daily temperature, total daily solar radiation, one-hour average atmospheric pressure, monthly average water salinity, monthly average acidity (pH) of water and monthly average water temperature. Predictor variable data were obtained from the Queensland Bureau of Meteorology (BOM 2017), Australia at the location of Sunshine Coast Airport (BOM station number 40861) located approximately 4 km from the observed WM habitat. The two response variables considered in this study were: (1) the total number of observations per day of WM engaged in any type of activities; and (2) the number of observations per day of WM engaged in nesting activities (i.e. construction or repairing of the nest structures). Both response variables were regarded as count variables, while the predictor variables were all numerical.

Two of the considered predictor variables – total daily solar radiation and maximum daily temperature – were expected to depend upon daily rainfall, and daily temperature was also expected to depend upon daily solar radiation. Because variables that depend on other variables should typically be distributed normally, skewness and kurtosis normality test was used to check for normality of total daily solar radiation and maximum daily temperature (D'Agostino et al. 1990). The application of this test to the indicated variables resulted in the *p*-values exceeding 0.3. This demonstrates that both variables were distributed approximately normally and did not require transformation.

Table 1**.** Major numerical predictor variables with the corresponding summary statistics including the average values and their standard deviations during the observation of WM behaviour.

Predictor Variable	**Mean Value**	**Standard Deviation**
Highest daily tide (m)	1.76	0.20
Lowest daily tide (m)	0.35	0.16
Daily rainfall (mm)	4.60	11.6
Maximum daily temperature (^oC)	25.7	3.7
Daily solar radiation (MJ/m^2)	17.6	7.8
Water salinity (g/kg)	19.5	14.0
Water pH level	6.6	2.7
Average water temperature (^oC)	18.7	8.6

5.6 Statistical Methodology

Statistical analysis was conducted using Stata14 statistical software (StataCorp 2015) to assess whether past or future meteorological and environmental events impact observed WM activity, particularly nesting activity (i.e. construction or repairing of the nest structures) Time series analysis was then used to determine time lags (Brockwell & Davis 1991; Hamilton 1994) and optimal lags (positive or negative) corresponding to maximal correlations between the WM observation numbers and lagged predictor variables were determined. The following predictor variables were examined for lag: hourly tidal levels, daily rainfall, hourly and daily atmospheric pressure, and daily solar radiation. Where a significant time lag was identified, further modelling was undertaken using the optimally lagged variable to more clearly examine correlation with WM observation numbers.

Both response variables (total number of WM observed engaging in any type of activities and the number of WM observed engaging in nesting activities) were recorded in the form of counts. Therefore, analysis is typically undertaken using either the Poisson regression model or negative binomial regression model (Cameron & Trivedi 1998). However, the Poisson model is a special case of the negative binomial model, and it is not applicable in the presence of over-dispersion, i.e., where the variance of the data exceeds its mean value (Cameron & Trivedi 1998). Therefore, to evaluate the presence of over dispersion, the log-transformed over-dispersion parameters were evaluated for both the response variables (Cameron & Trivedi 1998).

Significantly non-zero values of the log-transformed over-dispersion parameter highlight significant differences between the Poisson and negative binomial models, demonstrating the need for the use of the negative binomial model instead of the Poisson model (Cameron & Trivedi 1998). The *p*-values for the log-transformed over-dispersion parameters for WM total observation counts and WM nesting activities were equal to 0.057 and 0.098 respectively. This demonstrates the presence of over dispersion and significant differences between the Poisson and negative binomial models. Therefore, negative binomial regressions were used in this study to model observation counts.

Standard Structural Equation Modelling (SEM) cannot be used to examine negative binomial regressions, therefore Generalised Structural Equation Modelling (GSEM) was necessary for this purpose (StataCorp 2015).

One of the major benefits of GSEM is that both direct and indirect effects of different predictor variables on WM behaviour can be identified and characterised. As opposed to a direct effect, an indirect effect of one variable on another variable occurs through mediation of a third variable. Thus, there is an interaction chain: Variable 1 $\rightarrow$ Variable 3 $\rightarrow$ Variable 2 corresponding to the indirect effect of Variable 1 on Variable 2.

In many practical situations, the consideration of only direct effects may be insufficient as this might give an incorrect perception of the existing causal relationships and correlations between the variables. For example, it may be expected that daily rainfall is likely to have a causal effect on daily solar radiation (through increased cloud cover) and on maximum daily temperature. Therefore, daily rainfall could influence WM behaviour directly (for example, through the associated flooding) and indirectly (through the reduction of daily solar radiation and/or maximum daily temperature). Understanding these complex mutual effects and simultaneous quantification is only possible by analysing a network of significant direct and indirect effects using GSEM.

5.7 Results and Discussion

In this section, examination of WM behaviour using results generated by both generalised structural equation modelling and time series modelling is explored. Because of the many quantifiable steps performed in this study and to avoid inconvenience, both results and analysis/discussion are atypically presented in the same section.

Although not used in the analysis of this study, visual observations confirmed identical nesting behaviour of the water mouse, irrespective of nest style or location (Figs. 1 & 2).

Table 2. Camera monitoring at four sites captured nesting behaviour of the water mouse (*Xeromys myoides*) during 2012-2017 surveys. Vegetation types varied between sites of intertidal communities.

Site	**Community**	**Time of monitoring**	**No. of nests**	**Total camera trap days**
Maroochy River	Open to closed forest of *Avicennia marina*	Mar 2012 – Apr 2017	18	3089 - combined
Pumicestone Passage	Saline grassland	July 2013	1	14
Great Sandy Strait	Mixed species closed forest + saline grassland	July 2015 – Apr 2017	29	2078 - combined
Eurimbula NP	Mixed species closed forest	July 2017	2	31- combined

Figure 1. a) one water mouse evacuating and another water mouse remains on top of the nest (nest height 750 mm); response triggered by a high tide and excessive rainfall on 5 June; b) recovery of internal nest edifice by one of the two mice after flooding 6 June, Great Sandy Strait: (Photos Kaluza 2016).

Figure 2. Two mice work on external nest construction on 8 March 2012 Maroochy River: Nest height 650 mm (Photo Kaluza 2012).

5.7.1 Hourly Distributions of WM Observations

Distributions differed significantly for the summer and winter periods (Fig. 3). In particular, the average numbers of total WM observations and their nesting activities were significantly higher during the summer period (compare curves 1 and 2 in Figs. 3a, b) and winter months were characterised by much lower WM activity. This variation in seasonal activity was not expected as nests constructed by the WM provide year-round shelter and protection against high water with the WM reproductive cycle possibly occurring throughout the year (Van Dyck 1997).

In winter months, WM observation counts were approximately constant over the period of daily activities (approximately between 5pm and 6am) – Figs. 3a, b. At the same time, in summer, the situation was markedly different – there was a strong and significant peak of WM activities immediately after (or during) the sunset (see curves 1 in Figs 3a, b). Comparison of Figs. 3a and 3b, shows that this activity peak was dominated by extensive nesting activities within the first 2-3 hours after the sunset (Fig. 3b). This massive activity peak may be because of the nocturnal nature of WM and their need to repair and reinforce nesting structures after daytime tides and possible associated floods.

Once this immediate priority has been addressed, the level of WM activity on the nest mound drops significantly, including nesting activities. After 11pm in summer, WM activities were approximately the same as in the winter period. This corresponds with the routine activity level in the absence of the immediate nesting activities. Thus WM nesting activities appear to primarily occur within about 4 hours after the sunset, with activity peaking around 2 hours after the sunset (curves 1 in Figs. 3a, b). However, maintenance activity appears not as intense during the dry winter season (June – August). This is consistent with the absence of any significant activity peaks on curves 2 in Figs. 3a, b.

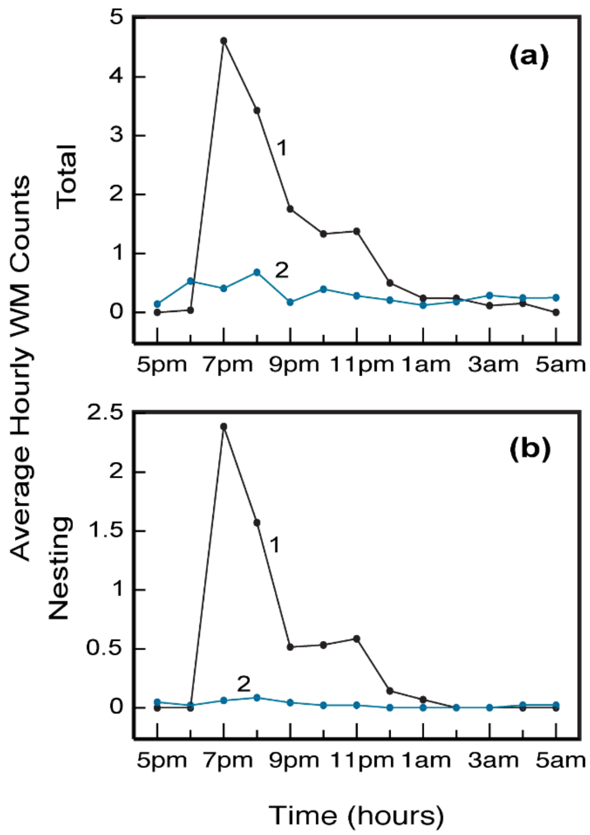

Figure 3**.** Average hourly WM counts over the typical daily activity period (5pm to 6am) for: (a) total observation counts (any type of WM activity); and (b) nesting activities. Curves 1 are for the summer period (December – February) in years 2012 to 2015, and curves 2 are for the winter period (June – August) in years 2012 to 2015. The time on the horizontal axis indicates the beginning of the respective hours, for example, 5pm indicates the hour between 5pm and 6pm, and 5am indicates the hour between 5am and 6am, etc.

5.7.2 Time Series Analysis

Because this particular WM habitat consisted of wetlands at the edge of a marine environment, it was expected that meteorological conditions, flooding events and local tidal patterns would have significant impacts on WM behaviour. These events were expected to be particularly relevant to WM nest maintenance because nesting structures are understood to protect WM from flooding and tidal events (Van Dyck & Gynther 2003; Gynther & Janetzki 2008).

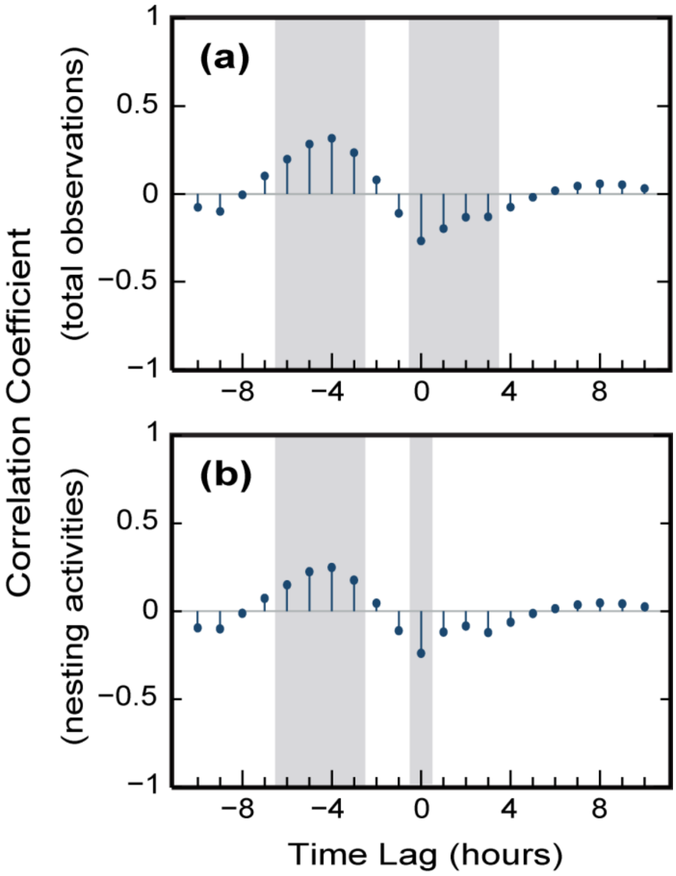

Figure 4**.** Correlation coefficients *R (y-axis)*: (a) between the hourly number of total observations of WM and local tide level for different (positive and negative) time lags (x-axis) in the local tidal level data; and (b) between the hourly number of observations of WM undertaking nesting activities and local tide level for different (positive and negative) time lags (x-axis) in the local tidal level data. The vertical shaded bands indicate statistically significant correlations ($p < 0.05$). The presented dependencies are for January (years 2012 to 2015) when the level of WM reproductive activities was the highest.

Correlations between WM observation counts and past and future meteorological events were calculated using time-series correlograms (Figs. 4 and 5). A correlogram represents the dependence of the correlation coefficient *R* between the respective WM observation counts and the assumed time lag for the variable of interest (e.g., hourly tidal levels or daily rainfall, etc.). The assumed lag was varied continuously within a reasonable interval, e.g., between – 10 hours and + 10 hours (for the hourly data - Fig. 6), or between – 10 days and + 10 days (for the daily data - Fig. 5).

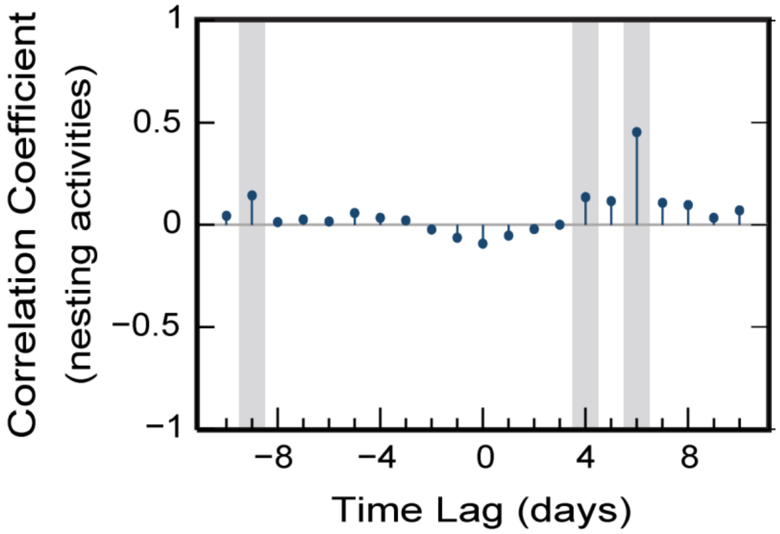

Figure 5. Correlation coefficients *R (y-axis)* between the daily number of observations of WM undertaking nesting activities and daily rainfall for different (positive and negative) time lags (x-axis) in the daily rainfall data. The vertical shaded bands indicate statistically significant correlations ($p < 0.05$). The presented dependence was derived on the basis of the overall database including summer and winter months in years 2012 to 2015.

Figure 4 shows the time lags (+/-) between WM observation counts and future tide levels for January (middle of the Australian summer) when a high level of reproductive activity is probable. During this time WM are expected to focus on maintaining their nesting structures to protect their young from exposure to dangerous external environmental and climatic factors.

Substantial correlation maxima exist between the numbers of WM total observations (WM nest maintenance activities) and tide level time, lagged by ~ -4 hours (Figs. 4a, b). The negative sign indicates that the observed WM activities occurred in response to the projected (future) tide level that was to occur in ~4 hours. +'ve optimum lag correlations (Figs. 4a, b) show that increasing the expected future tide level results in increased overall and nesting WM activity. Suggesting that WM have the capability to predict future tide levels, evaluate the expected threat to their nesting structures, and respond in advance by increasing their nesting activities (Fig. 4b).

Significant negative correlation between current (zero lag) tide level with WM nesting activities (Fig. 4b) and with total WM observations (Fig. 4a) is expected. This is because high water levels (caused by the current high tide) impede all types of WM activities (Van Dyck & Gynther, 2003). This trend remained significant into the future for around 3 hours for the total observation count (Fig. 4a).

Interestingly, no significant correlations are observed between tide levels 8 – 10 hours into the future (Figs. 4a, b). WM activities occur only between around 6pm and 6am (water mice are nocturnal animals), therefore it appears that WM do not prepare for tides occurring during daytime 8 – 10 hours after the end of WM daily activity period. However, this behaviour may not be detrimental because, a tide occurring 8 – 16 hours after the end of the WM daily activity period is preceded by an earlier tide that will initiate natural nocturnal activity, thus also preparing for the tide occurring significantly outside of the nocturnal activity period.

The relatively low (although still significant) correlation coefficients at the optimal time lag for tide levels (Figs. 4a, b) were calculated using the overall database, including daily and nightly tides (including those outside of the natural period of WM nocturnal activity). Therefore, the presence of daily tides to which WM might not respond directly results in a notable reduction in observed optimal correlation coefficients. Further, the pronounced maximum in both overall and nesting activity immediately after sunset (Figs.3a, b), related to the need to fix nesting structure caused by daytime tides, further contributes to reducing correlations between WM nesting activities and future tidal levels four (4) hours later. Under these circumstances, the pronounced significant correlation maxima (corresponding to future tidal levels four (4) hours later) obtained in Figs. 4a, b illustrates the strength of those correlations. Including the WM's ability to predict future tide levels (occurring within 3 – 6 hours – Figs. 4a, b) and to evaluate the associated dangers to their nesting structures.

Dependences evident in Figs. 4a, b are only typical for the summer months. No significant correlations were observed for the winter months of June, July and August. This is consistent with the much lower level of nest maintenance activity observed in winter months (curves 2 in Fig. 3).

A sharp and strong correlation maximum exists between WM observations undertaking nest maintenance and daily rainfall at the positive rainfall lag of 6 days, with significant correlations observed for days 4 and 6 (Figure 5). This shows that WM nest maintenance activity significantly increased approximately 6 days after rain. This is because cohesive mud is the primary substance used by WM to maintain their nests and after significant or lengthy periods of rainfall /tidal activity, the mud is too saturated. This may preclude WM from transporting it in their mouths to their nest for daubing.

The correlation coefficient (about 0.5 – Fig. 5) may be low because all days of observation were considered. However, winter observations revealed only limited nesting activities (Fig.

3). This probably caused a reduction in the optimal correlation coefficient. Had only summer months been considered, the optimal correlation coefficient may have been larger, indicating the strong trend for WM nest maintenance activities to occur on the 6th day after rainfall (Fig. 5).

No significant time lags were identified when examining past or future hourly or daily atmospheric pressure, or daily solar radiation. It appears that WM do not significantly change their behaviour because of past or future variations in daily average atmospheric pressure or daily average solar radiation.

5.7.3 GSEM Results: Hourly Database

For GSEM analysis, daily rainfall was merged with the hourly database so that each hour on a particular day of observation was assigned the average rainfall for that day. Rainfall may particularly affect WM behaviour and this allowed use of the rainfall data in the hourly model (Fig. 6 and Table 4).

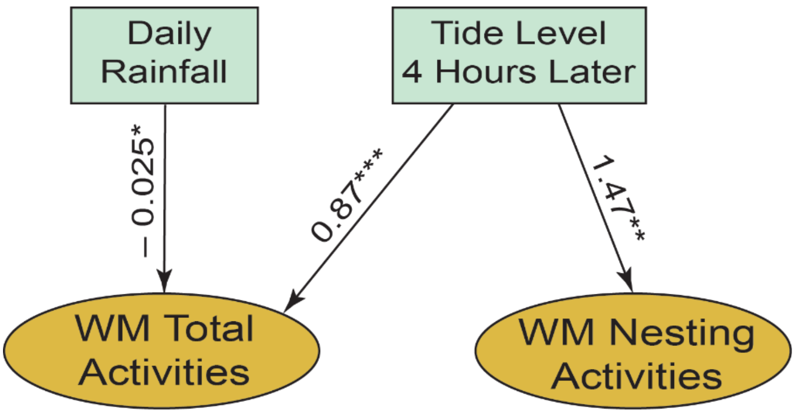

Figure 6. GSEM structure for the hourly counts of WM activities for observations in the middle of summer (January in years 2012 to 2015). Asterisks indicate the levels of statistical significance: (***) $p < 0.001$; (**) $0.001 \le p < 0.01$; (*) $0.01 \le p < 0.05$.

Because both response variables consisted of counts with over dispersion (see the Statistical Methodology section), negative binomial regressions were used for the development of the GSEM model (Fig. 6 and Table 3). The Tide Level 4 Hours Later (TL4h) significantly affected both response variables. Increasing TD4h by one metre was observed to increase total WM counts by a factor of exp. (0.87) ≈ 2.39 times, and WM nesting activities by a factor of exp. (1.47) ≈ 4.35 times. These results illustrate that WM nest maintenance appears to dominate other activity types; the rate of increasing counts of nesting activities (4.35) is significantly higher than that of increasing total observation counts (2.39).Therefore, the overall increase in total observation counts is largely related to (or dominated by) the increase in the counts of nest maintenance activity. These results strongly suggest the ability of WM to predict the level of the future tide (in about four hours' time) and undertake preventative measures aimed at reinforcing or repairing their nesting structure to withstand the adverse effects of the forthcoming tide.

Table 3. GSEM outcomes for hourly counts of WM activities.

Response Variables	**Predictor Variables**	**Regression Coefficient**	***p*-value**
WM Total Activities count (hourly)	Current Tide Level	0.87	< 0.001
	Daily Rainfall	– 0.025	0.032
WM Nesting Activities count (hourly)	Tide Level 4 Hours Later (TL4h)	1.47	0.001

Daily Rainfall does not appear to have a significant impact on nest maintenance by WM (Fig. 1), but it does appear to have a significant negative impact on total observation counts (Fig. 6). An increase in daily rainfall by 1 mm resulted in a reduction of the total number of WM observations by a factor of exp. $(-0.025) \approx 0.975$ (i.e., by about 2.5%). Increasing daily rainfall by 10 mm resulted in a reduction of the number of total WM observations by a factor of $\exp(-0.025 \times 10) \approx 0.779$ (i.e., by about 22.1%). Increasing daily rainfall does not interfere with WM nest maintenance, but significantly reduces the overall activities. This may be because this is a vital activity for the survival of WM and its offspring. Such activities appear to be undertaken largely irrespective of rainfall to ensure adequate protection from future tides and the associated flooding effects. Therefore, in the developed model, flooding effects associated with rainfall did not appear as dangerous as high tides. At the same time, increased rainfall significantly reduced total WM sightings/activities.

Further, as the future tide level (4 hours later) increases from around 0.2 m to around 1.8 m, the fraction of WM nest maintenance activity (out of the total number of WM observations) monotonically increased from around 0.2 (or 20%) to around 0.45 (or 45%) (Figure 7). Thus, the fraction of observations of WM nesting activities significantly increased with increasing future threats (in the form of higher tide levels) around four hours after the time of observation. This trend was only observed in summer months, particularly in January, i.e., presumed to be at the peak of the monsoon season.

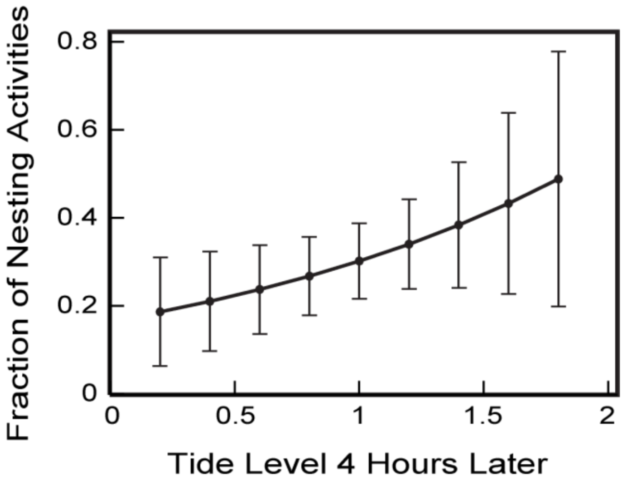

Figure 7. The dependence of the fraction of WM nest maintenance out of total WM observations on tide level (in meters) 4 hours later in the middle of summer (January in years 2012 to 2015). The error bars show the 95% prediction (not to be confused with confidence) intervals for the considered points.

5.7.4 GSEM Results: Daily Database

On most observation days, maximum daily temperature exceeded 20 C^o. Only on seven observation days (out of 102) was the maximum daily temperature below 20 C^o. If all observation days (including those with the maximum daily temperature below 20 C^o) were used, the resultant GSEM model malfunctioned; it failed to predict statistical errors for predicted WM observation counts, probably because of the insufficient number of observations with the maximum daily temperatures below 20 C^o. Additionally, the GSEM model was unduly extended into the temperature range $\leq$ 20 C^o. Therefore, those seven observations were removed from the model and were not further considered.

Data for the variables measured monthly, including Monthly Salinity, Monthly pH levels, and Monthly Water Temperature, were merged with the daily database so that each observation day on a particular month was assigned the values of these variables corresponding to that month. This allowed the use of the monthly-measured variables in the daily model (Fig. 8 and Table 5).

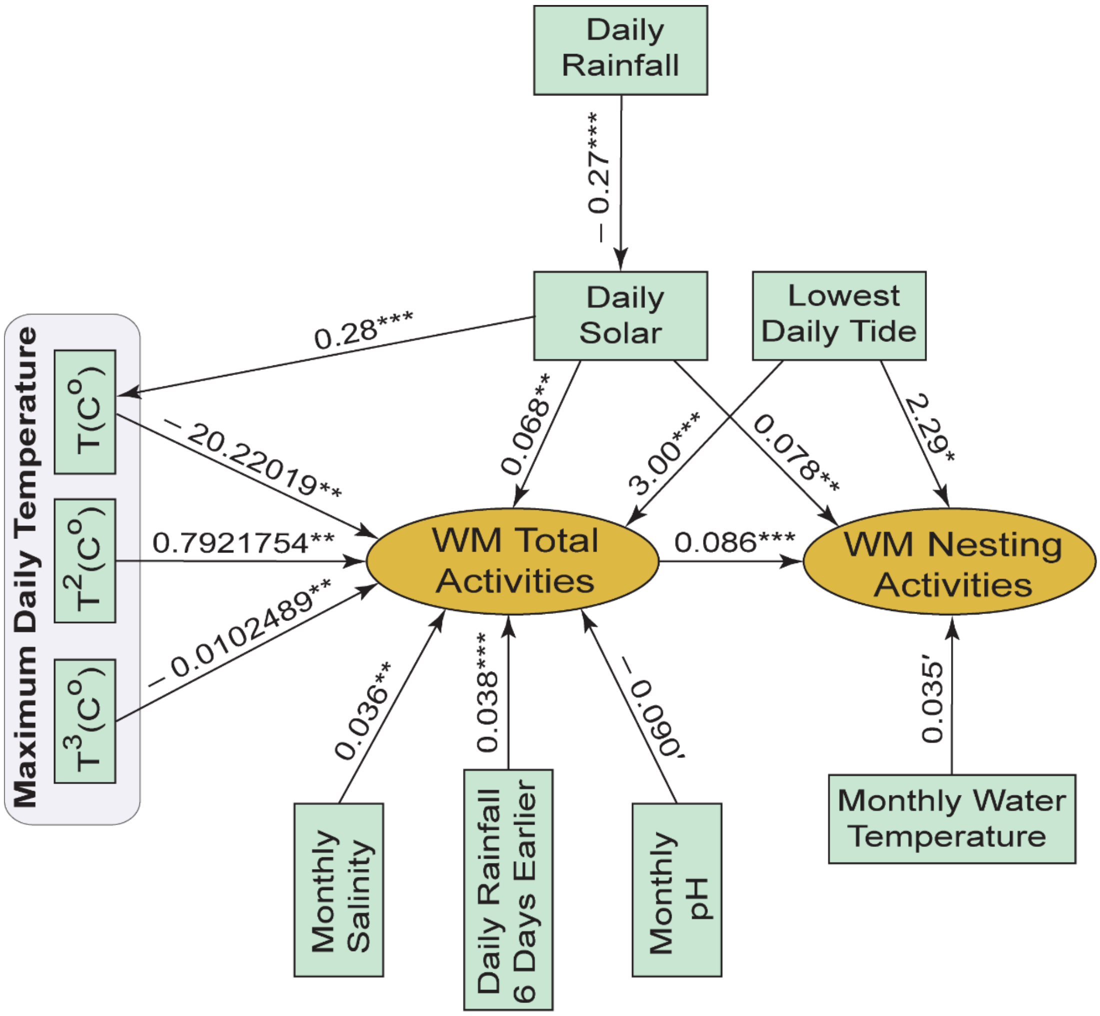

Figure 8. GSEM structure for daily counts of WM activities for observations over all seasons in years 2012 to 2015. Asterisks indicate the levels of statistical significance: (***) $p < 0.001$; (**) $0.001 \leq p < 0.01$; (*) $0.01 \leq p < 0.05$; and (′) $0.05 \leq p < 0.1$.

Interactions between the considered predictor variables and any possible non-linear effects were also evaluated. No significant interactions were found. However, the dependence of total WM observation count on temperature was found to be significantly non-linear with up to the fourth power of temperature being significant in the model (Fig. 8).

Table 4. GSEM outcomes for daily counts of WM activities.

Response Variables	Predictor Variables		Regression Coefficient	*p*-value
WM Total Activities count (daily)	Minimum Daily Tide Level		3.00	< 0.001
	Daily Rainfall 6 Days Earlier (DR6d)		0.038	< 0.001
	Daily Solar Radiation		0.068	0.002
	Monthly Salinity Level		0.036	0.002
	Monthly pH level		– 0.090	0.096
	Maximum Daily Temperature	T(C°)	– 20.22019	0.008
		T^2(C°)	0.7921754	0.006
		T^3(C°)	– 0.0102489	0.005
WM Nesting Activities count (daily)	WM Total Activities Count		0.086	< 0.001
	Minimum Daily Tide Level		2.29	0.014
	Daily Solar Radiation		0.078	0.001
	Monthly Water Temperature		0.035	0.066
Maximum Daily Temperature	Daily Solar Radiation		0.28	< 0.001
Daily Solar Radiation	Daily Rainfall		– 0.27	< 0.001

Regression coefficients for the non-linear temperature terms in Fig. 8 and Table 5 are given up to the 5th – 7th decimal places. This accuracy is required to ensure the correct calculation of the overall non-linear effect of Maximum Daily Temperature (Gramotnev pers. comm., 2017); for example, reducing the number of decimal places in the presented values of the regression coefficients by 1 results in errors in the count ratios (Eq. (1)) of around 1%.

$$\frac{N}{N_0} = \exp\{K_1(T - T_0) + K_2(T^2 - T_0^2) + K_3(T^3 - T_0^3)\}, \qquad (1)$$

where N and N_0 are the WM Total Activities counts at the Maximum Daily Temperature of T and T_0, respectively, and K_i (i = 1, 2, 3) are the regression coefficients for the respective maximum temperature terms in the first, second, and third powers (Fig. 8).

Via Equation (1), if the maximum daily temperature is increased from 25 C^o to 26 C^o, $N/N_0 \approx 1.20$, meaning an increase in WM Total Activity of ~20%. At the same time, if the maximum daily temperature is increased from 29 C^o to 30 C^o, then $N/N_0 \approx 0.79$, meaning a decrease in the WM Total Activity by ~21%. This demonstrates the importance and strength of the identified non-linearity of the dependence of the WM observation counts on maximum daily temperature.

The non-linear relationship between total WM observation counts and maximum daily temperature shows a strong and statistically significant maximum at around 28 C^o (Fig. 9), suggesting that the optimal maximum daily temperature for enhanced WM activities is around 28 C^o, with a significant reduction in activity both below 26 C^o and above 30 C^o (Fig. 9). The activity minimum observed at around 23 C^o is statistically insignificant due to increased prediction errors at both ends of the presented dependence (at low and high daily temperatures). Therefore, the increase in WM activity seen at low temperature (Fig. 9; < 23 C^o) was not considered further.

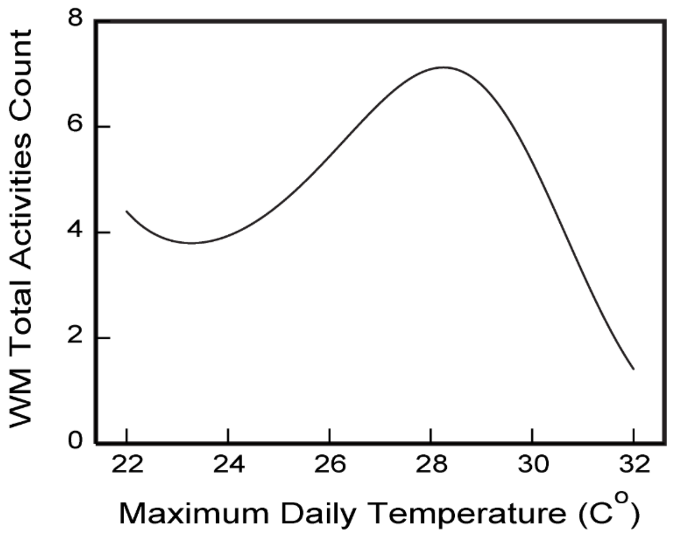

Figure 9. Dependence of the total observation count of any type of WM activities on maximum daily temperature obtained from the GSEM model in Fig. 8 and Eq. (1). The other predictor variables were assumed to take their mean values (see Table 2).

Several significant direct and indirect effects of different predictor variables affect WM total and nesting activities (Fig. 8); expectedly, WM total activities count is significantly correlated with the effect on WM nesting activities (Fig. 8). Lowest Daily Tide, Daily Solar Radiation, and Monthly Water Temperature are the only other three predictor variables that significantly (directly) affect WM Nesting Activities (Fig. 8), with the Lowest Daily Tide having by far the strongest direct impact. All other variables, including Maximum Daily Temperature are observed to have only an indirect effect on WM Nesting Activities through the mediation of WM Total Activities (Fig. 8). Daily Rainfall only indirectly affects both WM Total Activities and WM Nesting Activities, whereas Daily Rainfall six days earlier has a highly significant direct effect on WM Total Activities.

The dependence of WM total activity on daily rainfall six days earlier and on lowest daily tide level demonstrated significant exponential dependence, with a strong increase in WM total activity over the range of the considered predictor variables (Fig. 10). This was expected. A particularly strong dependence was observed for the daily rainfall six days earlier (Fig. 10a), with an increase in the total observation count from around five for 0 mm past rainfall to around 35 for 50 mm past rainfall. This observation is consistent with results shown in Fig. 5 that demonstrate a significant positive time lag of around six days between WM activities and past rainfall, because of the need for the mud to settle and partially dry after significant past rain before nest construction and/or repairing. Furthermore, the strong increase in WM activities evident in Fig. 10a suggests the need for WM to compensate for lost time (as a result of past heavy rain) to maintain the nesting structure effectively against the flooding dangers predominantly associated with high tides (see above section GSEM Results: Hourly Database).

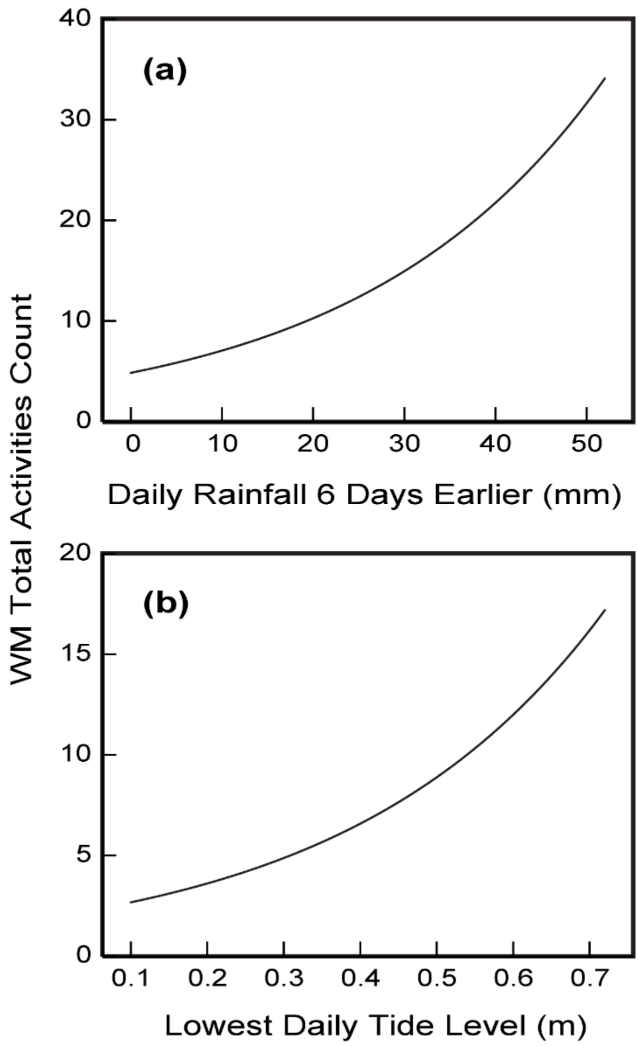

Figure 10. The dependences of the total observation counts of any type of WM activities on: (a) daily rainfall 6 days earlier; and (b) lowest daily tide level. The dependences were obtained from the GSEM model in Fig. 8. The other predictor variables were assumed to take their mean values (Table 1).

A lower daily tide level reduces the overall (average) danger caused by high tide levels resulting in an exponential reduction in WM activities (Fig. 10b). Interestingly, this significant trend exists irrespective of the highest daily tide level, and appeared to be insignificant in the model (Fig. 4).

The dependences of total and nesting WM counts as functions of daily solar radiation (Fig. 11a), and the dependence of the fraction of nesting counts in the total count as a function of daily solar radiation (Fig. 11b) were obtained by considering the total effects (i.e., the sums of the direct and indirect effects) of solar radiation on total WM observation counts and nesting WM observation counts.

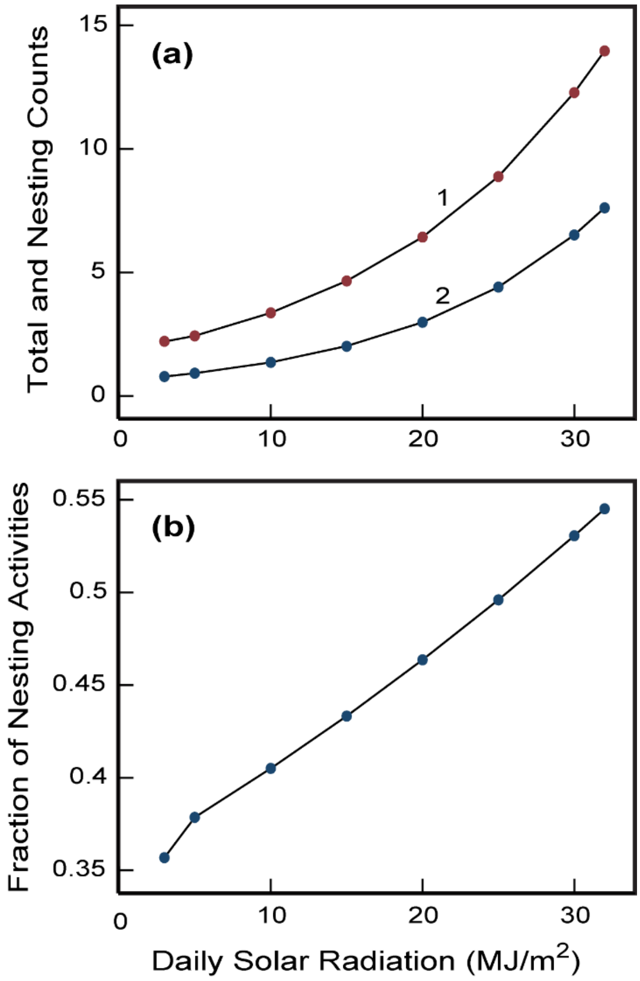

Figure 11. (a) The dependences of the total (curve 1) and nesting (curve 2) observation counts on daily solar radiation; and (b) the dependence of the fraction of nesting activity counts in the total count of WM observations on daily solar radiation. The dependences were obtained for the total effects of daily solar radiation using the GSEM model in Fig. 8. The other predictor variables were assumed to take their mean values (Table 1).

The fraction of nesting activities in the total observation counts increases monotonically from around 0.35 (for near-zero daily solar radiation) to around 0.55 (for the daily solar radiation of around 0.55 MJ.m^2) – Fig. 11 (b). This approximate linear dependence shows increased domination of nesting activities in the total observation count with increasing solar radiation. It is hypothesised that increased daily solar radiation improves conditions for undertaking nesting activities by way of increasing ambient temperature and reducing humidity, both of which are expected to facilitate removal of excessive moisture from the mud used by WM for their nesting structures, thereby increasing structure strength.

5.7.5 Conclusions

In this paper, detailed analyses based on Generalised Structural Equation Modelling and Time Series Modelling of WM behaviour in their natural wetland habitat was presented. These highly sought-after near-shore habitats are particularly vulnerable to human interference and expansion of urban development (Kaluza et al. 2016). Such development has significant capacity to permanently change the environmental cycle of tidal patterns in the wetland areas; their salinity, pH levels, and established natural temperature regimes. Changing climatic conditions add further to the uncertainties faced by these fragile ecological systems and their inhabitants, including WM. Analyses of quantitative data presented herein are the first consistent study of meteorological effects on WM behaviour, (including its crucial nesting activities) and are of significant importance for any relevant future conservation decision-making processes. Further, findings herein should provide for the development of new evidence-based programs to protect wetland habitat, essential to water mouse recovery. Primary findings include:

1. WM nesting activities primarily occurred within the first four hours after sunset, with the major peak of activity occurring around two hours after sunset.

2. This activity burst was only characteristic for the summer period corresponding to the peak of WM monsoon season. Beyond the four-hour interval after sunset, the average levels of WM activities (including nesting activities) were indistinguishable for the summer and winter periods.

3. Time series analysis and GSEM strongly suggest the ability of WM to predict future tide levels (in about four hours) enabling the undertaking of preventative measures aimed at reinforcing or repairing their nesting structures to withstand the adverse effects of the expected tide. The significant correlations between WM nesting activities and future tide level were observed only during the summer period corresponding to the possible peak of WM reproductive cycle.

4. A significant lag of around six days between local rainfall and increased overall WM activities was linked to excessive moisture in the mud, making nesting (and, potentially, other) WM activities difficult.

5. A network of direct and indirect effects of numerous predictor variables on WM overall and nesting activities was established and characterised using GSEM, thereby identifying the most important factors affecting WM behaviour in its natural habitat.

6. Daily solar radiation was found to have direct positive effects on both WM overall and nesting activities; this could also be explained by the role of solar radiation in maintaining suitable levels of moisture of the mud in the WM habitat.

7. The effect of temperature was significantly non-linear and the optimal maximum daily temperature for WM activities was around 28 C^{o}. This effect was also related to observed significant non-linearity's between the indirect effect of solar radiation on WM overall activities through the mediation of maximum daily temperature.

In conclusion, one of the major features of WM behaviour are their nest maintenance during summer months. This activity appears to dominate all other activity. WM demonstrate significant and fine-tuned behavioural patterns that are responsive to meteorological conditions and appear designed to mediate past and future environmental events thereby mitigating adverse impacts on their nesting capability.

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Chapter 6

6.0 Nest demise and risk factors threatening the persistence of the water mouse along the Pumicestone Passage, south east Queensland.

6.1 Abstract

The water mouse is a small and vulnerable rodent present in coastal wetlands of Queensland and the Northern Territory and in Papua New Guinea. Current knowledge regarding the distribution of the water mouse is incomplete and the loss of one local population has been documented in south-east Queensland (Kaluza et al. 2016), a region where pressures from urban and industrial development are increasing. In 2012 a survey targeting the water mouse was performed through 53.49ha of saltmarsh and mangrove communities at Hussey Creek, which borders the Pumicestone Passage. Water mouse presence was determined using established methodology, with seven nests and signs of feeding activity being located. Subsequently, a report prepared by Vardy and Anderson in May 2016, raised concerns about environmental impact for this site, caused by adjacent land management. Such detrimental impacts on this species are listed as a Matter of National Environmental Significance (MNES) under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*. Therefore, all seven water mouse nests were revisited to examine current status and occupancy. Five out of seven (71%) nests located in this area were no longer active indicating that water mouse presence is in decline at this site. This study addresses concerns for known water mouse nests in the Hussey Creek wetlands of the Pumicestone Passage of south-east Queensland.

Key words - Water mouse, *Xeromys myoides*, wetlands, saltmarsh, pollution, ecology, protected area management.

6.2 Introduction

The water mouse (*Xeromys myoides*) is listed as vulnerable under the Commonwealth's Environment Protection and Biodiversity Conservation Act (1999) and Queensland's Nature Conservation Act (1992). A National Recovery Plan (DERM 2010) has been prepared for this species, with protection measures reinforced by Referral Guidelines developed by the Commonwealth of Australia (2015) to help proponents of projects within water mouse habitat avoid significant impacts to the species. The water mouse is recognised as being a 'single national important population' with a patchy distribution along the south-east coast of

Queensland to the Northern Territory (Benfer et al. 2014). South-east Queensland is at the most southern extent of the species' range.

The nocturnal water mouse builds nest structures, often in the form of mud mounds, and forages for invertebrates such as crabs, molluscs, and flatworms in coastal habitats, primarily inter-tidal systems (Kaluza 2012). Adverse effects to the water mouse's environment include: habitat loss, degradation and fragmentation, changes to hydrology, acid sulfate contamination, introduced predators and possible climate change (Van Dyck & Gynther 2012). Previous studies suggest the species breeds twice annually, giving birth to 1-3 offspring, and the individual life span is approximately three years (Van Dyck 1997). Other research has concluded the main threat to the water mouse is inappropriate management of adjacent land leading to sediment or hydrology changes in the intertidal zone (Van Dyck et al. 2006; Gynther & Janetzki 2008). These adverse effects to water mouse populations must be avoided elsewhere in south-east Queensland because local loss can progress to regional species extinction.

In 2012 a survey targeting the water mouse was performed through 53.49ha of saltmarsh and mangrove communities at Hussey Creek, which forms part of the Pumicestone Passage. This area is of international importance and is situated within the 11,000 hectares protected by the Moreton Bay RAMSAR site. Access to the survey site was gained through a local government estate managed by the Sunshine Coast Council and by prior arrangement with the adjacent private land owner. A preliminary search of this area was conducted to determine what duration and timing would be required for a more thorough survey for the water mouse. A 2-hour reconnaissance visit was conducted on the 27th June 2012, with assistance from staff of the Queensland Parks & Wildlife Service. Subsequently a detailed mapping and assessment survey was undertaken on 23rd August 2012.

During this survey, it was noted that the saltmarsh was significantly degraded by roaming cattle due to the lack of fencing between the two land parcels. Nevertheless, water mouse presence was determined using established methodology, with seven nests and signs of feeding activity being located. A report of these findings and their implications was submitted to Sunshine Coast Council, Queensland Parks & Wildlife Service and the funding agency WetlandCare Australia (Kaluza 2012). The report's aim was to present the results from the survey via a comprehensive map and to provide recommended actions to assist with the present and future conservation of the water mouse.

Staff from the Department of Science, Information, Technology and Innovation (DSITI) undertook three sediment and water quality samples between 2015 and May 2016 within the surveyed site. This action was initiated because of a formal complaint regarding the burning of ‘waste power poles’ on private land adjacent to this wetland system.

A report prepared in May 2016 (Vardy & Anderson 2016) was based on concerns about environmental impact for this site caused by adjacent land management. The report stated “*the concentrated burn had tested positive within soil and water samples over 3 separate occasions. Indicating elevated levels of arsenic, chromium and copper had leached into the sediment on the property with a low indication at background sites. Additional testing on groundwater samples detected arsenic and chromium concentrates to be above the relevant GILS, warranting investigation on this issue*”. However, there was no indication of metals being present in saltmarsh on the south-east corner of the property (Vardy & Anderson 2016) and therefore the national guidelines for the protection of aquatic ecosystems (ANZECC & ARMCANZ 2000) were not in breach. These findings were provided to the Department of Environment and Heritage Protection (Investigation Petroleum Gas and Compliance) Brisbane.

However, subsequently, at the request of the Department of Environment and Heritage Protection (Investigation - Petroleum Gas and Compliance) Brisbane, I re-surveyed the Hussey Creek intertidal site on the 22 June 2016 to determine any changes in the extent of water mouse activity based on previous findings in 2012.

In this paper I present the results of that survey and examine variations in population evident over that temporal period, possibly affected by the ‘burning’ event described previously.

6.4 Methods

Relevant approvals and Ethics statement

Water mice are protected and presently listed as ‘vulnerable’ under the Federal Environment Protection and Biodiversity Conservation Act (1999) and are supported by a national recovery plan (2010). Permission to enter the study sites was granted by the Queensland Parks and Wildlife Service (QPWS) and Marine Parks Authority, and private landholders (MPP QS2015/GS033; WISP15971115; TWB/12/2015; WITK16035715; WITK16215415). The project was approved by the Animal Ethics Committee of Agriculture, Forestry and Fisheries (DAFF) (AEC permit number: CA 2014/08/797), and the project was undertaken in accordance with Australian and New Zealand Standard Research Classification; ANZSRC code: 050202, Conservation and Biodiversity.

In 2012, Kaluza (2012) identified all potential water mouse habitat at the Hussey Creek site using high-resolution aerial photography and GIS vegetation datasets maintained by the Queensland Herbarium. These habitats primarily consisted of intertidal wetlands containing a saltbush (*Enchylaena tomentosa* var. *glabra*), beaded samphire (*Sarcocornia quinqueflora*), marine couch (*Sporobolus virginicus*), knobby club rush (*Isolepis nodosa*) and jointed rush (*Juncus kraussii*), as well as mangrove forests dominated by grey mangrove (*Avicennia marina* var. a*ustralasica*), orange mangrove (*Bruguiera gymnorhiza*), stilted mangrove (*Rhizophora apiculata*) and milky mangrove (*Excoecaria agallocha*).

All areas of suitable habitat were surveyed in the Hussey Creek site (Kaluza 2012) but there remain some unsurveyed sites along the Pumicestone Passage. Water mouse habitats were thoroughly surveyed by foot at low tide to minimise the possibility of overlooking nests. Once found, nests were categorised as either active or inactive based on signs of recent water mouse activity (e.g. fresh foot prints, mud daubing, vegetation disturbance, or the presence of fresh prey remains). The type of nest was recorded, along with physical characteristics including nest height, basal circumference and vegetation species present within 5 m of the nest. The number of entrance holes was also recorded, along with evidence of nest damage by predators. I also identified water mice prey remains present around the nests.

The Hussey Creek site was re-surveyed on 22 June 2016, with all methods and recording of data replicating the first survey on 23rd August 2012, although the absence or presence of water mouse activity at known nests for this site was also recorded.

6.5 Results

The re-survey of this site in June 2016, I determined that steps had been taken to prevent cattle accessing the intertidal area, with the construction of fencing between the two properties. However, approximately 23 goats (*Capra aegagrus hircus*) were observed (and recorded by camera) roaming in the saltmarsh zone.

Figure 1. Shows a sample of untethered goats in water mouse habitat (Photo Kaluza 2016).

In 2012, five of the seven water mouse nests (WMN) recorded were active, with a high impact of cattle disturbance evident throughout the saltmarsh zone. During the 2016 assessment, each water mouse nest previously located in 2012 was revisited to examine its current status and occupancy (Table1; Fig. 2). Three previously active nests were found to have deteriorated or collapsed, as judged by the lack of visible mud daubing associated with mound maintenance activity typically undertaken by water mice occupying the nest structure. Only two of the five nests found to be active in 2012 remained active at the time of the 2016 survey. Examples of nests that remained active or that were no longer active are illustrated in Figs 2-5.

Table 1. State of occupancy of water mouse nests four years after the first visit to the Hussey Creek site.

Site	Latitude	Longitude	WMN 2012	Active 2012	WMN 2016	Active 2016
Hussey Creek	-26.92287	153.05795	1	Yes	1	No
Hussey Creek	-26.92320	153.05891	2	Yes	2	Yes
Hussey Creek	-26.92350	153.06004	3	No	3	No
Hussey Creek	-26.92335	153.06281	4	Yes	4	No
Hussey Creek	-26.92299	153.06358	5	Yes	5	Yes
Hussey Creek	-26.92300	153.06343	6	No	6	No
Hussey Creek	-26.91939	153.06350	7	Yes	7	No

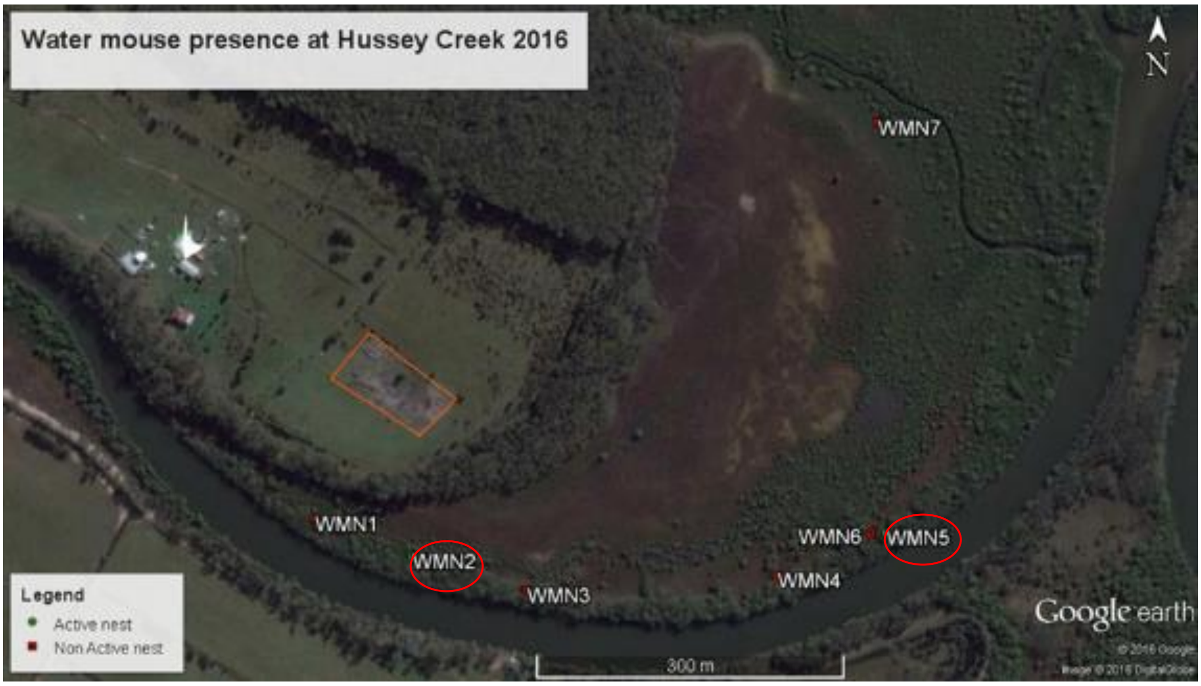

Figure 2. Map of the seven water mouse nests in the intertidal zone along Hussey Creek showing the locations of the two active (circled) and five inactive nests surveyed in 2016 (GIS mapping using Google Earth Pro: Kaluza 2016).

Figure 3. (a) Water mouse nest 1 (WMN1), (b) water mouse nest 4 (WMN4), and (c) water mouse nest 7 (WMN7) all recorded as being active on 23 August 2012 (Photos Kaluza 2012).

Figure 4 (a), Water mouse nest 1 (WMN1) showing significant collapse of its internal mud structure, (b) water mouse nest 4 (WMN4) indicates no daubing or nest maintenance behaviour, (c) water mouse nest 7 (WMN7) demonstrating a lack of water mouse activity on 22 June 2016 (Photos Kaluza 2016).

Water mouse nests 2 & 5 exhibited normal daubing activity (Fig. 4) associated with water mouse nest maintenance behaviour, but the remaining nests indicated signs of collapse or decline (Fig. 3).

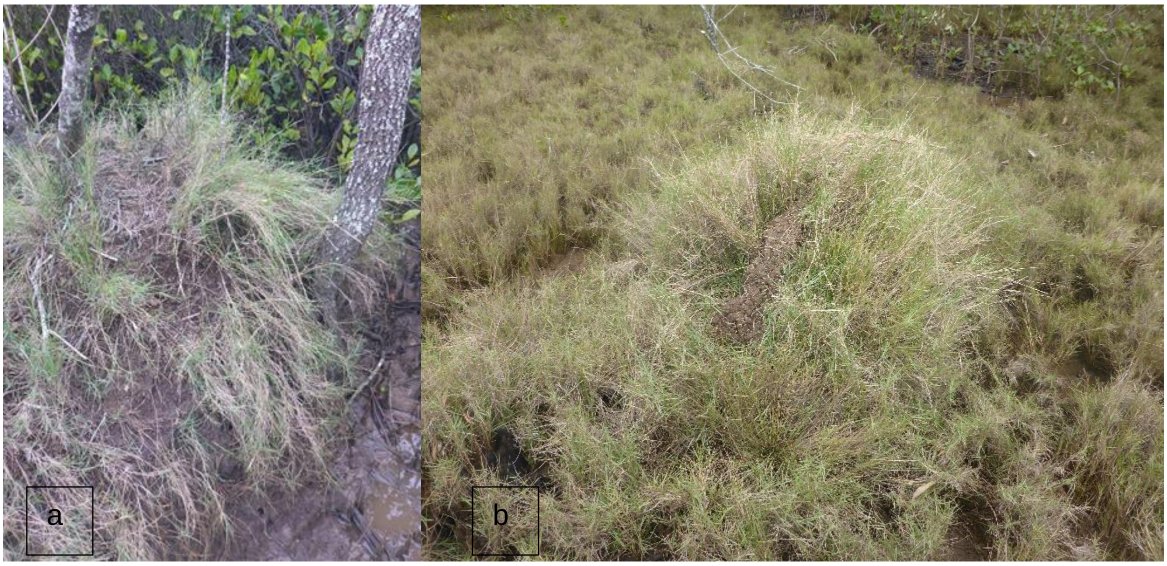

Figure 5. (a) Water mouse nest 2 (WMN2) and (b) water mouse nest 5 (WMN5) both active on 22 June 2016 (Photos Kaluza 2016).

6.6 Discussion

In 2012 the saltmarsh appeared badly degraded due to poor agricultural practices and inadequate management of adjacent land. At that time, disturbance by cattle to water mouse nests was documented as an issue of concern, with recommendations for action being provided in a report to relevant authorities. Although a boundary fence was subsequently installed by the local government to assist land management, approximately 23 goats observed in the intertidal habitat in 2016 appeared to be adversely impacting the local environment.

Vardy and Anderson (2016) outlined environmental impact caused by the burning of treated waste power poles on the surveyed property, and in particular, the probable negative consequences for adjacent water mouse habitat. Such detrimental impacts on this species are listed as Matters of National Environmental Significance (MNES) under the Commonwealth's Environment Protection and Biodiversity Conservation Act (1999). The initial soil sampling conducted at the site and surrounding areas, in October 2015 (Vardy & Anderson 2016) testing (for absorption levels of arsenic, copper and chromium (for comparison with Environmental Investigation Levels (EILs)) initially occurred when the burnt logs and ash were still *in situ,* inclusive of background examination. The further two extensive sampling rounds were conducted after the contaminated ash had been removed into a pile. At the time, measured traces of metal were higher than EILs but were not detected in samples taken at depth, nor was any contamination into the saltmarsh on the south-east boundary of the property detected. Vardy and Anderson (2016) concluded that, a total 21% of surface samples were contaminated with arsenic and copper (Vardy & Anderson 2016), exhibiting readings above the recommended EILs. This signified that the site was still contaminated, after clean up. Importantly, results from groundwater samples indicated arsenic, chromium and copper were present, warranting further robust testing of the sites groundwater quality (Vardy & Anderson 2016).

The observation in 2016 that a total of five out of seven (71%) nests located in this area were no longer active (Table 1.), indicating that water mouse presence is in decline at this site. The reduction in the number of active nests over the period 2012 to 2016 from seven to two (71% decline) may be due to this contamination of the site and groundwater.

However, the soil surrounding each nest was not tested, therefore I am unable to verify this assumption. But, because the abandoned nests were situated within intertidal areas adjacent to the contaminated site, it is probable that the arsenic, chromium and copper detected in the broader soil and water quality samples contributed to the decline in nest activity; although this is contrary to Vardy and Anderson’s suggestion that metal transference did not occur into the sampled area of saltmarsh. Vardy and Anderson (2016), however, also suggest the need for ongoing testing of water quality at the site. Therefore the hypothesis that the decline in nest numbers is due to this contamination cannot be discounted.

It is recommended that a long-term monitoring plan be established to determine if the actual cause of nest decline was associated with the set contamination or other adverse environmental factors.

6.7 Conclusion

Water mouse nests on the edge of their known habitat area were comprehensively surveyed in both 2012 and 2016 to identify temporal changes in activity. A deterioration in nest activity of 71% was observed. However, because of the combination of ecological issues evident at the site, and the four-year gap between surveys the exact cause of the decline in water mouse nests cannot be determined confidently. However, based on the previous demise of one local water mouse population in south-east Queensland from changes to adjacent land management (Van Dyck et al. 2006), it is probable that chemical contamination from activities occurring on the adjoining property at Hussey Creek played a role in the decline of the water mouse population health via groundwater leaching at this site. Alteration to hydrological and sedimentation processes upon adjoining land have the potential to adversely impact water mouse populations. Ongoing monitoring of affected sites and further research of detrimentally affected habitats is necessary to better understand and manage the long-term ecology of this vulnerable species.

6.8 References

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Chapter 7

7.0 Thesis conclusions

Throughout this thesis I have presented widespread and significant research that I progressed in order to understand the vulnerable water mouse. This work will also be valuable in suggesting recovery measures for this vulnerable species. Further to these measures, I have evaluated the species' National Recovery Plan Key Actions to identify water mouse current distribution and density, critical habitat, behavioural response and potential threats.

In this chapter I summarise and conclude my work examining the conservation and ecology of water mice along the Maroochy River of south east Queensland.

7.1 Main aims

The main aims of this research were to:

1. examine the key actions that are crucial for the preservation of water mouse populations,
2. assess if implementation of some of these key actions can meet the desired conservation outcomes, and
3. determine whether resources were substantial for the period of study in question.

The addressing of each of these aims is considered below.

I achieved my first aim by surveying water mouse populations of the Maroochy River. This survey provided substantial insight on the enigma of the water mouse and implications for population recovery. My study determined that the techniques used to locate and assess nest activity were lengthy due to the ambiguous behaviour of the species; (recall Figures 1.1 and 1.2). My work confirmed baseline data on nest density (Figures 3.2 and 3.3) using a longitudinal study designed to estimate individual numbers for each active nest per hectare of suitable habitat (NRP Key Action: 2.3 and 3.1). This also confirmed a population hotspot for the species abundance for the Maroochy River (NRP Key Action: 3.1-3.4). These findings led to a refinement in data collection on the species' extended-range via further surveys and monitoring periods, laying the foundation for Chapters 4 and 5.

To achieve the second aim; fourteen of the seventeen recommended Key Actions from the species' National Recovery Plan (NRP) were successfully implemented during the study period along coastal wetlands of the Sunshine Coast, Great Sandy Strait and Moreton Bay Region. This linked information from coastal and island communities across south east Queensland to derive new locality records for water mouse presence and/or absence in known areas to address NRP Key Actions 1.1-1.4; 2.3; 3.1-3.5; 4.1 and 5.1-5.4.

In Chapter 4.7 and Figure 4.1 Examination of habitat association and assessed impacts of known threats to the species' survival, deduced that distinct issues for the water mouse's persistence were commonly linked to adjacent land practices confirmed by decades of research; noted in Chapters 1 and 2. The research presented in Chapter 5 was designed to quantify the importance of continuous monitoring by testing the response variables (1 and 2) against predictor variables associated to meteorological variables. This work addressed Key Actions 3.2-3.4; 5.2 of the NRP and provides a foundation for future research examining the impact of climatological and meteorological events on water mouse behaviour.

The final aim addressed the current implications for future management of water mouse populations in light of limited contemporary resources. These limitations constrained me to undertake my research using stringent budgets or in a pro-bono manner, either by myself or with in-kind support offered by various stakeholders. Actions that I initiated include: prepared workshops, implemented pilot programs and training for the entirety of this study; examination of new methods for monitoring nest maintenance by the water mouse using camera traps over extended periods (Chapter 5); linked variation in water mouse population with long term management strategies (Chapter 3-6); live trapping included micro-chipping individuals to investigate causes of population expansion or demise and assisted agency threat abatement practices (Kaluza 2017); fostered internships in local areas of universities across professional regions (Chapters 3-5) to promote future research and stewardship. Additionally, results from this study provided significant baseline data on water mouse presence, in areas normally inaccessible by government agencies. Increased awareness of public involvement through voluntary land agreements as successful conservation initiatives and necessary to achieve all three aims in my thesis (Chapter 3; 4; 5 and 6 and addressed NRP Key Actions 5.1-5.4). This work utilised available resources to obtain valuable data that has addressed deficiencies on current distribution, available habitat and effects impacting water mouse recovery.

Finally, these findings have assisted the Commonwealth Government's Threatened Species Unit to implement a new referral guideline for the vulnerable water mouse that will be used in conjunction with existing legislation of the EPBC Act (1999). Although exhaustive, these efforts to conserve the present population have fallen short of the current NRP desired outcomes because they are limited by:

1. The timely need for extended resources and cost of recovery, and
2. A working committee to upgrade the Key Actions in the NRP for the vulnerable water mouse.

7.2 Additional original contributions

I also made additional original contributions through my work. The results of my thesis (inclusive of technical reports) were used by (Tim McGrath) the Department of Energy and Environment (DoEE) to review the dated National Recovery Plan (NRP). This provided an understanding of new processes threatening the water mouse resulting in action and recognition through a new 'Australian Government made Recovery Plan for the water mouse' to replace the existing recovery plan which does not sunset under the EPBC Act (1999) until 2021. With this information, the Australian Commonwealth Government has commenced work on a new recovery action plan for this species.

7.3 Implications

The impact of this work is significant. However, the existing problem of aiding a threatened species to recovery can still be improved. It will, take time, money, education and further collaborative effort from various organizations. Effectively, the study on long term monitoring moved a step closer to understanding the rodents' adaptive measures and used cautiously, should provide managers with direction in adjacent land management practice. It showed (Chapter 4.7) that my data supports previous qualitative knowledge on habitat preference by Van Dyck (1997), proving a strong correlation between free standing mounds in sensitive saltmarsh, although the eluding question remains: as to why in certain areas of plant association, nest absence may still occur. Admittedly, examination into the mammals' gestation and life cycle is still data deficient. Suggesting a robust study on the incubation period of the terrestrial rodent may provide key insight into its ability to survive and thrive in a semi-aquatic area.

7.4 Future directions

This study exemplifies the amount of research that is further required for the management of just one of many threatened species living in a vulnerable reality.

Accordingly, I recommend that future studies should investigate:

1. Advanced understanding to connect diet and habitat impacts, inclusive of fire ecology in areas adjacent to nest structures and the effects on local population,
2. Permanent, consistent hydrology and sediment testing would aim to interpret the significance of habitat to the water mouse for better adjacent land practices and possible future translocation if numbers continue to decline,
3. Improved resources for threat abatement practices that incorporates long term research findings into pest and fire strategies across agencies,
4. Pollutants and chemical run off such as ‘flock’ used to alter the acid sulfate levels in soil during adjacent land practice; or impurities brought in on tidal occurrence; inclusive of plastics, oil spill etc. that can impede nesting activity,
5. The use of ground-penetrating radar to investigate the use of nesting chambers, shafts and nest access, of mounds in tidal areas,
6. Water mouse biology, importantly gestation cycle and their life span, thus linking reproductive patterns to seasonal events. Allowing for improved methods for non-invasive monitoring on pregnant females during gestation,
7. Micro-chipping of individual mice per nest, combined with the use of stationary ringed scanners, molded into nest access points. This would assess nest usage, occupancy and movement between dwellings for broader knowledge on home range,
8. Yearly health checks, monitoring individuals and nests, habitat, especially before, during and after adjacent land changes, to minimise habitat degradation,
9. A team leader for water mouse recovery is required to direct future work, retain equipment for specific use on approved monitoring practices and report directly to State, Federal agencies and stakeholder groups, and

10. Extension of resources, conservation practices, policy and research strategies, incorporating larger buffer zones between wetlands and riparian zones (>500 m) for improved protected area management.

Conservation of the vulnerable water mouse is a lengthy process, but the results will assist decision making in areas of socio-economics, climate change and threatened species protection.

7.5 Conclusion

This thesis documents the extensive, multi-faceted research that has been undertaken over a substantial period of time to assess the conservation status of the vulnerable water mouse (*Xeromys myoides*). The implications of this work will be important and ongoing; already my work has provided a foundation upon which a new Policy Guideline and a new Recovery Action Plan have been formulated, under the *Environment Protection Biodiversity and Conservation Act* (1999) for threatened species management. This effort has addressed the paucity of data that exists for many water mouse populations and has provided a framework of action that if implemented could substantially arrest the unfortunate decline of Australia's threatened water mouse populations.

In her concluding talk, at the TED conference in Monterey California 2002, dedicated primatologist and conservationist Jane Goodall, gave a lasting message to assist all species on earth: '*it's in our hands. It's in your hands and my hands and those of our children. It's up to us. We're the ones who can make a difference'*. The research I have described in this thesis will hopefully encourage others to carry on.

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Appendix one

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

UQ Research and Innovation
Director, Research Management Office
Nicole Thompson

Animal Ethics Approval Certificate

19-May-2015

Please check all details below and inform the Animal Welfare Unit within 10 working days if anything is incorrect.

Activity Details

Chief Investigator:	Dr Luke Leung, Agriculture and Food Sciences
Title:	Distribution and ecology of the water mouse in south-east Queensland.
AEC Approval Number:	SAFS/DAFF/185/15/DAFF
Previous AEC Number:	
Approval Duration:	19-May-2015 to 19-May-2018
Funding Body:	
Group:	Native and exotic wildlife and marine animals
Other Staff/Students:	Janina Kaluza, Rosie Booth, Ben Allen, Ian Gynther, Matthew Gentle
Location(s):	Other Queensland Location

Summary

Subspecies	Strain	Class	Gender	Source	Approved	Remaining
Native Rats and Mice	Water Mouse (Xeromys myoides)	Adults	Mix	Natural Habitat	0	0
Native Rats and Mice	Various	Adults	Mix	Natural Habitat	0	0

Permits

Scientific Purposes Permit TWB/12/2015	No Start Date to 30-Apr-2020
Scientific Purposes Permit WISP15971115	01-May-2015 to 30-Apr-2020

Provisos

Animal numbers are not shown on this approval certificate, as the approved animal numbers are provided under CA 2014/08/797 Qld DAFF Community Access AEC Approval.
This certificate is to show that the project has been ratified by a University of Queensland AEC.

Approval Details

Description	Amount	Balance
Native Rats and Mice (Various, Mix, Adults, Natural Habitat)		
19 May 2015 Ratification - Initial Approval	0	0
Native Rats and Mice (Water Mouse (Xeromys myoides), Mix, Adults, Natural Habitat)		
19 May 2015 Ratification - Initial Approval	0	0

Animal Welfare Unit
UQ Research and Innovation
The University of Queensland

Cumbrae-Stewart Building
Research Road
Brisbane Qld 4072 Australia

+61 7 336 52925 (Enquiries)
+61 7 334 68710 (Enquiries)
+61 7 336 52713 (Coordinator)

animalwelfare@research.uq.edu.au
uq.edu.au/research

Please note the animal numbers supplied on this certificate are the total allocated for the approval duration

Please use this Approval Number:

1. When ordering animals from Animal Breeding Houses
2. For labelling of all animal cages or holding areas. In addition please include on the label, Chief Investigator's name and contact phone number.
3. When you need to communicate with this office about the project.

It is a condition of this approval that all project animal details be made available to Animal House OIC.
(UAEC Ruling 14/12/2001)

The Chief Investigator takes responsibility for ensuring all legislative, regulatory and compliance objectives are satisfied for this project.

This certificate supercedes all preceeding certificates for this project (i.e. those certificates dated before 19-May-2015)

Animal Welfare Unit
UQ Research and Innovation
The University of Queensland

Cumbrae-Stewart Building
Research Road
Brisbane Qld 4072 Australia

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animalwelfare@research.uq.edu.au
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Appendix two

Department of National Parks, Sport and Racing QUEENSLAND GOVERNMENT

Permit *Marine Parks Act 2004*

PERMIT NO. **QS2015/GS033**

TERM OF PERMISSION:

5 August 2015 to 4 August 2021

THIS PERMISSION IS GRANTED TO:

Permit holder: The University of Queensland
Ms Janina Kaluza

Place of Business: 3 Wildflower Street
SUNSHINE COAST QLD 4567

for use and entry of

Great Sandy Marine Park

in accordance with the details as stated in Part A, and subject to the conditions stated in Part B.

Signed: .... Date: 5 August 2015

Sue Gregory
Delegate of the Chief Executive,
Department of National Parks, Sport and Racing

Part A:

LOCATION TO WHICH THIS PERMISSION APPLIES:

Great Sandy Marine Park

Zone(s): Conservation Park Zone - CPZ 9 – Great Sandy Strait (including GSS islands and western Fraser Island intertidal areas).
Marine National Park Zone - MNP 9 - Marsh Creek and MNP 23 - upper Kauri Creek. Refer to the following maps attached:

- Map 1- Great Sandy Straits North – including River Heads and Turtle Cove;
- Map 2 – Great Sandy Straits South – including Tin Can Bay Area and Kauri Creek; and
- Map 3 – Burrum River to Marsh to Beelbi Creek

PURPOSE OF USE OR ENTRY AUTHORISED BY THIS PERMISSION:

Conduct of research to examine the conservation and ecology of the threatened water mouse (*Xeromys myoides*)

Part B:
CONDITIONS OF PERMISSION:

1. Location

Activities described in the `purpose of use and entry' of this permit must only take place in the locations described in `Part A' of this permit.

2. Disturbance to adjacent areas

The activity must be conducted in a manner that causes minimal disturbance to the marine ecosystem (e.g. adjacent mangroves, corals and the substrate).

3. Notification of research

The Chief Executive must be notified by email to sunshinefraserpermits@npsr.qld.gov.au and to the (Senior Ranger) alan.dyball@npsr.qld.gov.au for Great Sandy Marine Park of the intention to conduct research involving protected wildlife

Notification must be received at least five (5) working days prior to the proposed research and include a brief description of the research (including the duration of research, and location/s of research).

4. Conduct of research

(a) All research is to be undertaken in accordance with:-

i. Marine park permit application dated 3 March 2015 and additional information provided by email on 2 March 2015;

ii. UQ Animal Ethics Approval; and

iii. A current Scientific Purposes Permit from the Department of Environment and Heritage – WISP15971115.

(b) The permit holder is to ensure that:-

i. Remote sites that are less frequented by members of the public are to be chosen in the first instance as study locations in preference to other more accessible locations.

ii. Any campsite established to support the conduct of sampling is to be located adjacent to the study location outside of the marine park ie above the highest astronomical tide (HAT) mark.

iii. All equipment and rubbish is to be removed from the campsite on completion of sampling at each study location.

(c) The permit holder is authorised to conduct the following activities/procedures to the Xeromys myoides (water mouse):

i. camera trapping
ii. capture using baited Elliot Traps

iii. weigh, measure and determine age and breeding status
iv. collect DNA tissue samples (from the tip of the animals ear)
v. collect saliva samples
vi. collect fur samples
vii. implant microchips
viii. Transport for photography purposes as detailed in the application.

(d) All material and equipment placed in the marine park in connection with this permission, including each Elliot trap, must be clearly marked with the name of the permit holder and permit number QS2015/GS033;

(e) All material and equipment used in the activity, including the fluorescent flagging tape and cotton trap line, must be removed from the marine park on completion of sampling;

(f) A member of the research team is to remain in the vicinity of the study location over the course of the sampling period to supervise the site and to check the sampling gear for entanglements and/or other wildlife issues. If it becomes necessary to leave the study location unattended for an extended period of time, all sampling gear will be removed and will be replaced upon return to the site.

(g) Disturbance of shorebird habitat

The permit holder must ensure that:

i. There is no unreasonable disturbance to shorebird habitat as a result of the research activities. Refer to Appendix 1 - Shorebird high tide roost maps within the Great Sandy Marine Park.

5. Non-target species

All non-target species must be released as soon as possible after capture and as close to the site of capture as possible.

6. Report

The following reports must be submitted:

(a) Within 20 working days of each sampling period, a catch summary that includes the following information:
i. the location where traps were set
ii. the name and number of each species captured and released from each site, including non target species and
iii. any incidents resulting in the injury and/or mortality of a captured species.

(b) At the end of the research, a summary of the research findings.

The returns must be lodged with The Administration Officer, Assessments and Approvals, Department of National Parks, Sport and Racing;
e-mail to southernpermitsteam@npsr.qld.gov.au and

The Senior Conservation Officer, Great Sandy Marine Park, email to amanda.delaforce@npsr.qld.gov.au

7. Insurance

(a) For the Term of this Permit, the Principal Holder must take out and maintain the following insurances:

(i) where required by law, insurance under the Workers' Compensation and Rehabilitation Act 2003, or its equivalent under another jurisdiction with the consent of the Chief Executive; and

(ii) where not covered under the above subclause (a)(i), accident insurance sufficient to cover workers, volunteers and eligible persons (as defined under the Workers' Compensation and Rehabilitation Act 2003) with the consent of the Chief Executive; and

(iii) a public liability insurance policy for not less than $20 million on a claims occurring basis in respect of the death of, or injury to persons, or loss or damage to property; and

(iv) any other insurances as reasonably required by the Chief Executive.

(b) The Principal Holder must ensure that the insurance policies required under this this clause are with:

(i) an insurer who is:

a. authorised under the Insurance Act 1973 (Cth);

b. registered with the Australian Prudential Regulation Authority as an authorised insurer; and

c. has a Standard & Poor's rating of no less than A-; or

(ii) if the Principal Holder is globally insured, another insurer with the written approval of the Chief Executive.

(c) The Principal Holder must ensure that in relation to the insurable interests under this clause, insurance policies are effected to cover all invitees, employees, contractors, agents, members or clients of the Principal Holder and (where possible) name the State as an interested party.

(d) Before undertaking any activities on the Relevant Area, the Principal Holder must have in place all insurances required by this clause.

(e) In any circumstance where the insurances required under this Permit are cancelled, altered or expire before the expiry date of this Permit, the Principal Holder must cease all activities on the Relevant Area until such time as alternative insurance policies that comply with the requirements of this clause have been obtained.

(f) The Principal Holder must provide copies of certificates of currency for the insurances required under this clause if requested by the Chief Executive, acting reasonably.

(g) If the Principal Holder is an individual or sole trader, then clause (a)(i) is satisfied if the Principal Holder maintains:

(i) personal accident insurance covering all medical treatment, hospitalisation and medical expenses; and

(ii) income protection insurance; and

(i) death and disability insurance;

equivalent to the coverage and entitlements provided to employees under the statutory provisions of the Workers Compensation and Rehabilitation Act 2003 (Qld).

(h) Where the Principal Holder –

(i) is a Commonwealth, State or Territory government department, agency or statutory body; and

(ii) is a self-insurer; and

(iii) has provided the Chief Executive with a certificate from an appropriately authorised officer to that effect,

the Principal Holder is deemed to have complied with this clause.

(i) If the Principal Holder breaches its obligations under this clause, the Chief Executive may immediately cancel this Permit by written notice to the Principal Holder.

8. Compliance with laws

The Principal Holder must at its own expense punctually comply with all statutes, ordinances, local laws, regulations or rules in force at the time, which apply to the Relevant Area and adjoining land and/or the Principal Holder's use of the Relevant Area and adjoining land.

9. Principal Holder's Authority

The Principal Holder must have the power, authority and ability to be issued this Permit and must perform its obligations under this Permit with all due skill, care and diligence.

10. Indemnity

(a) The Principal Holder:

(i) indemnifies; and

(ii) releases and discharges

the State (including its Representatives) from and against all actions, proceedings, claims, demands, costs, losses, damages, liability and expenses which may be brought against, or made upon the State (or any Representative) or which the State (or any Representative) may pay, sustain, or be put to by reason of, or in consequence of, or in connection with this Permit and the occupation and use of the Relevant Area by the Principal Holder, except to the extent of any negligent act of the State (or any Representative).

(b) The Principal Holder must notify the Chief Executive in writing of any death, injury, loss or damage immediately upon the Principal Holder becoming aware of such death, injury, loss or damage.

(c) If the Principal Holder breaches its obligations under subclauses (a) and (b), the Chief Executive may give notice to the Principal Holder stating the breach and if the breach is not remedied in accordance with the timeframe set out in that notice, the Chief Executive may immediately cancel this Permit by written notice to the Principal Holder.

11. No liability for consequential or indirect loss

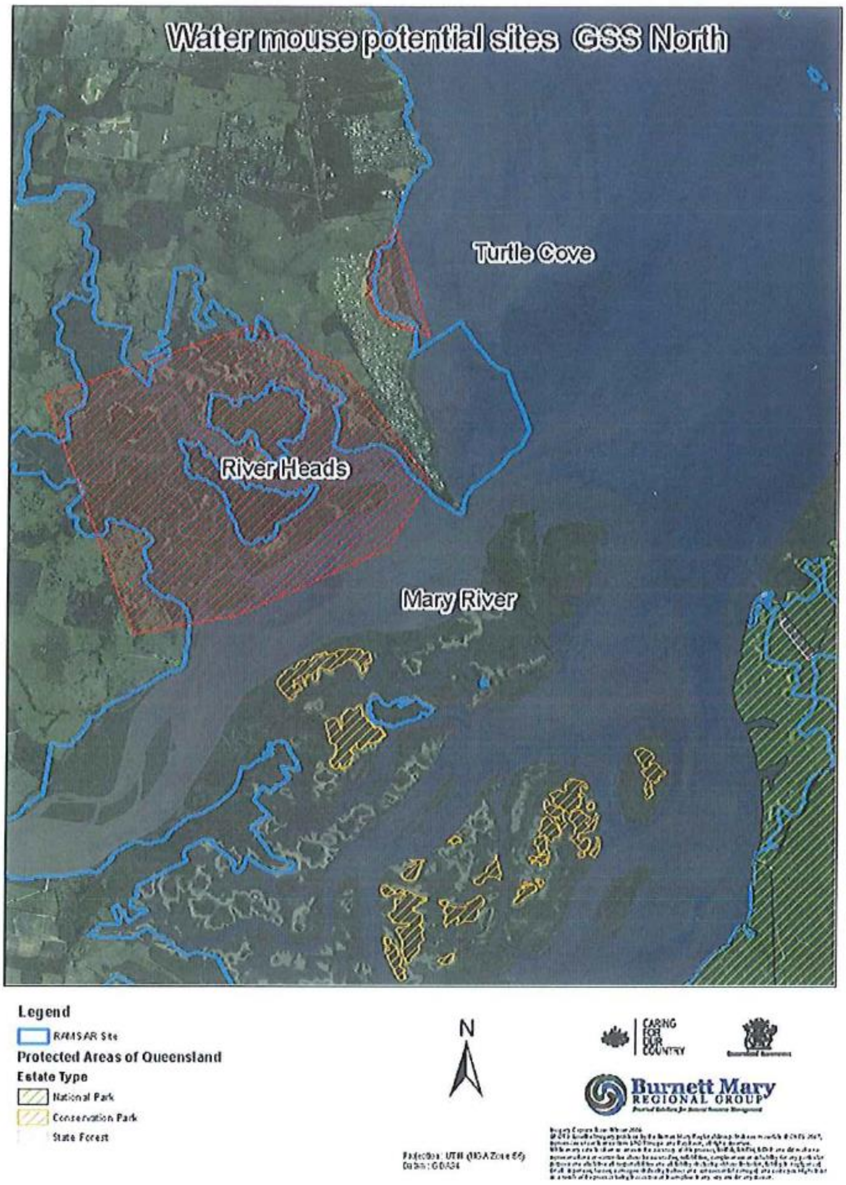
The State and its Representatives will not in any circumstances (including for negligence) be liable for any loss of revenue, loss of profit, loss of anticipated savings or business, loss of opportunity (including opportunity to enter into or complete arrangements with third parties), loss of data or goodwill, loss of reputation, or any indirect or consequential loss, whether arising in contract, tort (including negligence) or otherwise, in connection with this Permit.

12. No Warranty and Risk

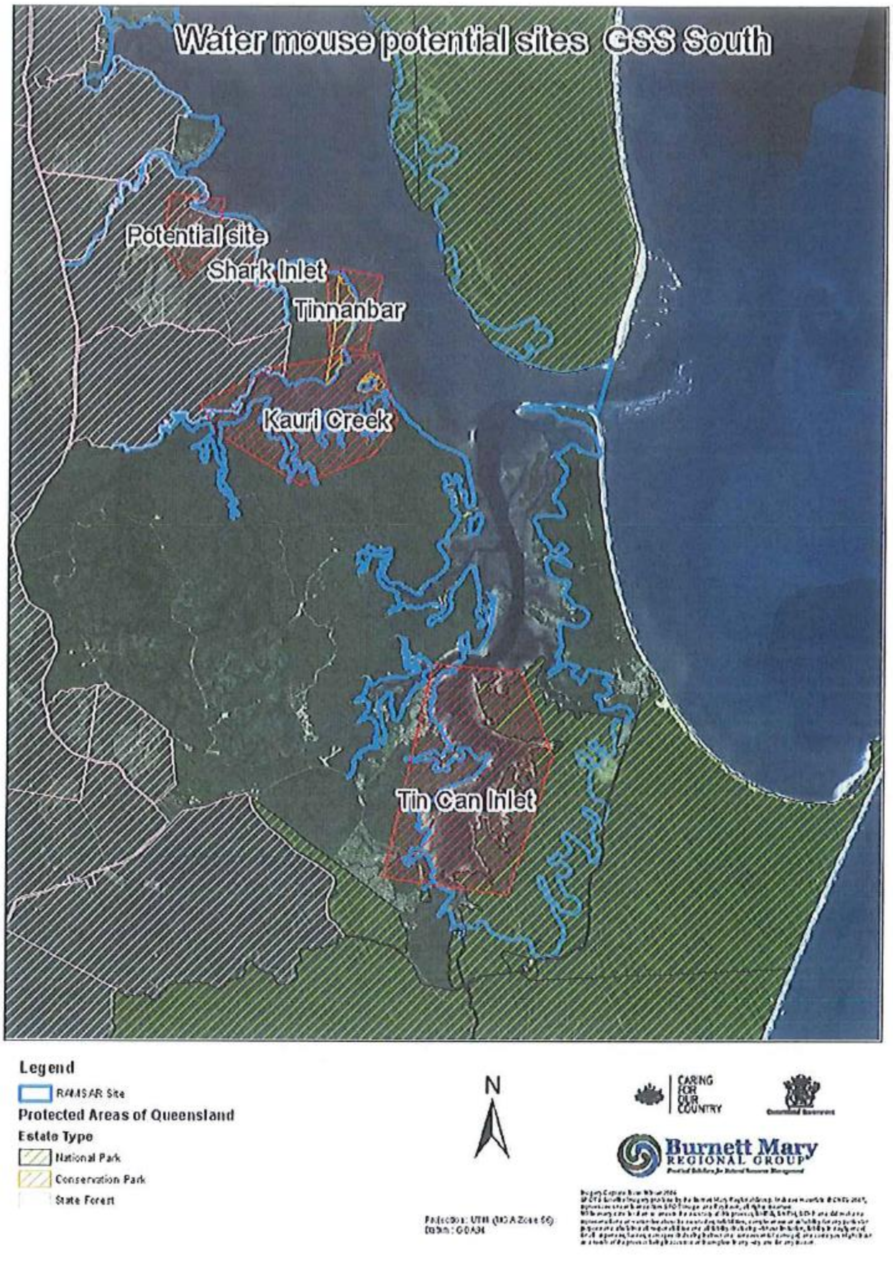
(a) The Chief Executive does not warrant that the Relevant Area is free from defect or that it is safe, fit, suitable or adequate for the Approved Activities. To the full extent permitted by law, all warranties as to fitness, suitability and adequacy implied by law are expressly negatived.
(b) The Principal Holder uses the Relevant Area entirely at its own risk and must first check the Relevant Area to ensure that it is suitable for the Approved Activities under this Permit before undertaking any Approved Activities.

Attachment 1 –

Map 1 - Great Sandy Strait North



Map 2- Great Sandy Straits South



Map 3 – Burrum River and march/Beelbi Creeks

Appendix three

Notice of decision - permit[1] application

This notice is issued by the administering authority to advise of a statutory decision on a permit application.

Ms Janina Kaluza
3 Wildflower Street
SUNSHINE BEACH QLD 4567

Our reference: 428142

Dear Ms Kaluza

Re: Decision made in relation to your application

Your application received on 20-MAR-2015 has been assessed and the decision in regard to your application is specified below:

Permit applied for	Permit Number	Decision
Take, Use, Keep or Interfere with Cultural or Natural Resources (Scientific Purpose) under Nature Conservation (Administration) Regulation 2006	WITK16035715	Granted

For the permit applied for that has been granted, the conditions of approval are attached. Where applicable, a Statement of Reasons is provided in relation to the decision. Please note that for the approval, this Notice of Decision and the relevant attachments constitute the permit documentation. Please retain this approval documentation for your records.

Included with this notice is advice on review and appeal processes that may be available to you. Should you seek a review or appeal, you are advised to seek independent advice before taking such action.

If you require more information, please contact Jacqui Brock on the telephone number listed below.

Yours sincerely

Andrew Mullens
Department of Environment and Heritage Protection
Date

Enquiries:
Wildlife - Toowoomba - EHP
PO Box 102
TOOWOOMBA QLD 4350
Phone: (07) 4688 1415
Fax: (07)

<u>Attachment</u> **- Permit/Statement of Reasons**

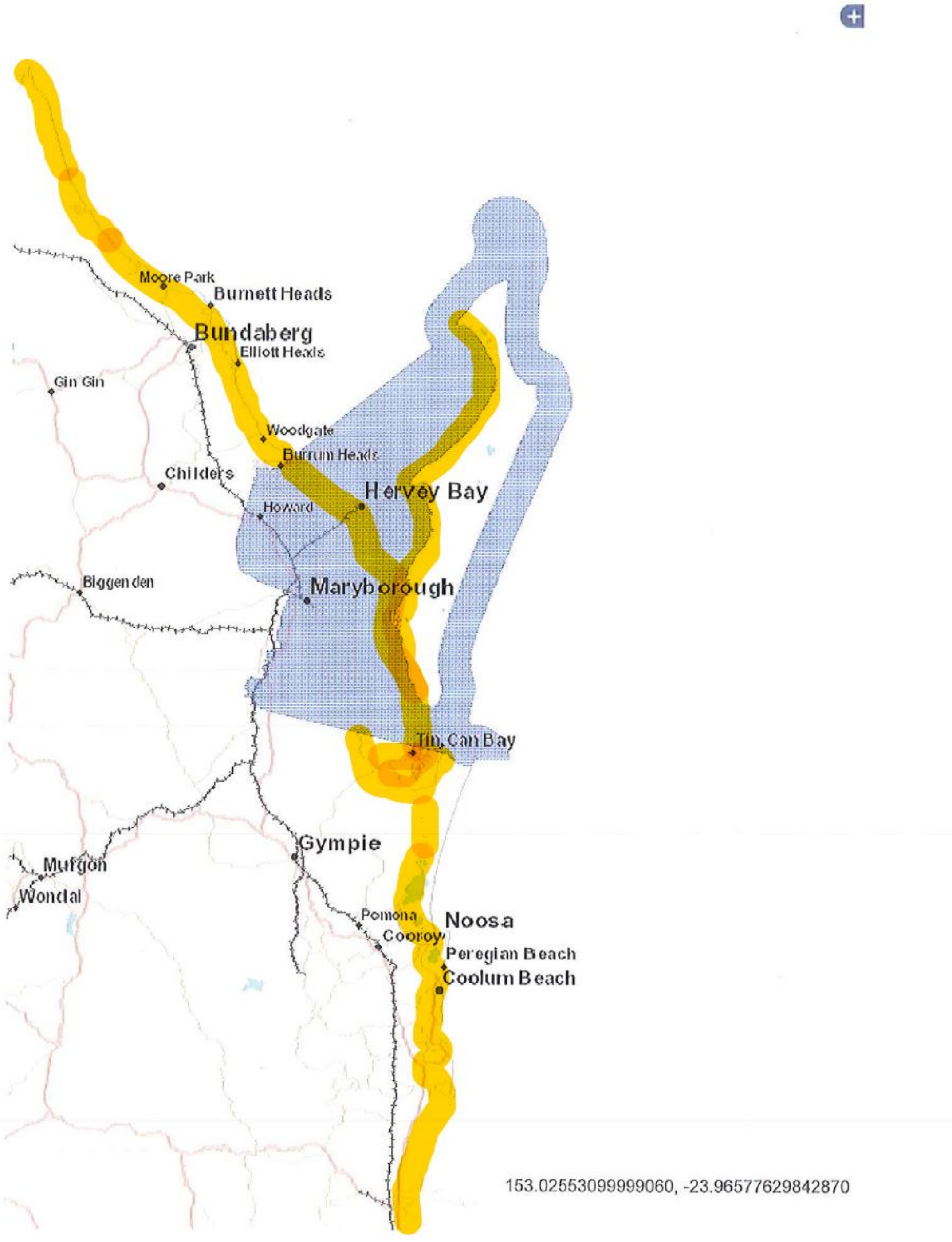
1 Permit includes licences, approvals, permits, authorisations, certificates, sanctions or equivalent/similar as required by legislation.

Department of Environment and Heritage Protection
www.ehp.qld.gov.au ABN 46 640 294 485

Queensland Government

Qntime Keymap

Page 1 of 1



http://qntime.nrm.qld.gov.au:9051/spatialtool/keymap.jsp

22/01/2015

Map of Native Title – Butchulla Claim: Areas of study approved in permit WITK16035715.

Appendix four

Queensland Government

Department of
Environment and Heritage Protection

PERMIT TO COLLECT
BIOLOGICAL OR GEOLOGICAL MATERIAL FROM QUEENSLAND FOREST RESERVES, STATE FORESTS, TIMBER RESERVES AND OTHER STATE LANDS

PERMIT NUMBER: TWB/12/2015

This permit authorises, **Janina Kaluza of 3 Wildflower Street, Sunshine Beach, Queensland,** to access the area(s) specified in **Schedule 1** for the purpose of collecting the biological and/or geological material prescribed in **Schedule 2** over the period specified in **Schedule 3** subject to the general conditions attached and the following specific conditions:

1. **Authorised method of collection**: As per permit WISP15971115
2. **Approved structures for the activity**: Nil
3. **Scientific Purposes Permit Number WISP15971115 must accompany this permit.**
4. Prior to commencing work, the Permit Holder must contact the Department of National Parks, Sport and Racing. Contact should be made using the on-line form at http://www.nprsr.qld.gov.au/licences-permits/commercial/research-field-work-form.php at least seven days prior to entering the reserve. Details of actual times and proposed locations on the reserve shall be given.
5. The Permittee must contact the HQPlantations Pty Ltd Office (during business hours) on 5488 2127 for advice on forest road suitability and/or notification of incidents occurring on Plantation Licence Area one week before commencing any activity on the Plantation Licence Area.
6. At the completion of research, a copy of any resulting research paper, research results and / or the collection details must be provided to HQPlantations Pty Ltd (C/0 Post office, Red Road, BEERBURRUM QLD 4517) as soon as possible.
7. The Permittee is to report all incidents involving death of or injury to any person to HQPlantations. Incident involving death or serious injury (involving hospitalisation) must be reported to HQPlantations Regional Manager immediately on 0427 427 601. All other injuries and incidents must be reported the next business day.

GENERAL CONDITIONS

1. In the event of wet weather, the Permittee must contact both the Queensland Parks and Wildlife Service (QPWS) and HQPlantations Pty Ltd during business hours for advice on forest road suitability and/or notification of incidents occurring on State Forest.

2. It is a requirement that the Permittee and participants shall at all times
    a. comply with any direction contained or given by a sign or notice erected, placed or displayed on the Permit area, and
    b. comply with any direction given by a Plantation Officer or Forest Officer in regard to the use of the permit area where such direction is necessary maintain good order of the Permit area and safety of any person using same.

3. Reserving or cordoning off any part of the permit area so as to imply exclusive use is not permitted unless is for legitimate safety reasons or as instructed by the authorising officer.

4. Traversing must be restricted to formed roads only. Vehicle use within plantation areas must be restricted to major through roads suitable for two-way traffic.

5. Unless specifically authorised, collections shall not be carried out within Scientific Areas, Feature Protection Areas, State Forest Parks, Forest Drives or in the vicinity of established recreational facilities.

6. The permittee must carry this permit at all times and produce it if requested by a QPWS or HQPlantations Pty Ltd Officer.

7. Unless otherwise specified, this permit does not authorise the use of firearms within the permit area.

8. At the completion of collection and subsequent determinations, the research results must be returned to the issuing office as soon as possible.

9. If new species or lower taxa are described from the collection:
    - Holotype material of any fauna group is to be lodged with the Queensland museum, where practicable;
    - For Class Insecta, duplicate material is to be lodged with the Australian National Insect Collection, CSIRO Canberra or Queensland Museum, where practicable;
    - For flora, type material (holotype or isotypes) to be lodged with the Queensland Herbarium.

10. Any accidents involving persons or livestock or damage to any vehicles or property, must be reported to QPWS by the next working day.

11. The permittee shall not pledge, transfer or in any way charge the rights and benefits granted by this permit in whole or in part to any other person.

12. QPWS and HQPlantations Pty Ltd reserve the right to close roads as required for operational purposes (e.g. harvesting and establishment of plantations) or during periods of adverse weather conditions. Entry into areas closed for any reason is prohibited.

13. Stock or improvement including any fence or grid must not be interfered with. All gates opened must be securely closed immediately after use.

14. Notwithstanding the currency of this permit, the use of State Forest roads/tracks in a manner or at such times (e.g. during periods of wet weather) when such use would cause unreasonable damage to the road surface is prohibited.

15. All litter and other waste materials generated by this activity must be removed from the State Forest upon completion of the activity.

16. Participants must be made aware of the fire risk during any briefing. Contact 000 to report any fire on a State Forest.

17. No open fires are permitteed in the Plantation Licence Area. Gas or alternate fuel stoves must be used for cooking purposes.

18. The Permittee must ensure vegetation is not damaged by trampling.

19. All care must be taken to not damage vegetation and forest product. No cutting of vegetation is permitted. Where vegetation or natural features block access, access is prohibited.

20. The Permittee must be aware of their obligations under the Land Protection (Pest and Stock Route Management) Act 2002 with regards to the spread and control of declared plants.

21. Indemnity

21.1 The permittee -
(a) indemnifies; and
(b) releases and discharges
the State of Queensland ("the State") and HQPlantations Pty Ltd from and against all actions, proceedings, claims, demands, costs, losses, damages and expenses which sustain or be put to by reason of, or in consequence of, or in connection with the occupation and use of the Estate(s) identified in the table(s) below ("the Estate") by the permittee except to the extent of any negligent act of the State or HQPlantations Pty Ltd, its servants or agents.

21.2 The Permittee is to report all incidents involving death or injury to any person to QPWS and HQPlantations Pty Ltd. Incident involving death or serious injury (involving hospitalisation) must be reported to the offices listed in Conditions 5 and 6 of this permit. All other injuries and incidents must be reported the next business day.

16.3 The permittee must notify the QPWS and HQPlantations Pty Ltd in writing of any loss or damage immediately upon the permittee becoming aware of such loss or damage.

22. The Permittee is responsible for ensuring all participants use appropriate personal protective equipment including safety helmets, safety boots and high visibility clothing.

23. **Compliance with Laws**
    a. the Permittee must at their own expense during the term comply with all Acts of Parliament, local laws, regulations or rules for the time being in force which apply to the Permit Area and/or the Permittee's use of the Permit area.

24. **No Warranty**
    24.1 the State does not warrant that the Permit Area is free from defect or that it is safe or suitable for the Permitted Use.
    24.2 the Permittee uses the Permit Area entirely at its own risk and acknowledges that it has checked the area to ensure that it is suitable for the Permitted Use.

SCHEDULE 1

The holder of this permit has the authority to collect from the following areas, subject to any conditions attached. **TUAN STATE FOREST**

SCHEDULE 2

The permit holder is authorised to collect and/or interfere with material as specified on permit **WISP15971115**

SCHEDULE 3

Period over which the permit is valid**: 1 May 2015 until 30 April 2020 inclusive or until advised otherwise in writing.**

Authorising Officer .... Place of Issue**: Toowoomba**

Sally Egan

Date: 01/05/2015 ....

Appendix five

Permit[1]

This permit is issued under the following legislation:

S12(F) Nature Conservation (Administration) Regulation 2006

Scientific Purposes Permit

Permit number: **WISP15971115**

Valid from: **01-MAY-2015** **to** **30-APR-2020**

Parties to the Permit

Role	Name	Address
Principal Holder	Ms Janina Kaluza	3 Wildflower Street SUNSHINE BEACH QLD 4567

Permitted Location Activity Details

Location (s)	Activity (s)
Non Protected Areas - Queensland	Research on non-protected areas for scientific purposes

Permit Details

Species Details

Location	Activity
Non Protected Areas - Queensland	Research on non-protected areas for scientific purposes

Common Name	*Scientific Name*	*Category*	*Quantity*
water mouse	Xeromys myoides	Live	Unlimited Animal/s Parts/Products

1 Permit includes licences, approvals, permits, authorisations, certificates, sanctions or equivalent/similar as required by legislation.

Conditions of Approval

Agency Interest: Biodiversity

PB1 AUTHORISATION

This permit authorises the holder to capture and release the listed wildlife on non-protected areas for the purpose of a project studying the ecology and conservation of the water mouse in South East Queensland's river catchments.

This permit is issued subject to the Principal Holder holding the current approval of a registered animal ethics committee and current Marine Park permits where relevant.

The Principal Holder is authorised to conduct the following activities/procedures to the Xeromys myoides (water mouse):
- camera trapping
- capture using baited Elliot traps
- weigh, measure and determine age and breeding status
- collect DNA tissue samples (from the tip of the animal?s ear)
- collect saliva samples
- collect fur samples
- implant microchips
- transport for photography purposes as detailed in the application.

Samples may be transported to and kept at The University of Queensland, Gatton Campus, Gatton, Queensland.

The Principal Holder may also weigh, measure, assess, take fur clippings and mark any non-target fauna captured.

Ten individual water mice may be microchipped with GPS data loggers.

Measurements of water mouse mounds may be taken including basal area, height, sub-surface soil, and temperature in order to quantify characteristics of mounds.

Unless otherwise specified, all practices and procedures undertaken pursuant to this permit are to be in accordance with those details contained in and attached to the Application for a Scientific Purposes Permit signed by the Principal Holder on 3 March 2015.

PB2 Unless otherwise stated, activities authorised by this permit including the collection of voucher specimens, must be conducted in accordance with the methods detailed in the Terrestrial Vertebrate Fauna Survey Guidelines for Queensland available at
http://www.ehp.qld.gov.au/ecosystems/biodiversity/fauna-survey.html
All animals are to be released unharmed at the point of capture within 24 hours of capture.

Any accidental mortality during capture or subsequent handling is to be reported immediately to the Project Officer (Scientific Permits), Department of Environment and Heritage Protection, Toowoomba. The Queensland Museum has first refusal of any material resulting from mortality.

The Principal Holder must ensure that all traps are in good working order and checked immediately prior to use.

Any trap must (if in operation) be checked at least twice daily, however in extreme weather conditions traps must also be checked in the middle of the day.

Traps must be clearly labelled with a current name and telephone number.

Traps must not be placed in an area that could flood during the trapping session.

Animals must be released at a time of day appropriate to the behaviour of the species.

Bedding such as dry leaf or other naturally occurring biodegradable organic material must be provided in Elliott traps and cage traps.

Traps must be decommissioned when not in use.

The Principal Holder is to ensure that all the provisions of the (Queensland) Interim Hygiene Protocol for Handling Amphibians are upheld. This document is available on-line at http://www.ehp.qld.gov.au/licences-permits/plants-animals/documents/tm-wl-amphibian-hygiene.pdf

Care must be taken when repositioning logs and rocks to prevent animal injuries and to avoid causing habitat disturbance.

PB3 PROVISIONS PRIOR TO COMMENCING RESEARCH

Permission must be obtained from the landholder prior to commencing activities on freehold/leasehold land.

Marine Park permits must be obtained prior to commencing activities in Marine Parks unless released from this obligation by the Department of National Parks, Sport and Racing.

PB4 GENERAL CONDITIONS

This permit (or a copy plus proof of identity of the permit holder) must be carried while engaged in any activity authorised by the permit. Additional assistants can be authorised by the permit holder to undertake the listed activities. Additional assistants must carry a copy of the permit endorsed by the Holder with the additional assistants name and residential address and must carry a form of current coloured photographic identification.

If new species or lower taxa are described from the collection the Holotype material of any fauna group is to be lodged with the Queensland museum, where practicable.

Environmental impact is to be kept to a minimum.

All collection and handling equipment, items of clothing (including footwear) and vehicles must be cleaned before and after each separate collection activity.

All equipment (nets, flagging tape, markers etc) and any waste generated during the execution of this research project is to be removed prior to the expiry date of this permit.

All collecting activities are to be effected away from public view.

The Principal Holder must not engage in the activity authorised by this permit for any commercial purpose or for the purpose of bio-prospecting.

PB5 REPORTING

A Return of Operations and Scientific or Educational Purposes Permit Report must be submitted on the standard reporting forms:
- within 10 business days of the anniversary date of the permit each year the permit is in force; and
- within 10 business days of the expiry date.

The return is to show numbers of specimens of each species, the type of habitat and specific locality or localities where they were collected. This information is to be supplied to the Project

Officer (Scientific Permits), Department of Environment and Heritage Protection, PO Box 102, Toowoomba or electronically to SPPreport.southern@ehp.qld.gov.au. Please refer to the Wildlife Data Return Guidelines available at www.ehp.qld.gov.au for assistance completing the form.

A copy of any resulting publication from this research is to be provided to the Project Officer (Scientific Permits), Department of Environment and Heritage Protection, PO Box 102, Toowoomba or electronically to SPPreport.southern@ehp.qld.gov.au.

Signed

Sally Egan
Delegate
Department of Environment and Heritage Protection

Appendix six

Queensland Government	***DAFF Animal Ethics***	Form: AE 07
	DECISION of the ANIMAL ETHICS COMMITTEE (AEC)	

1. Applicant details

Name: Janina Kaluza		
Organisation:		Centre:
Postal Address: 3 Wildflower Street Sunshine Beach Qld 4567		
Phone:	Mobile: 0404 574 867	E-Mail: 1mightywatermouse@gmail.com

2. Project Details

Title of the Project	AEC Application Reference Number
Distribution and ecology of the water mouse in south-east Queensland.	**CA 2014/08/797**

3. AEC Decision

The project application has been considered by the AEC and is:

Approved with conditions

Any inquiry regarding this response should be directed to the AEC Coordinator or Chair in the first instance. The Coordinator of Chair may be contacted via the DAFF Call Centre on 13 25 23.

* **Conditions:**

Please consider the use of some flooring in the traps when transporting the animals in the traps.

Period of approval inclusive of the following start and end dates: Approved Start Date: 1 September 2014 Approved End Date: 31 August 2017	Animal type and number approved: Native rats and mice (water mice) – Various numbers Various species and numbers [excluding fish]

Appendix seven

National recovery plan for the water mouse (false water rat) *Xeromys myoides*

Queensland Government

Northern Territory Government

Australian Government

National recovery plan for the water mouse (false water rat) *Xeromys myoides*

Prepared by: the Department of the Environment and Resource Management and Mark J. Breitfuss, David J. Nevin and Samuel J. Maynard of *Kellogg Brown & Root Pty Ltd*

Cover photograph: Water mouse (false water rat) *Xeromys myoides* (image by Totally Wild, Network 10)

Copies may be obtained from the:
Assistant Director-General
Sustainable Communities and Landscapes
Department of the Environment and Resource Management
GPO Box 2454
Brisbane QLD 4001

Disclaimer:
The Australian Government, in partnership with the Queensland Department of the Environment and Resource Management and the Northern Territory Department of Natural Resources, Environment, the Arts and Sport, facilitates the publication of recovery plans to detail the actions needed for the conservation of threatened native wildlife.

The attainment of objectives and the provision of funds may be subject to budgetary and other constraints affecting the parties involved, and may also be constrained by the need to address other conservation priorities. Approved recovery actions may be subject to modification due to changes in knowledge and changes in conservation status.

Publication reference:
Department of the Environment and Resource Management 2010. National recovery plan for the water mouse (false water rat) *Xeromys myoides*. Report to Department of Sustainability, Environment, Water, Population and Communities, Canberra. Department of the Environment and Resource Management, Brisbane.

Abbreviations:

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
EPBC	Environment Protection and Biodiversity Conservation Act 1999
DEEDI	Queensland Department of Employment, Economic Development and Innovation
DERM	Queensland Department of Environment and Resource Management
DPIFM	Northern Territory Department of Primary Industries, Fisheries and Mines
GIS	Geographic Information Systems
NCA	Queensland Nature Conservation Act 1992
NRETAS	Northern Territory Department of Natural Resources, Environment, the Arts and Sport
SEQ	South East Queensland
TPWC	Territory, Parks and Wildlife Conservation Act 2000
VMA	Queensland Vegetation Management Act 1999
WildNet	A centralised, searchable database of Queensland's flora and fauna that is maintained by the Queensland Department of Environment and Resource Management
WPSQ	Wildlife Preservation Society of Queensland

Table of Contents

1. Executive Summary

Species description and taxonomy

The water mouse or false water-rat *Xeromys myoides* Thomas 1889 is a small native rodent recorded from coastal saltmarsh including samphire shrublands, saline reed-beds and saline grasslands, mangroves and coastal freshwater wetlands. The water mouse has small eyes and small, rounded ears. The dorsal coat is slate-grey and the belly is white. It has a maximum head and body length of 126 mm and maximum weight 64 g. The water mouse is a specialised mammal and is distinguished from other species that may be encountered in similar habitat because of its overall size and appearance. The species is also known as the false water rat and yirrkoo.

Current species status

The species is listed as 'Vulnerable' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the Queensland *Nature Conservation Act 1992* (NCA) (listed as false water-rat). In the Northern Territory *X.myoides* is listed under the *Territory Parks and Wildlife Conservation Act 2000* (TPWC Act) as 'Data Deficient'. The species is recorded on Appendix I of CITES[1]. Currently, the common name used is water mouse and for the purposes of this report, *X. myoides* will be referred to as the water mouse.

Habitat and distribution

The water mouse has been recorded in coastal saltmarsh, mangrove and adjacent freshwater wetland habitats in the Northern Territory, Queensland and New Guinea. In Queensland, the species is known from the Proserpine area south to near the Queensland/ New South Wales border. In the Northern Territory, it has been recorded from widely separated sites in Arnhem Land, the South Alligator River, Daly River and Melville Island.

Threats to species' survival

In Queensland, habitat loss, through clearing and fragmentation, and habitat degradation due to altered hydrology are the most significant threatening processes for the water mouse. In addition, site-specific impacts from introduced animals, recreational vehicles, habitat modification including by changes in soil chemistry due to disturbance of acid sulphate soils, and pesticide applications may contribute to local population extinctions. Reflecting the very different development pressures across its disjunct range, the main threats in the Northern Territory are quite different and include coastal habitat change due to saltwater intrusion, spread of exotic pasture grasses, impacts of feral animals and livestock (especially associated with intensification of pastoral activities), and possibly predation by feral cats.

Recovery objective

The overall objective of the recovery plan is to improve the conservation status of the water mouse and its habitat through habitat protection, reducing threats to species' survival, research and increasing public participation in recovery activities.

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[1] Appendix I includes those species that are most endangered among CITES listed animals and plants. They are threatened with extinction and CITES prohibits international trade in specimens of these species except where the purpose of import is not commercial.

Summary of actions
Key actions required for the recovery of the water mouse include confirming and documenting the current distribution of the species; mapping known populations and their habitat; assessing the impact of known threatening processes; developing and implementing a threat management plan to rehabilitate habitat at priority sites; engaging the community in efforts to protect existing populations by establishing voluntary agreements with relevant land owners and managers; and coordinating the recovery process.

Evaluation and review
This is the first national recovery plan for the species. The plan will be reviewed within five years from adoption as a national recovery plan. Relevant experts will review implementation actions and their effect on the recovery of the water mouse.

2. General Information

The water mouse (false water-rat) *Xeromys myoides* Thomas 1889 is a small native rodent recorded from coastal saltmarsh including samphire shrublands, saline reed-beds and saline grasslands, mangroves and coastal freshwater wetlands. The water mouse, also known as the false water rat and yirrkoo, is the only member of the genus and, together with the water rat *Hydromys chrysogaster*, comprises the Tribe Hydromyini in Australia (Walton and Richardson 1989).

Conservation status
The water mouse is listed as 'Vulnerable' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999) and the Queensland *Nature Conservation Act 1992* (NCA). It is listed as Data Deficient in the Northern Territory under the *Territory Parks and Wildlife Conservation Act 2000* (TPWC).

International obligations
The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) lists *X. myoides* (as False Water Rat) on Appendix I.

Affected interests
Australian Government
Department of the Environment, Water, Heritage and the Arts
Department of Defence

Queensland Government
Department of Environment and Resource Management
Department of Employment, Economic Development and Innovation
Queensland Museum

Local government
Local government areas throughout the range of the species in Queensland

Land councils (and the Traditional Owner groups they represent)
Queensland South Native Title Services Ltd
Central Queensland Land Council Aboriginal Corporation
Gurang Land Council Aboriginal Corporation
Northern Land Council
Tiwi Land Council

Regional natural resource management (NRM) boards
Reef Catchments Mackay Whitsunday
Fitzroy Basin Association
Burnett Mary Regional Group for Natural Resource Management Inc
SEQ Catchments
Natural Resource Management Board (NT) Inc

Non-government organisations and the community
Landcare groups
Conservation organisations and natural history groups
Research institutions
Private landholders and leaseholders

Northern Territory Government
Department of Natural Resources, Environment, the Arts and Sport
Department of Resources

Local government
Local government areas throughout the range of the species in the Northern Territory

Non-government organisations and the community
Landcare groups
Indigenous ranger groups
Conservation organisations and natural history groups
Research institutions
Private landholders and leaseholders

Consultation with Indigenous peoples
The water mouse occurs in coastal saltmarsh, mangrove and adjacent freshwater wetland habitats in coastal areas of central and south-east Queensland, the mainland and near-shore islands of the Northern Territory and in New Guinea. As a consequence of this broad distribution, implementation of components of this recovery plan will require assistance and input from a range of Indigenous peoples who either have management responsibility for affected lands or have a cultural connection to lands critical for the conservation of the water mouse.

Consultation with Indigenous stakeholders in the development of actions for the recovery of this species was sought in Queensland and the Northern Territory. Implementation of the actions within this plan includes consideration of the role and interests of Indigenous peoples in the water mouse's conservation. It may also require training and the development of appropriate education and information materials. All activities will be undertaken in a manner that respects the cultural traditions of Aboriginal peoples throughout the species' range.

Benefits to other species and communities

Protecting habitat critical to the survival of the water mouse will benefit a range of listed threatened and migratory (as recognised under the JAMBA[2] ,CAMBA[3] and ROKAMBA[3] bilateral agreements) species as well as 'Endangered' and 'Of concern' regional ecosystems. These include Illidge's ant-blue butterfly *Acrodipsas illidgei*, swamp orchid *Phaius australis*, *Durringtonia palidosa* and coastal lowland vegetation communities such as inter-tidal mangrove, saltmeadow, paperbark (*Melaleuca*) wetland, and coastal heathland (wallum). Table 1 lists these species and communities.

Conserving and protecting these species and habitat areas will result in a number of positive flow-on effects for terrestrial and aquatic ecological processes.

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[2] JAMBA: Agreement between the Government of Australia and the Government of Japan for the protection of migratory birds in danger of extinction and their environment. (Australian Treaty Series 1981 No. 6).

[3] ROKAMBA: Agreement between the Government of Australia and the Government of the Republic of Korea on the protection of migratory birds and exchange of notes. (Australian Treaty Series 2007 ATS 24).

Table 1. **Significant biodiversity benefits from protecting habitat critical to survival of *Xeromys myoides***

Common Name	Scientific Name	Habitat	Legislation	Status
Illidge's ant-blue butterfly	Acrodipsas illidgei	Coastal wetland and mangrove	NCA	Vulnerable
Latham's snipe	Gallinago hardwickii	Coastal, inter-tidal and freshwater wetlands	EPBCA	Migratory
Australian painted snipe	Rostratula australis	Coastal, inter-tidal and freshwater wetlands	EPBCA/NCA	Migratory Vulnerable
common greenshank	Tringa nebularia	Coastal, inter-tidal and freshwater wetlands	EPBCA	Migratory
lesser sand plover	Charadrius mongolus	Coastal and inter-tidal wetlands and rocky reefs	EPBCA	Migratory
grey plover	Pluvialis squatarola	Inter-tidal wetland and rocky reefs	EPBCA	Migratory
grey-tailed tattler	Heteroscelus brevipes	Coastal wetland and rocky inter-tidal	EPBCA	Migratory
bar-tailed godwit	Limosa lapponica	Coastal, inter--tidal and freshwater wetlands	EPBCA	Migratory
eastern curlew	Numenius madagascariensis	Coastal and/or inter-tidal wetlands	EPBCA NCA	Migratory Near threatened
whimbrel	Numenius phaeopus	Coastal and/or inter-tidal wetlands	EPBCA	Migratory
Pacific golden plover	Pluvialis fulva	Coastal and inter-tidal wetlands and rocky reefs	EPBCA	Migratory
terek sandpiper	Xenus cinereus	Coastal and inter-tidal wetlands	EPBCA	Migratory
yellow chat (Alligator Rivers subspecies)	Epthianura crocea tunneyi	Coastal wetland	EPBCA/ TPWCA	Endangered/ Vulnerable
Cooloola sedgefrog	Litoria cooloolensis	Coastal and freshwater 'acid' wetlands	NCA	Near threatened
wallum rocketfrog	Litoria freycineti	Coastal and freshwater 'acid' wetlands	NCA	Vulnerable
wallum sedgefrog	Litoria olongburensis	Coastal and freshwater 'acid' wetlands	EPBCA/NCA	Vulnerable
wallum froglet	Crinia tinnula	Coastal and freshwater 'acid' wetlands	NCA	Vulnerable
grey-headed flying-fox	Pteropus poliocephalus	Eastern coastal vegetation	EPBCA	Vulnerable
estuarine crocodile	Crocodylus porosus	Coastal, estuarine and	NCA	Vulnerable

9

Common Name	Scientific Name	Habitat	Legislation	Status
		freshwater wetlands		
Oxleyan pygmy perch	Nannoperca oxleyana	Coastal and freshwater 'acid' wetlands	EPBCA/NCA	Endangered Vulnerable
honey blue-eye	Pseudomugil mellis	Coastal freshwater wetland	EPBCA/NCA	Vulnerable
swamp orchid	Phaius australis	Coastal and freshwater wetlands	EPBCA/NCA	Endangered
	Garcinia warreni	Inter-tidal wetland (mangroves)	TPWCA	Endangered
	Monocharia hastata	Coastal wetland	TPWCA	Vulnerable
	Utricularia dunstaniae	Coastal wetland	TPWCA	Vulnerable
	Utricularia singeriana	Freshwater wetland	TPWCA	Vulnerable
durringtonia	Durringtonia paludosa	Coastal and freshwater wetlands	NCA	Near threatened
Regional Ecosystem 12.1.1[4]		*Casuarina glauca* open forest on margins of marine clays	VMA	Endangered
Regional Ecosystem 12.2.7		*Melaleuca quinquenervia* or *M. viridiflora* open forest to woodland on sand plains	VMA	Of Concern

VMA – Vegetation Management Act 1999 (Queensland)
EPBCA – Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)
NCA – Nature Conservation Act 1992 (Queensland)
TPWCA – Territory Parks and Wildlife Conservation Act 2000 (Northern Territory)

Social and economic impacts

It is not expected that the implementation of recovery actions will have any significant adverse social or economic impacts. Implementation of this recovery plan will have advantages in improved land management of a range of regional ecosystems. Any management actions to conserve the water mouse to be undertaken on private land will be in consultation with and with the approval of the landholders. Required changes to

[4] From the *Regional Ecosystem Description Database* that lists the status of regional ecosystems as gazetted under the Queensland *Vegetation Management Act 1999* (their vegetation management status), and their biodiversity status. This database is maintained by the Queensland Department of Environment and Resource Management. Available from: http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems/introduction_and_status/ Accessed 2009-06-04

land use or restriction of activities recommended within this recovery plan may be offset by the support and incentives provided by voluntary conservation mechanisms.

3. Biological information

Species description

The water mouse is a relatively small, specialised mammal (Ball 2004) and is distinguished from other species that may be encountered in similar habitat because of its overall size and appearance. Body dimensions from a Northern Territory specimen (Magnusson et al. 1976) and detailed studies of populations from south-east and central Queensland are summarised in Table 2 and provide an indication of adult characteristics (Gynther and Janetzki 2008).

Table 2. Body characteristics of adult *Xeromys myoides*

Feature	Male (average)	Female (average)
Head and body length (mm)	72-126 (105)	74-124 (102)
Tail length (mm)	62-94 (85)	63-99 (82)
Weight (g)	32-64 (42)	32-64 (42)

The water mouse has small eyes and small, rounded ears. The dorsal coat is slate-grey in colour whereas the belly is clearly defined and white (Van Dyck 1997). Sparse, white speckling has been observed on some adult individuals.

Life history and ecology:
Nesting strategies

The water mouse is probably entirely nocturnal, sheltering during the day and between tidal cycles in constructed nesting mounds and natural or artificial hollows. *Xeromys myoides* is also known to utilise artificial structures where no other suitable sites exist (Van Dyck et al. 2003). The first published description of an active nest was of a structure built against the base of a small-leaved orange mangrove *Bruguiera parviflora* on Melville Island, Northern Territory (Magnusson et al. 1976).

A range of nesting strategies for the water mouse has been identified at mainland and island locations in south-east Queensland (Van Dyck and Gynther 2003). Five different strategies are described from four different vegetation communities. Nesting structures are summarised broadly by Van Dyck and Gynther (2003) as being:

- free-standing
- small elevated sedgeland 'islands'
- within living or dead trees
- within the bank above the high water mark
- within human-made spoil heaps.

In the Mackay region of Queensland *X. myoides* was only observed using sloping mud nests constructed among the buttress roots of mangrove trees, although nests excavated in banks may have gone undetected (Ball 2004).

A two-year survey of water mouse populations in the Great Sandy Strait and Wide Bay/Burnett regions of Queensland identified 207 nest structures at 22 sites across these previously poorly sampled areas, with the highest concentration of nests being found in the Kauri Creek catchment and Tin Can Inlet (Burnham 2002).

Diet and foraging activity

From observational accounts in tidal areas, the water mouse utilises exposed mangrove substrata to hunt for invertebrate prey amongst pneumatophores (roots rising above the ground or water) and in shallow pools. These activities occur nocturnally when individuals follow the tide out to the low water mark and forage until advancing waters inundate the mangrove community (Van Dyck 1997). The ecology of *X. myoides* utilising non-tidal environments has not been investigated.

Food preference studies have not been conducted for the water mouse. However, the species is known to frequent regular feeding locations, depositing the remains of previous meals in middens (Van Dyck 1997). From these, fragments of shell and other remains have been collected and identified to provide information on the range of organisms targeted for feeding. These comprise a number of invertebrates including grapsid crabs, other inter-tidal crustaceans, pulmonate snails and marine gastropods (see Newman and Cannon 1997, Van Dyck 1997 for all known prey species). These species are common in inter-tidal saltmarsh habitats in south-east Queensland (Breitfuss et al. 2004).

Reproductive biology

To date, little is known about the reproductive biology of the water mouse, although the species has been successfully held in captivity for short periods (S Van Dyck pers. comm. 2007). A study by Van Dyck (1997) on North Stradbroke Island (Queensland) found up to eight animals of mixed age and gender may share a mound, however, there is generally only one sexually active male present. The nest may also be used by successive generations of water mouse over a number of years.

Distribution

In Australia, the water mouse is currently known from coastal areas of central and south-east Queensland from Proserpine south to the Queensland/New South Wales border region (Van Dyck and Gynther 2003; Ball 2004) and a small number of near-coastal sites in the top end of the Northern Territory (McDougall 1944; Redhead and McKean 1975; Magnusson et al. 1976, Van Dyck 1997; Woinarski et al. 2000). A map illustrating known records of the species is provided in Appendix 1.

In Queensland the water mouse has been recorded on the mainland from the Proserpine region, at Mackay, an area south of Gladstone, and from south-east Queensland between Hervey Bay and the Coomera River (50 km south-east of Brisbane). Additional records are from Fraser Island, Bribie Island, North Stradbroke Island and South Stradbroke Island.

In the Northern Territory, the water mouse has been recorded from widely separated sites on the Glyde River and Tomkinson River in Arnhem Land and the South Alligator River, Daly River and Melville Island (Woinarski 2006; Woinarski et al. 2007), although most of these records are now very dated. The species has also been recorded from Papua New Guinea (Hitchcock 1998). Specimens were collected close to a seasonally inundated freshwater wetland surrounded by *Melaleuca* forest on the Bensbach River floodplain (Hitchcock 1998).

Within Queensland different survey strategies appear to be more suited to particular sections of the species' range. For example, nest site surveys that enable a convenient and relatively rapid assessment of the presence/absence of the species in southern Queensland (Burnham 2002, Van Dyck and Gynther 2003) are not as useful along the central Queensland coast where free-standing nests have not been encountered and other nest types are detected infrequently (Ball 2004). Most records of the water mouse in the latter area have resulted from Elliott trapping. Interestingly pitfall trapping has proved successful in the Northern Territory at sites where previous cage and Elliott trapping did not capture the species (Woinarski et al. 2000). Pitfall trapping is seldom used by workers targeting the water mouse in Queensland.

Exploratory surveys for the water mouse have been conducted at locations in addition to those at which the species is known to occur (Van Dyck and Gynther 2003; S Van Dyck and I Gynther pers. obs). In particular, wetland habitats directly south of the New South Wales/Queensland border and in Brisbane have been surveyed, with no positive records to date. Currently, the distribution of *X. myoides* is patchy but the reasons are unclear for the species' apparent absence from areas that possess similar habitat to occupied sites. The water mouse may also fail to be detected during re-survey of sites that had known populations (Ball 2004) or may be captured where earlier efforts were unsuccessful (Woinarski et al. 2000). The cause of such temporal changes in distribution and abundance are unknown. There has been no targeted survey for this species across its Northern Territory range.

To date, only a preliminary, inconclusive investigation of the extent of genetic variation within *X. myoides* has been undertaken, based on a small sample size (Vitalone 2002). A more detailed analysis is required to determine whether the current, fragmented populations that occur over the species' essentially linear range in Australia and New Guinea are genetically distinct. The value of such an investigation is that it could reveal the existence of cryptic species or some form of population structuring, and determine if the pattern of fragmentation is a result of historical or contemporary and/or anthropogenic influences. The results of such research would have implications for the conservation management of the water mouse, identifying whether recovery action should be targeted at the species as a whole or at separate demographic units or distinct taxa.

Habitat critical to the survival of the species
The characteristics of vegetation communities and landforms associated with areas where the water mouse has been captured are detailed in a number of published and unpublished reports (e.g. Woinarski et al. 2000; Burnham 2002; Van Dyck and Gynther 2003; Ball 2004). These accounts describe nests or capture of individuals from both freshwater and saline habitats associated with various coastal and freshwater flora assemblages and a range of landform features. Vegetation types utilised by the water mouse include sedgeland composed mainly of freshwater vegetation, chenopod shrubland including succulents and dwarf shrubs, *Sporobolus* grassland and salt meadows, and a range of mangrove communities.

Habitat modelling has not been conducted for any part of the national distribution of the water mouse. However, habitat suitability maps or maps indicating locations of significant water mouse populations have been produced for the Central Queensland Coast and Southeast Queensland bioregions. Ecological information and expert knowledge was used to demarcate 'essential habitat' for the species as part of the Queensland DERM Biodiversity Planning Assessments. These assessments function as biodiversity and nature conservation information tools to assist land use and land management decision-making, e.g. assessment of clearing applications under Queensland's *Vegetation Management Act 1999*. Due to the paucity of water mouse records, no detailed mapping has been undertaken in the Northern Territory.

Important populations
The water mouse is recorded from a number of protected areas in central and south-east Queensland. These include:

- Cape Palmerston National Park, Cape Hillsborough National Park and Sandringham Bay Conservation Park in central Queensland

- Eurimbula National Park, Great Sandy National Park, Poona National Park, Great Sandy Conservation Park, Beerwah Forest Reserve and Bribie Island National Park in south-east Queensland
- Protection zones within the Southern Moreton Bay Marine Park in south-east Queensland.

Within the Great Sandy Strait, south-east Queensland, some populations of water mouse are located within the Fraser Island World Heritage Area, and others occur within the Wide Bay Military Reserve.

A large percentage of the water mouse populations in the Great Sandy Strait and Moreton Bay areas of south-east Queensland occur in inter-tidal habitats within the Great Sandy Strait and Moreton Bay Ramsar[5] Sites.

In south-east Queensland, high density populations of *X. myoides* occur within the Great Sandy Strait (including Tin Can Bay), Pumicestone Passage and southern Moreton Bay (including the western shores of North and South Stradbroke Islands).

In the Northern Territory, land on which the water mouse is known to occur on Melville Island and the mainland is managed by Traditional Owners. Access to these sites is by permit, through the Tiwi Land Council and the Northern Land Council respectively.

One Northern Territory population is known from Kakadu National Park, but there is no knowledge of this population other than a broad location described at the time of its discovery in 1903 (Woinarski 2004).

Threats to Species' Survival

Physical

The most important issues for the water mouse are the loss, degradation and fragmentation of freshwater and inter-tidal wetland communities utilised by the species. Whilst clearing results in the obvious loss of habitat structure, processes that degrade or fragment core elements of a habitat can reduce potential feeding resources and nesting opportunities, extend edge effects, promote weed invasion and increase predatory pest densities or their impacts on native fauna.

In some parts of Queensland, water mouse habitats are often within areas of significant urban expansion and have been cleared to accommodate human development and infrastructure. For example, certain areas of mangrove and adjacent saltmarsh and freshwater wetland habitats have been cleared and/or modified for development in the Southeast Queensland bioregion. As an illustration, approximately 94% remains of the pre-clearing mappable area of 53,499 ha of mangroves (Regional Ecosystem 12.1.3), while the equivalent figure for tidal saltmarsh communities (Regional Ecosystem 12.1.2) is 87% of a pre-clearing extent of 32,713 ha (Accad et al. 2008).

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[5] *The Convention on Wetlands* (Ramsar 1971) is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. These sites are included on the List of Wetlands of International Importance.

At a local level, habitats important for the water mouse are influenced by a number of natural and artificial physical processes. Natural physical processes include:

- fluctuations in sea level that result in altered patterns of vegetation zoning between mangrove, saltmarsh and terrestrial communities
- subsidence and accretion of inter-tidal sediments that results in modified community distribution, structure and composition
- natural flooding events that directly limit or reduce the distribution of the water mouse.

More broadly, much of the floodplain wetlands of northern Australia are likely to be highly susceptible to change arising from even small rises in sea levels associated with global climate change. Such saltwater intrusion will cause losses of productive freshwater habitats and their replacement by saline systems. Too little is currently known about the habitat requirements of the water mouse in this region to assess whether this environmental change will be detrimental, neutral or beneficial to this species.

Other potential threats to the survival of *X. myoides* include:

- changes in hydrology, including increased freshwater inflows and sedimentation from stormwater runoff as a result of adjacent residential development
- physical changes to saltmarsh such as runnelling or bundwall construction that modify tidal amplitude and frequency of inundation
- reclamation of inter-tidal and terrestrial habitats as a result of deposition of dredge spoil
- use of recreational vehicles in inter-tidal areas due to the long-lasting damage they cause through destruction and degradation of habitat
- modified water levels and salinity in tidal waterways resulting from installation of flow control gates for flood mitigation
- drainage of coastal and terrestrial wetlands for urban and industrial developments
- inappropriate burning of sedgeland, grassland and adjacent *Melaleuca* wetland communities.

Artificial physical processes may also impact on the water mouse indirectly. For example, changes to salinity and sediment loads caused by increased stormwater runoff from expanding urbanisation are detrimental to populations of grapsid crabs, a major food source for *X. myoides* (Ball et al. 2006).

<u>Biological</u>
Direct biological impacts on the water mouse include predation pressures from native and introduced fauna, competition for food resources and modification of suitable habitat by feral and hard-hoofed animals such as pigs.

Predation pressures from feral and domestic dogs, foxes and feral and domestic cats are likely to pose significant threats to populations of the water mouse, particularly those located close to urban environments in parts of coastal Queensland. However, these pressures have not been quantified for isolated populations. Remains of the water mouse have been detected in dingo scats on Fraser Island (K Twyford pers. comm. 2007), although the population-level significance of predation of *X. myoides* by dingoes is unknown.

Destruction or degradation of habitat by feral and hard-hoofed animals (e.g. pigs) has been recorded from a number of populations of the water mouse (Burnham 2002; S Van Dyck and I Gynther pers. obs). In the Northern Territory, much of the lowland wetland communities of this species is being deliberately or inadvertently transformed by the spread of exotic plant species, including *Mimosa pigra* and exotic pasture grasses (such as para grass and olive hymenachne). The impacts of such changes on the status of the water mouse are uncertain.

<u>Chemical</u>
In south-east and central Queensland, saltmarsh and mangrove habitats occur adjacent to agriculture (e.g. sugar cane lands) and urban development. Herbicides and pesticides are employed for pest management, but may also persist in natural environments (Zimmerman et al. 2000), possibly impacting non-target populations and potentially affecting the water mouse and/or its prey and habitat.

Changes in soil chemistry, for instance the development of acid sulphate soils as a result of disturbance and exposure to air of 'at risk' soils, may disrupt mangrove habitat, e.g. mangrove and saltmarsh communities near Tweed Heads in the late 1980s (C Easton pers. comm. 2002).

Off-shore pollution events such as oil spills have the potential to negatively influence the function and health of mangrove and saltmarsh communities. As a result, the cumulative impacts from these activities may result in secondary effects on populations of the water mouse and/or its primary food sources.

Populations under threat
Local reductions and disappearances of water mouse populations have been recorded both in Queensland and the Northern Territory in the past 30 years and at least one local extinction event has been recorded at Coomera Waters adjacent to the Coomera River, Gold Coast (Van Dyck et al. 2006.). Exploitative reclamation of coastal habitats for urban development is a primary factor involved in the loss of habitat important for the water mouse. The impacts from these types of habitat loss are difficult to quantify, however, some populations in south-east Queensland are known to have been affected, whether directly or indirectly, by development activities (Van Dyck et al. 2006). For example, monthly trap censuses demonstrated the decline and eventual disappearance of a robust population of *X. myoides* over a five-year period coincident with the development of the adjacent 118 ha, 1100-allotment Coomera Waters canal estate (Van Dyck et al. 2006). No further captures of water mouse were recorded despite increased trap effort over the subsequent 16 months. The precise cause of this local extinction is unclear but may be the result of one or more factors associated with the estate's development (Van Dyck et al. 2006).

4. Recovery objectives, performance criteria and actions

Overall objective
The overall objective of the recovery plan is to improve the conservation status of the water mouse and its habitat through habitat protection, reducing threats to species' survival, research and increasing public participation in recovery activities.

Specific objectives

Specific objective 1: Identify habitats supporting populations of the water mouse and map the current distribution.

Action 1.1: Conduct surveys to confirm the current distribution of the water mouse.

- Based on live trapping and/or positive nest identification, conduct surveys of all previously known populations across the range of the water mouse to confirm the species' continued presence.
- Wherever captures are made, collect relevant DNA samples (ear clip, tail tip or blood) from individuals in each subpopulation to contribute to an investigation of genetic variation within the species. Genetic researchers should be contacted to determine the appropriate samples to be collected and to ensure optimal sampling strategies are implemented. Investigate the potential to use non-intrusive sampling methods, e.g. hair samples.
- Record key habitat features and biological associations for all survey locations.

Performance criteria: Historic and other previously known sites are surveyed to confirm the species' continued presence.

Potential contributors: NRETAS, QMuseum, Regional NRM boards (i.e. Reef Catchments Mackay Whitsunday Burnett Mary Regional Group for Natural Resource Management Inc, SEQ Catchments, Natural Resource Management Board [NT] Inc), research institutions, volunteers, DERM.

Action 1.2: Consolidate existing Queensland and Northern Territory water mouse databases to form a comprehensive national dataset, including survey results and sites supporting extant populations.

- Produce an up-to-date and verified national database of all records of water mouse on *WildNet* including historical, specimen-backed and contemporary records. The database will record information on survey locations, survey effort, habitat type, tenure and disturbance history, as well as presence/absence of the species. This will serve as a register of sites with extant populations and will assist in directing future survey effort, reassessing conservation status of the water mouse, prioritising sites for active management and targeting areas for habitat protection through conservation agreements.
- Maintain and review the database on an ongoing basis to ensure the data remain current and accurate.

Performance criteria: Within two years, record on *WildNet* accurate, comprehensive details of all sites supporting extant populations.

Potential contributors: DERM, NRETAS

Action 1.3: Produce high-quality GIS mapping and undertake spatial analysis of habitat supporting extant populations, particularly for sites under most severe threat.

- Review existing maps of historical capture and nesting locations to provide a baseline for further mapping.
- Evaluate and improve existing GIS habitat models to assist in planning field surveys of new areas covered by these models under Action 1.4.
- Ascertain the most appropriate GIS habitat modelling techniques to be applied to areas not covered by the existing habitat models to enable the occurrence of the water mouse elsewhere to be predicted.
- Based on the outcome of this work, integrated with the results of Actions 1.1-1.2 and 1.4, produce up-to-date mapping of extant populations and their geographic extent, relating the status of current and historical sites to key landscape types, habitat features, vegetation associations, tidal inundation regimes and land use.
- Determine whether habitat corridors link occupied sites.
- From this new mapping, identify sites protected under State or Commonwealth legislation and those on other land tenures.

Performance criteria: GIS maps produced by Year 3 and updated annually. Local maps of extant populations are produced within two years.

Potential contributors: DERM, NRETAS

Action 1.4: Conduct surveys and ecological assessments of potential water mouse habitat.

- Following an evaluation of existing GIS habitat models and the development of additional GIS habitat modelling for other areas within the range of the water mouse (Action 1.3), conduct targeted trapping and nest surveys at predicted new sites, particularly those possessing a high correlation of key characteristics to known water mouse locations.
- Target areas adjacent to known populations to determine the geographic extent of the species. In particular, areas of extensive mangrove and saltmarsh vegetation between previously identified locations across the range of the species should be surveyed. In south-east Queensland, survey effort should be extended on river systems such as the Noosa and Maroochy Rivers to more fully define the distribution and upstream extent of occurrence of the water mouse.
- Where appropriate, collect genetic samples as in Action 1.1.
- Update *WildNet* with the results of these surveys and habitat assessments.

Performance criteria: For each locality, at least one additional site with potential habitat is surveyed annually.

Potential contributors: QMuseum, Regional NRM boards, research institutions, conservation groups, volunteers, DERM, NRETAS

<u>Specific objective 2</u>: Describe key biological and ecological features of the water mouse and its habitat.

Action 2.1: Determine whether genetic differentiation exists across populations of the water mouse.

- Conduct a genetic analysis of the DNA samples collected from subpopulations of the water mouse from Actions 1.1 and 1.4 to investigate the degree of genetic variation inherent within the species. Ideally, the sampling would represent the entire distribution of the species in Australia. This analysis may possibly demonstrate the existence of cryptic species or determine the extent of population structuring present within what is essentially a fragmented, linear distribution around the northern and eastern coasts of Australia. The potential for the existence of more than one species or genetically identifiable population has significant implications for the conservation status, as well as for managing the species and individual populations to ensure the maintenance of genetic diversity.
- Consult genetic researchers to determine the appropriate samples to be collected (e.g. tail tips or ear clips for mtDNA; blood for allozymes) and to ensure optimal sampling strategies are implemented. Investigate the potential to use non-intrusive sampling methods (e.g. hair samples).

Performance criteria: The degree of genetic variation within the overall distribution of the water mouse is determined and a report produced within three years of the commencement of the investigation. Paper(s) detailing findings of the research produced by the plan's fifth year.

Potential contributors: QMuseum, research institutions, NRETAS

Action 2.2: Understand the reproductive biology of the water mouse.

- Focus research efforts towards providing a greater understanding of basic reproductive features of the water mouse. This information will be important for determining the species' capacity for recovery once threatening processes are ameliorated. Current knowledge of the reproductive biology of the species is minimal. Data are required about: breeding behaviour, mating characteristics, nesting structures and their function, development to sexual maturity, external genitalia, gestation period, fecundity, foetal development, brood size and reproductive seasonality in the wild.
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Performance criteria: Research plan is developed during the recovery plan's first year of implementation and paper(s) produced within five years of commencement of the recovery plan, to detail findings of this research.

Potential contributors: research institutions, DERM, NRETAS

Action 2.3: Investigate selected field populations to describe poorly known ecological features of the water mouse.

- Investigate characteristics of field populations, such as home range, feeding/foraging areas, population structure and inter/intra-specific competition. The focus should be towards basic biological and ecological characteristics that are currently little understood. This study should be site-specific and based on information gaps, and should include targeted monthly work on at least two field populations over three years.
- Although selection of potential locations for regular investigation will depend upon factors such as ease of access and size of the water mouse population, sites should be chosen from different parts of the known range of the species to encompass any variation in life history characteristics across the distribution. In south-east Queensland, suitable populations would be those from Pumicestone Passage (e.g. Donnybrook) or southern Moreton Bay (e.g. McCoys Creek).

Performance criteria: Research plan developed during the first year of implementation of the recovery plan. Regular study of at least two populations conducted for three years. Reports and paper(s) produced within five years of commencement of the recovery plan, detailing findings of the research.

Potential contributors: NRETAS, research institutions

Specific objective 3: Monitor population trends and identify and manage threats to species' survival.

Action 3.1: Conduct a monitoring program of selected representative water mouse populations to measure trends in abundance of the species and efficacy of management actions.

- Develop a robust monitoring protocol and establish a long-term monitoring program at representative sites, especially where such monitoring can measure the efficacy of management actions and/or the responses of this species to environmental change or the impacts of known or putative threats.

Performance criteria: Consistent monitoring protocols developed during the recovery plan's second year of implementation. Monitoring program trialled and results analysed. Robust monitoring program implemented for at least three representative sites. Resulting trend data are reported annually.

Potential contributors: NRETAS, Regional NRM boards, research institutions, DERM

Action 3.2: Assess the impact of known threats to species' survival on extant populations of the water mouse.

- Assess the impact of identified processes that threaten species' survival, including: habitat destruction and fragmentation from development (e.g. Sunshine Coast and northern Gold Coast of south-east Queensland); direct and indirect effects of stormwater runoff from residential developments (e.g. Mackay region of central Queensland); damage to habitat caused by recreational vehicle usage (e.g. Tin Can Bay/Great Sandy Strait area of south-east Queensland); habitat degradation by feral and hard-hoofed animals (e.g. pigs); predation by native and introduced fauna (e.g. saltmarsh areas of Pumicestone Passage, south-east Queensland); cattle grazing and trampling (e.g. Coomera River, Gold Coast; Daly River floodplains, Northern Territory); inappropriate fire events that may directly threaten individuals nesting structures and expose foraging water mice to a greater risk of predation by removing vegetation cover in sedgeland, grassland and adjacent *Melaleuca* communities (e.g. Pumicestone Passage); and impacts of weed invasion on aspects such as the viability of extant water mouse populations and the restriction of re-colonisation of populations into adjacent habitats.
- Use the results of site-specific studies to formulate and guide future management actions.

Performance criteria: Report produced within three years of commencement of recovery plan detailing results, implications and recommendations for all extant populations of the water mouse.

Potential contributors: NRETAS, Regional NRM boards, research institutions, DERM

Action 3.3: Investigate the relative impact of potential threats to species' survival.

- Model the likely impacts on habitat suitability of factors arising from global climate change (particularly change in seawater levels).
- Study the potential direct and indirect impacts of chemical pesticide treatments on field populations of the water mouse, in particular, products employed for mosquito control in coastal wetlands that affect non-target invertebrate populations. Possible areas for study include wetlands adjacent to higher density human populations on the Gold and Sunshine Coasts of south-east Queensland, particularly where housing developments have recently been completed or construction is due to commence.
- Through a desk-top review of available literature, examine the possible indirect impacts on the water mouse of chemical pesticide treatments used to control mosquitoes.
- Investigate pesticides registered for use in sugar cane production (e.g. in the Mackay area of central Queensland and the Maroochy River area of the Sunshine Coast) to determine whether they have adverse impacts or indirect impacts on the water mouse.
- Assess the potential direct and indirect impacts on the water mouse of major changes to soil chemistry and water quality. Potential study locations include the Gold and Sunshine Coasts of south-east Queensland where industrial, residential, marina or other significant developments are planned or have commenced. If possible, review the impact on the water mouse of sand quarrying operations at Donnybrook on the western side of Pumicestone Passage in south-east Queensland, where an important population of water mice occurred prior to extraction activities commencing.
- Study the foraging ecology of feral predators in and adjoining inter-tidal vegetation communities (e.g. foxes and cats in the Pimpama River to Coomera River corridor of the Gold Coast) to determine the significance of impacts on the water mouse.

Performance criteria: Report produced within five years of commencement of this recovery plan, detailing results, identifying additional confirmed threats and providing recommendations for mitigating threats to species' survival.

Potential contributors: NRETAS, research institutions, DERM

Action 3.4: Develop and implement a threat management plan.

- Based on the recommendations from Actions 3.1-3.3, produce a threat management plan to identify threats to species' survival and outline measures to mitigate these threats, e.g. control of feral predators; creating conservation reserves; encouraging land holders and land managers to protect and conserve habitat (e.g. by fencing to exclude cattle; instigating appropriate and carefully planned fire regimes for habitat adjacent to occupied sites, etc.); and enhancing the quality of habitat adjacent to extant populations including through use of buffer zones.
- Identify and implement management actions to reduce or remove threats to species' survival at five priority locations for the water mouse.

Performance criteria: Production of a threat management plan and annual reports detailing work undertaken at five selected sites.

Potential contributors: NRETAS, local governments, Regional NRM boards, landholders

<u>Specific objective 4</u>: Rehabilitate habitat to expand extant populations.

Action 4.1: Regenerate habitat corridors at five sites.

- Based on the findings from Actions 1.1-1.4 and the results of Actions 2.1 and 3.1-3.4, develop a site rehabilitation plan and establish active regeneration programs at selected sites adjacent to and linking extant water mouse populations, working in collaboration with interested landowners or land managers wherever possible. Exclusion fencing, revegetation, removal of introduced species (plants and animals), restoration of natural hydrology and modification of stormwater inflows from residential areas may facilitate natural regeneration of sites. Results of survey and monitoring efforts conducted previously suggest possible sites for rehabilitation in south-east Queensland could include the lower Noosa and Maroochy Rivers; the western shore of Pumicestone Passage; and the Behms Creek to Pimpama River corridor and Coomera River area of southern Moreton Bay. On the central Queensland coast, potential areas for such work include the Glen Isla/Goorganga area; McCready's Creek, Reliance Creek and unallocated land along Rocky Dam Creek.
- Monitor rehabilitated sites at three-monthly intervals and conduct assessments against criteria detailed in the rehabilitation plan.

Performance criteria: Rehabilitation plan developed within first year of recovery plan implementation, and regeneration programs commenced at five sites within two years. Progress of site regeneration is reported annually thereafter.

Potential contributors: DERM, NRETAS, local governments, Regional NRM boards, conservation groups, volunteers

Action 4.2: Evaluate the potential for artificial nesting structures to encourage re-colonisation of suitable habitat by the water mouse.

- Investigate the degree to which artificial nesting structures (based on previously published, successful designs; see Van Dyck et al. 2003) are used by the water mouse. If determined to be viable and practical, installation of these structures may encourage animals to take up residence in sites that lack natural opportunities for nesting but which otherwise possess suitable habitat. This approach may facilitate the expansion of existing water mouse populations. Such work could be undertaken in conjunction with habitat rehabilitation projects at south-east Queensland sites identified in Action 4.1 (e.g. at Behms Creek, or Pimpama River).
- Use the results of the investigation to refine the design of the artificial nesting structures so as to enhance colonisation under field conditions.

Performance criteria: Trials utilising artificial nest structures are conducted at two sites. Results and recommendations, including any refinements in design of artificial nest structures, reported within four years of commencement of recovery plan.

Potential contributors: QMuseum, research institutions, conservation groups

<u>Specific objective 5</u>: Increase public awareness of, and involvement in, water mouse conservation.

Action 5.1: Collaborate with Indigenous landowners to exchange knowledge about the water mouse, its environment, threats to species' survival and management.

- Improve current understanding of the species' biology and ecological requirements, as well as knowledge of threats to species' survival. This approach will enhance the conservation management of the water mouse.
- Develop communication products to facilitate this information exchange.

Performance criteria: Relevant Indigenous landowners have an appreciation of the conservation significance of this species, and are supportive of its conservation management. Relevant Indigenous knowledge of this species is applied where appropriate to guide management actions.

Potential contributors: DERM, NRETAS, landholders, Land Councils, Traditional Owners

Action 5.2: Investigate opportunities for protecting the habitat of extant populations on freehold land and land managed by local, State and Commonwealth governments through establishment of voluntary conservation agreements.

- Use the findings from the survey and mapping activities conducted in Actions 1.1-1.4 to identify landowners or land managers who have *X. myoides* on their properties or lands adjacent to mapped sites.
- Investigate opportunities to protect this habitat through various voluntary mechanisms (such as nature refuges, voluntary conservation agreements, *Land for Wildlife*) involving the landowners or managers and the relevant level of government.
- Consider employing incentives schemes to secure habitat critical for the protection of extant populations.

Performance criteria: Voluntary conservation agreements to protect land supporting (or adjacent to) extant populations are established within five years of commencement of this recovery plan.

Potential contributors: DERM, Department of Defence, DEEDI, local governments, landholders

Action 5.3: Develop and implement management plans for populations of water mouse occurring on land that is subject to voluntary conservation agreements.

- Establish extension programs for landowners and land managers who have entered into a voluntary agreement to protect *X. myoides* under Action 5.2, with the aim of explaining how to manage the species and its habitat.
- Apply the results of Actions 3.2-3.4 to identify relevant threats to the water mouse population and determine how these threats are best mitigated at specific sites.
- Working with the relevant parties, develop site-specific management plans for the water mouse populations for land covered by voluntary conservation agreements.

- Assist landowners and land managers in securing funding to implement the property-specific management plans for the water mouse.

Performance criteria: Management plans are developed and implemented within five years of recovery plan implementation for all land covered by voluntary conservation agreements representing known habitat or potential habitat of the water mouse.

Potential contributors: local government, Regional NRM boards, landholders

Action 5.4: Develop and implement a community awareness and education program focusing on the water mouse.

- Formulate and implement a community extension and education program in local government areas where the water mouse is known to exist, with the aim of increasing public awareness of issues relevant to the survival of the species. Previously, the Wildlife Preservation Society of Queensland (WPSQ) conducted a program involving community training in water mouse survey and nest identification techniques, followed by field days and community-based surveys in locations including the islands of southern Moreton Bay in south-east Queensland. As part of this program, an educational brochure was produced and information on the water mouse made available on the WPSQ web site (refer http://www.wildlife.org.au).
- Review this earlier program and the existing brochures, posters etc, with the aim of producing new or revised materials, holding additional field days or guided walks, and developing novel approaches to broaden the audience receiving the educational message about the water mouse. So as to build community awareness and capacity to support the recovery effort it will be important to identify the appropriate target audience and design the materials and approaches accordingly,.

Performance criteria: Community awareness and education program for key local government areas is developed and implemented within five years.

Potential contributors: local governments, Regional NRM boards

Summary table

Table 3 outlines the recovery actions described above, including the relative priority of each action, and potential stakeholders.

Table 3. Summary of recovery implementation

Action	Performance criteria	Potential contributors	Priority*
Specific objective 1: Identify habitats supporting populations of the water mouse and map the current distribution			
1.1: Confirm current distribution of the water mouse	Surveys of previously known water mouse populations conducted and DNA samples collected	NRETAS, QMuseum, Regional NRM boards, research institutions, volunteers, DERM	1
1.2: Consolidate data concerning all water mouse records and survey results	Comprehensive database of water mouse information incorporated on *WildNet* within two years of recovery plan implementation and data regularly maintained and updated.	DERM, NRETAS	2
1.3: Produce GIS mapping and undertaken spatial analysis of water mouse habitat	GIS database produced within two years. Maps of extant populations produced within two years of implementation of recovery plan.	DERM, NRETAS	1
1.4: Conduct surveys and ecological assessments of potential water mouse habitat	For each locality, at least one additional site with potential water mouse habitat is surveyed annually.	QMuseum, Regional NRM boards, research institutions, conservation groups, volunteers, DERM, NRETAS	2
Specific objective 2: Describe key biological and ecological features of the water mouse and its habitat			
2.1: Determine whether genetic variation exists across populations of the water mouse	Genetic variation across overall distribution of the water mouse determined, and a report produced within three years of commencement of the investigation. Paper(s) detailing findings of research produced within five years of recovery plan implementation.	QMuseum, research institutions, NRETAS	1
2.2: Understand the reproductive biology of the water mouse	Research plan developed within one year of implementation of the recovery plan and paper(s) produced detailing findings of the research within five years	Research institutions, DERM, NRETAS	3

2.3: Investigate selected field populations of the water mouse	Research plan developed within one year of implementation of the recovery plan. Regular monitoring of two populations conducted for three years. Reports and paper(s) detailing findings of the research produced within five years	NRETAS, research institutions	2
Specific objective 3: Identify and manage threats to species' survival			
3.1. Monitor representative populations	Consistent monitoring protocols developed during the plan's second year. Monitoring program trialled and results analysed. Robust monitoring program implemented for at least three representative sites. Resulting trend data reported annually.	NRETAS, Regional NRM boards, research institutions, DERM	1
3.2: Assess impact of known threats to species' survival	Report results, implications and recommendations within three years of commencement of recovery plan.	NRETAS, Regional NRM boards, research institutions, DERM	1
3.3: Investigate relative impact of potential threats to species' survival	Report produced within five years of commencement of this recovery plan, detailing results, identifying additional confirmed threats and providing recommendations for mitigating threats to species' survival.	NRETAS, research institutions, DERM	2
3.4: Develop and implement threat management plan	Production of a threat management plan and annual reports detailing work undertaken at five sites.	NRETAS, local governments, Regional NRM boards, landholders	1

Specific objective 4: Rehabilitate habitat to expand extant populations			
4.1: Regenerate habitat corridors at five sites	Rehabilitation plan developed within first year of recovery plan implementation, and regeneration programs commenced at five sites within two years. Annual progress reports prepared thereafter.	DERM, NRETAS, local governments, NRM boards, conservation groups, volunteers	3
4.2: Evaluate the potential for artificial nesting structures to encourage re-colonisation of suitable habitat by the water mouse	Trials utilising artificial nest structures conducted at two sites, with results and recommendations reported within four years of commencement of recovery plan.	QMuseum, research institutions, conservation groups	2

Specific objective 5: Increase public awareness of, and involvement in, water mouse conservation			
5.1: Collaborate with Indigenous landowners to exchange knowledge about the water mouse, its environment, threats to species' survival and management	Relevant Indigenous landowners have an appreciation of the conservation significance of this species, and are supportive of its conservation management. Relevant Indigenous knowledge of this species is applied where appropriate to guide management actions.	DERM, NRETAS, landholders, Land Councils, Traditional Owners	2
5.2: Investigate opportunities for protecting the habitat of extant populations through voluntary conservation agreements	Voluntary conservation agreements to protect land supporting (or adjacent to) extant populations established within five years of commencement of this recovery plan.	DERM, Department of Defence, DEEDI, local government, landholders	1
5.3: Develop and implement management plans for populations of water mouse occurring on land that is subject to voluntary conservation agreements	Management plans developed and implemented within five years of recovery plan implementation for all land covered by voluntary conservation agreements that is known habitat or potential habitat of the water mouse.	Local government, Regional NRM boards, landholders	1
5.4: Develop and implement a community awareness and education program focusing on the water mouse	Community awareness and education program about the water mouse developed for key local government areas and implemented within five years of recovery plan commencement.	Local government, Regional NRM boards	2

* Priority ratings are: 1 - action critical to meeting plan objectives; 2 - action contributing to meeting plan objectives; 3 - desirable but non-essential action.

5. Management Practices

Appropriate management of the habitat of the water mouse is critical to the survival of the species. Issues that are known or considered to impact negatively upon *X. myoides,* based on current knowledge of the biology of the species include:

- clearing, drainage and/or other modification of coastal freshwater and inter-tidal wetland communities utilised by the species to accommodate human development, infrastructure and extractive industry;
- reclamation of inter-tidal and terrestrial habitats due to deposition of dredge spoil;
- fragmentation of coastal vegetation communities due to the direct impacts (e.g. loss of habitat, limited dispersal opportunities, reduced genetic exchange) and indirect impacts (e.g. increased feral predation, increased weed invasion);
- disturbance/exposure to air of potential acid sulphate soils due to potential for changes in soil chemistry, e.g. acidification that may adversely the health of mangrove, saltmarsh and other vegetation communities;
- changes to natural hydrology that adversely impact on inter-tidal communities (including prey species) or the adjacent terrestrial community;
- activities that threaten the integrity of the supralittoral bank, a physical feature of the inter-tidal habitat commonly used for nesting by the water mouse;
- mechanical changes (e.g. runnelling, construction of bundwalls) to saltmarsh that modifies tidal amplitude and frequency of inundation;
- presence of recreational vehicles on inter-tidal wetland areas;
- degradation of habitat through grazing and trampling of wetland, saltmarsh and mangrove areas;
- discharge of wastes (stormwater runoff from residential areas, thermal effluents, sewage, and industrial and urban wastes) into estuaries;
- offshore oil pollution events, which have the potential to damage the function and health of mangrove communities;
- installation of flow control gates for flood mitigation, which modify water levels and salinity in tidal waterways;
- spread of exotic pasture grasses on floodplain and other wetland habitats;
- chemical (fertiliser, herbicide and pesticide) usage on land adjacent to water mouse habitat.

6. Cost of recovery

The estimated costs associated with implementing this National recovery plan for the water mouse *Xeromys myoides* are provided below:

Table 4. Costs of water mouse recovery

Action	Year 1 ($)	Year 2 ($)	Year 3 ($)	Year 4 ($)	Year 5 ($)	Total per action
Action 1.1	36 000	36 000	0	0	0	$72 000
Action 1.2	12 000	12 000	12 000	12 000	12 000	$60 000
Action 1.3	16 000	16 000	16 000	16 000	16 000	$80 000
Action 1.4	4400	4400	4400	4400	4400	$22 000
Action 2.1	0	15 000	10 000	10 000	0	$35 000
Action 2.2	0	15 000	15 000	15 000	0	$45 000
Action 2.3	0	15 000	15 000	15 000	0	$45 000
Action 3.1	10 000	20 000	10 000	10 000	10 000	$60 000
Action 3.2	0	72 000	50 000	0	0	$122 000
Action 3.3	12 000	12 000	12 000	12 000	12 000	$60 000
Action 3.4	35 000	20 000	20 000	20 000	20 000	$115 000
Action 4.1	14 000	44 000	44 000	44 000	44 000	$190 000
Action 4.2	0	12 000	12 000	12 000	0	$36 000
Action 5.1	0	10 000	10 000	0	0	$20 000
Action 5.2	Indirect costs only					—
Action 5.3	0	4000	4000	4000	4000	$16 000
Action 5.4	40 000	10 000	10 000	10 000	10 000	$80 000
Total per year	**$179 400**	**$317 400**	**$244 400**	**$184 400**	**$132 400**	**$1 058 000**

7. Evaluation of recovery plan

Relevant experts will review implementation actions and their effect on the recovery of the water mouse. A full review of progress will be conducted within five years from adoption as a National recovery plan.

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10. Appendices

Appendix 1. Known current and recent historical records for *Xeromys myoides* in Australia.