Northern Australia Environmental Resources Hub

National Environmental Science Programme

Defining metrics of success for feral animal management in northern Australia

Final report

Justin Perry, Nathan Waltham, Jason Schafer, Jonathon Marshall, Peter Negus, Alisha Steward, Joanna Blessing, Sara Clifford, Mike Ronan, Katherine Glanville, Peci Lyons, Eric Vanderduys, Stewart Macdonald, Andrew Hoskins, Catherine Robinson, Eric Nordberg, and Shania Wilson

CSIRO

James Cook University Australia

Queensland Government

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Perry J,[1] Waltham N,[2] Schafer J,[2] Marshall J,[3] Negus P,[3] Steward A,[3] Blessing J,[3] Clifford S,[3] Ronan M,[3] Glanville K,[3] Lyons P,[1] Vanderduys E,[1] Macdonald S,[1] Hoskins A,[1] Robinson C,[1] Nordberg E[1] and Wilson S[1] (2021) *Defining metrics of success for feral animal management in northern Australia.* CSIRO, Australia.

1. CSIRO
2. James Cook University
3. Queensland Government Department of Environment and Science

Cover photographs

Front cover: Time lapse photograph of a waterhole near Peach Creek, Cape York Peninsula, in May demonstrating rapid change in water quality following pig impacts (photo Kalan Enterprises 2016).

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Partner organisations

Kalan Enterprises

Tim Jaffer, Dion Creek, Jenny Creek, Naomi Hobson, Gabriel Creek, Dylan Creek, Jamey Cash, Stephen Peter, Rodger Paii, Shaka Bero, Edline Creek, Dallas Harold, Bradley Creek, Lucretia Huen, Douglas Huen, Terrence Creek, James Clarmont (deceased), Walter Peter, Tom Pratt, Shahmin Pratt.

Aak Puul Ngantam

Sandy Whyte (D), Celia O'Rourke, Robbie Weedon, Melissa Sinclair

Walgnal trip
Marybelle Pamtoonda (D)
Sammy Kerindan
Alistair Pamtoonda
Vernon Marbendinar

Archer River trip
Dawn Koondumbin
Neville Thompson/Woolla
Travern Pemuggina
Rhinna Pemuggina
Phyllis Pemuggina

Current APN board
Keri Tamwoy
Dawn Koondumbin
Anthony Yunkaporta
Neil Hector Peinkinna
Delys Yunkaporta

Past board
Mavis Ngallamatta (D)
Clarence Peinkinna
Johnathon Korkatain
Bruce Martin
Phyllis Yunkaporta

Current rangers
Aaron Woolla
Dion Koomeeta
Murray Korkatain
Edmond Woolla
Garreth Kerindun
Jim Pootchemunka
Ben Upton
Steven Marpoondin

Past rangers
Wilton Woolla
Bryce Koongoteema
Horace Wikmunea
Alistair Pamtoonda
Gary Namponan
Lloyd Yunkaporta

Acronyms and abbreviations

APN............... Aak Puul Ngantam

CES............... Cultural ecosystem services

CSIRO........... Commonwealth Science Industry Research Organisation

D.................... deceased

DAWE........... Department of Agriculture, Water and the Environment

DES............... Department of Environment and Science (Queensland)

ESS............... Ecosystem services

JCU............... James Cook University

Kalan............. Kalan Enterprises

MDS.............. Multidimensional scaling

NAILSMA...... North Australian Indigenous Land and Sea Management Alliance

NESP............. National Environmental Science Program

NRM.............. Natural resource management

QILSR........... Queensland Indigenous Land and Sea Ranger program

SEEA............. System of Environmental-Economic Accounting

TO................. Traditional Owner

UAS............... Unmanned aerial systems

Acknowledgements

This project builds on a long-term feral animal management and monitoring program developed by Kalan Enterprises (Kalan) and Aak Puul Ngantam (APN) and their partners (CSIRO and Balkanu). Kalan and APN have developed their feral animal management research and management agenda to meet the objectives of Traditional Owners in the region and have invited science organisations (CSIRO, James Cook University and the Queensland Department of Environment and Science) to contribute to the outcomes. APN and Kalan have conducted systematic feral pig (*Sus scrofa*) control and monitoring in the Archer River basin for the past six years. Kalan Enterprises built and maintained pig and cattle exclusion fencing around eight waterholes and APN has excluded pigs and cattle from three waterholes. These fenced waterholes provide a basis for conducting more in-depth scientific assessment of feral animal impacts in the region.

Kalan and APN have worked with their partners to build a baseline dataset which includes surveying pig activity transects, setting up pig feeders and traps to measure pig density, setting up and maintaining time lapse cameras, flying unmanned aerial systems to take photographs of water holes and regular culling activities. Rangers have conducted regular aerial surveys which have supported the development of a comprehensive systematic population dataset that is informing the project activities. Rangers from Kalan and APN have worked with researchers to collect detailed terrestrial fauna, limnology, and water quality data. The aim of this research is to better understand the impacts of feral animals on elements of biodiversity so that rangers can measure and report on the impact of management actions to their members (Traditional Owners) and to funders of land management activities.

Microsoft contributed to the development of novel analytical methods and technology solutions that have underpinned much of the impactful work completed in this project. Key Microsoft staff include Steve Van Bodegraven, Tianji Dickens, Michael Keane and Nejhdeh Ghevondian.

CSIRO Health and Biosecurity staff provided valuable input into the preliminary development of data dashboards to support planning for marine turtle protection. Jens Froese (CSIRO) contributed to the conceptual framing of habitat values that supported the development of the water hole typology product.

Executive summary

Project 2.5 has delivered research outcomes that have led to direct changes in the way feral pigs and cattle are being managed across millions of hectares on Cape York Peninsula. Research partners have increased the baseline knowledge of feral pig impacts and management through the production of technical mapping products, software, monitoring tools and peer reviewed journal articles.

The team has communicated these impacts through a variety of media and has delivered presentations and advice to a broad cross-section of organisations including government policy departments, land management organisations and conservation entities. Project outcomes are supporting national initiatives for feral animal control.

Project highlights include:

- 51 Indigenous participants
- 5 journal articles published
- 8 journal articles in preparation or in review
- 1 Queensland Government mapping product
- 1 software product (HealthCountryV2 – Turtle Trackers)
- 1 digital dashboard
- 2 iPad applications
- substantial media interest
- 2 award nominations, finalist in both (NT NRM Awards, i-Awards – merit award)
- 1 award winner (Mumbrella, Best use of owned media)
- 3 national committees using project data (African Swine Fever taskforce, national feral pig management strategy – development, national feral pig management implementation).

Project 2.5 has developed real-world solutions that can be practically implemented by land managers.

1. Introduction: Project 2.5 – Defining metrics of success for feral animal management in northern Australia

1.1 Project aim

This project aimed to determine the impact of feral pigs and cattle across aquatic systems in the Archer River basin in the context of regional and local feral animal control, local aspirations, and government priorities. The project sought to evaluate metrics used to assess how well control measures work in mitigating threats to aquatic ecosystems. These outcomes have been aggregated using a digital reporting system which compares investment in control with consequent impacts on environmental values.

nespnorthern.edu.au/projects/nesp/feral-animal-management/

1.2 Partnerships and study location

Project 2.5 was developed in partnership with Traditional Owners from Aak Puul Ngantam (APN) and Kalan Enterprises (Kalan). The project has led to the establishment of new management and monitoring methods that have been embedded into work programs for our on-ground partners and have helped to operationalise long-term adaptive management strategies.

Research partners included the Queensland Department of Environment and Science (DES), James Cook University (JCU) and CSIRO Land and Water. Research was undertaken near Coen and south of the Archer River on Cape York Peninsula (Figure 1).

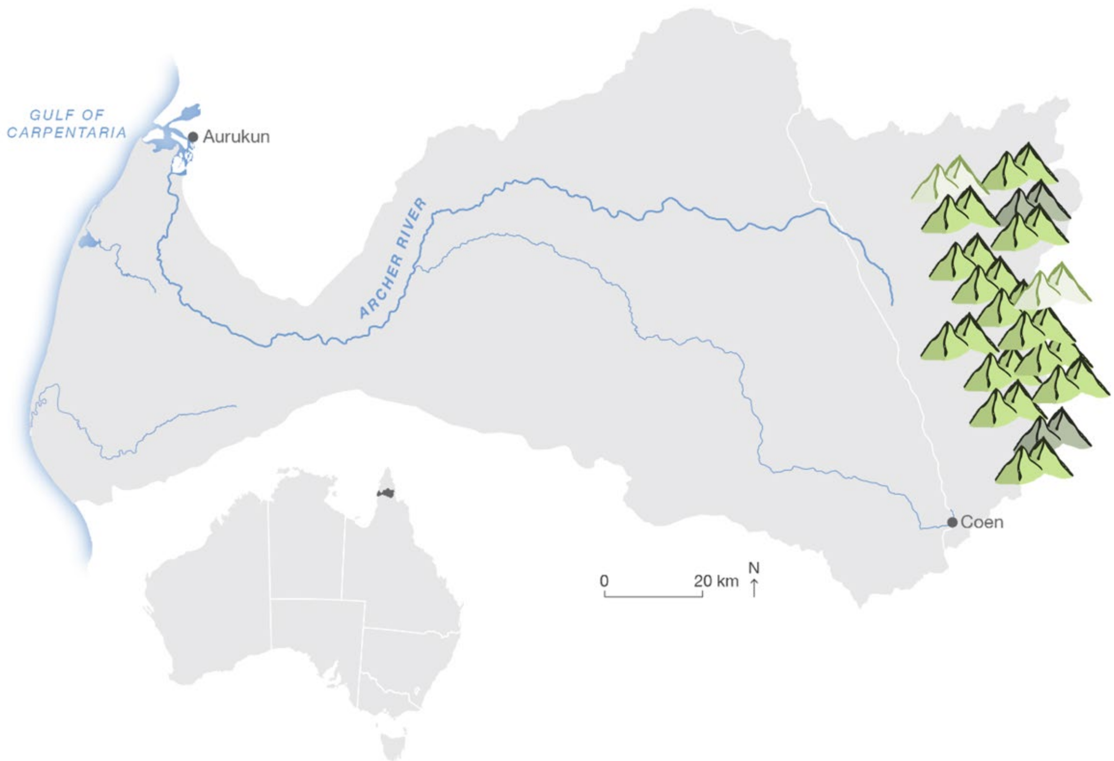


Figure 1. Research was undertaken in the Archer River basin, Cape York Peninsula, Queensland.

1.3 Background

There is growing recognition of the importance of wetlands, including their cultural values that relate to biodiversity and ecosystem health (Jackson and Palmer 2015, McGregor et al. 2010). This increase in understanding is occurring in a broader policy and research debate that aims to extend measurement and valuation of natural resources and assets beyond their intrinsic ecosystem property to incorporate nature's services of regulating processes and the material and non-material benefits it provides society (Cherry 2011, Department of Environment and Science 2021). This increasing awareness brings into focus the necessity of valuation methods and information that incorporates our understanding of the diversity of wetlands across landscapes and regional settings with the multiple values that society associates with them and the interdependency of human society with their environment (Kumar et al. 2017).

This project aimed to better define the impacts of feral animals on wetland health, and on values that acknowledge the biophysical dimensions of wetland diversity and Indigenous wetland values and its heterogeneity across the landscape in response to feral pig management regimes.

1.4 Feral pigs

The feral pig is the same species as the mythologised Eurasian wild boar and is the superspecies for the well-known and domesticated pig, *Sus scrofa domestica*. In general, the wild boar is listed as least concern on the International Union for Conservation of Nature (IUCN) Red List, though local populations vary widely. For instance, in the United Kingdom there may be as few as 1,500 wild boar (DEFRA 2021), while across Greece, population estimates range between 16,000 and 23,000 (Tsachalidis and Hadjisterkotis 2009). In Australia, numbers are difficult to estimate as their range is vast and few systematic population surveys have been completed. One study suggested 13 to 23 million (Hone, 1990). With the capacity to build this kind of feral population in 200 years, it is unsurprising pigs are among the world's top invasive species (Lowe et al. 2000). Feral pigs are a paradox in Australia and in much of the world. Viewed as a pest by agriculturalists, pastoralists, wildlife conservationists and late-night highway users, feral pigs eat or destroy crops, muddy waterholes used by cattle, and prey on lambs. Feral pigs also prey on wildlife, compete with native species for resources, cause erosion and alter wetland systems. Comparative studies between similar forests in England (where pigs have been actively removed) and Poland (where pigs exist in high density) illustrate the dramatic effect on understory and the role of pigs as ecosystem engineers.

There is a perception that all sectors of society are united in the goal of removing feral pigs and thus reducing their impact. However, for some sectors, pigs are a source of recreation (hunters), money (meat and skin export, pet food, and to some small extent, the local food market), or importantly, food. Feral pigs are so important to Indigenous groups that there are many instances of people deliberately moving feral pigs to improve hunting, and wilding domestic pigs to improve the feral stock for eating. The use of pigs as a food source by Traditional Owners is a multifaceted issue. On one hand, pigs can be eaten. On the other, pigs are a direct competitor for other human food sources such as turtles, birds, yams, and other roots, flowers, herbaceous plants and fungi. Pigs also deplete Traditional Owner food sources indirectly by engineering and destroying habitat, altering production by changing the physical structure of the environment, nutrient flow and ground cover, and interrupting ecosystem services required for the propagation of these alternate food sources. There is a clear dichotomy in the agenda of Australians with respect to feral pig management requiring a more nuanced approach to establish socially acceptable control measures.

1.4.1 Markets for feral pigs

Pigs are an important dietary element of many European and Asian countries. Recent unacceptably high radiation levels in wild boars across Europe and Asia have rendered the meat unsafe for human consumption (Dvořák et al., 2010, Strebl and Tataruch, 2007), presenting export market opportunities for countries with excess wild pigs, such as Australia and the USA. In Europe, wild pig populations can be managed through hunting which has led to some countries establishing rules to reduce pressure on wild pigs. In Australia, hunting has a limited impact on wild populations due to the connectivity of natural systems, inaccessibility of much of the land where pigs are hunted, vast distance to accessible markets, low human population, and limited demand for feral pig meat. Due to these factors hunting pressure has not exerted any control on pig populations, even at a local scale.

1.4.2 Diet and breeding biology

Feral pigs are typically crepuscular, sleeping in the daytime in vegetative nests, wallows or under creek overhangs and caves. They tend to live in social or semi-social groups of females and young, with males moving among mobs. In general, large adult boars have bigger home ranges, with the mean home range of pigs in Australia around 9 km^2 (Saunders and McLeod 1999). Feral pigs are omnivorous and eat a protein-rich diet of plants and animals (Chimera et al. 1995). They are opportunistic and switch diet according to food availability (Barrios-Garcia and Ballari 2012). Pigs will eat carrion and prey on smaller animals opportunistically. In northern Australia, this translates to a wet-season diet primarily of grasses, forbes, pandanus nuts and similar greenery, and a dry-season diet of subterranean roots, with a concomitant increase in activity around billabongs and watercourses (Corbett 1995). Very few pigs are found more than 2 km from water, particularly in the dry season (Hone and Atkinson 1983). In general, adults tend towards grasses while juveniles preferentially forage forbes (Wishart et al. 2015). Feral pigs are generalists in their diet but also in their behaviour: although primarily crepuscular, feral pigs will change their habits readily when pressured by hunting (Tisdell 1982).

Pigs are somewhat polygynous though not polyandrous, and mate more or less randomly rather than assortatively or with some hierarchy (Hampton et al. 2004). However, bigger boars are more successful at breeding than smaller boars, and also roam the farthest with some studied animals roaming 30 km to breed (Hampton et al. 2004). Bigger boars, and more successful sows are also less likely to be caught in traps than less successful breeders (Hampton et al. 2004). Pigs first breed at about eight months, with a mean litter of six, which are weaned at 2 to 3 months (Hone and Robards 1980). Multiple litters within a season are not uncommon, particularly if conditions are favourable, as pig breeding cycles are flexible and strongly linked to nutrition and plant phenology (Baber and Coblentz 1987).

1.4.3 Published pig impacts

Feral pigs have a direct physical impact in both natural landscapes as ecosystem engineers as well as in the cultural landscape as pests. Rooting and rutting is damaging at the ecosystem level: directly damaging the ground and vegetation (Mitchell et al. 2007) and affecting plant species richness (Hone 2002); increasing erosion; influencing soil chemistry and fungal and microbial life; and slowing regeneration (Barrios-Garcia and Ballari 2012). Pigs prey on native animals, including frogs, lizards, annelids, turtles, birds and bird eggs, but also compete with native animals and with Traditional Owners for food such as yams, roots and tubers. The precise effects of pig ecosystem engineering are not well understood and most likely differ broadly across different habitats and ecotypes (Barrios-Garcia and Ballari 2012), and require further study, particularly in the Australian landscape which is often nutrient- or water-limited (Hughes 2003).

In horticultural and agricultural land, there are both direct and indirect monetary losses due to feral pigs. Direct losses include foraging on and destroying crops, preying on lambs, and ruining infrastructure (Tisdell 1982). Pigs can be highly destructive: in one recorded case approximately 6 hectares of a cereal crop was eaten and uprooted by a mob of 25 pigs in one week (Tisdell 1982). Pigs damage infrastructure such as fences, bores, drainage and irrigation, and roads and airfields (Tisdell 1982). Lastly, the financial burden of pig control management can be costly for landholders. Indirectly, pig destruction could cause a shift in produce prices, with a flow-on cost increase to consumers. Farmers may switch to a crop less palatable to the pigs but that may also reduce profit. There are flow-on effects of pig damage to infrastructure, such as machinery damaged on pig-rutted grounds, or slowed transport. Famers may also need to pay pig hunters.

Pigs are also a threat in terms of biosecurity, as actual or potential disease vectors. There is a recent southward spread in swine brucellosis (Ridoutt et al. 2014) with concomitant cases of zoonotic transfer (Mor et al. 2016) acting as a caution to hunters and other people who directly or indirectly encounter pigs. Feral pigs in Australia have been found to harbour *Giardia* and *Cryptosporidium* and are the only known vector of *Balantidium coli* (Hampton et al. 2006). All three of these parasites cause problems in humans and are transmitted when pigs contaminate drinking water supplies. The further threat is from the potential to spread other disease: pigs have a greater ability than most other species to harbour disease (Hampton et al. 2006), and there are legitimate fears of feral pigs facilitating the rapid spread of such diseases as anthrax, tuberculosis, leptospirosis, and foot and mouth if these diseases enter Australia. Feral pigs are very widely spread and most sampling and testing for disease is opportunistic, which makes disease detection difficult. One author suggests that up to 3,077 pigs may need to be sampled before any disease outbreak would be detected (Hone and Pech 1990).

1.4.4 Positive benefits of pigs

Feral pigs can be a source of income. The meat, skin, lard and bristles can be harvested and sold, and although Australian consumers do not eat a lot of feral pig, there has been a mercurial feral pig meat export industry, with exports primarily to Europe. Pigs are efficient scavengers and hunters – very little is left behind after lamb predation – and they scavenge carrion, reducing the potential for disease outbreak. As a source of meat for human consumption, feral pigs present some issues, primarily logistic. Many pigs are in remote, hard to access, or seasonally inaccessible areas with limited access for mobile cool rooms and long distances to processing facilities and the marketplace. Pig meat has high potential in Australia for pet food, meat meal, and fertilisers such as blood and bone.

In some cases, rather than pay professional hunters to remove problem pigs, farmers make money charging tourists to shoot pigs. In the case where farmers are making an income from pigs, the impetus to eradicate is diminished. Ad-hoc feral pig management and conservation in contemporary Australia includes illegal dumping of 'white boars' to fatten the wild pig stock, and translocation of captured feral pigs to better, more suitable, or more easily accessed, hunting grounds.

1.5 Current feral animal control funding in the study areas and the reporting requirements for those

APN and Kalan receive (or have received) funding for feral animal control from various funding sources. The major funding is through the federal government's Working on Country program (Kalan; The Indigenous Ranger Program | National Indigenous Australians Agency (niaa.gov.au)) and the Queensland state government's Queensland Indigenous Land and Sea Ranger funding (APN; Indigenous Land and Sea Ranger program | Environment, land and water | Queensland Government (www.qld.gov.au)). APN also receives direct funding through the joint Commonwealth and Queensland state funded 'Nest to Ocean' program to reduce the impact of marine turtle nest depredation. (Nest to Ocean Turtle Protection Program | Parks and forests | Department of Environment and Science, Queensland (des.qld.gov.au))

The Working on Country and Queensland Indigenous Land and Sea Ranger program (QILSR) managers require an annual work program to be written and reported on. The Nest to Ocean program requires an annual work plan and includes minimum reporting and monitoring standards. Under this funding model various metrics and success criteria are reported on.

For QILSR there are four categories of management activities with associated metrics that are reported on in the context of feral animal management.

1. Indigenous knowledge transfer
   - number of Traditional Owners and community members in addition to rangers involved in on-ground activities
2. Native plants and animals
   - threatened communities and species protection (total km of fencing)
   - marine and migratory species (number of nesting survey days, number of turtle tracks recorded, number of turtle nests)
   - biosecurity (quarantine training and activities, marine debris, pests and disease awareness)
3. Feral animal management
   - exclude cattle from high value environmental areas (total km of fencing)
   - maintain fencing for pigs (total km of fencing, fencing activities)
   - install motion sensor cameras (number of cameras)
   - undertake feral animal management (total number of pests removed)
4. Soil and vegetation management
5. Number of environmental condition and biodiversity surveys/monitoring activities completed.

The reporting requirements above are centred on activities and outputs rather than biodiversity or cultural outcomes. The broader narrative of the report and ongoing interaction between the APN rangers and the QILSR coordinators provides a far more detailed understanding of the impacts of land management activities, but these interactions are not readily accessible in the current reporting framework.

This suggests that defining social, cultural and environmental metrics that can be reported upon in a robust way would benefit land-management monitoring programs for assessing their investment and supporting ranger groups such as APN and Kalan to secure better environmental and cultural outcomes.

1.6 Indigenous-led adaptive management of Cape York's cultural–ecological wetland system

A foundational feature of feral animal management in Cape York is that its land management decisions are led by Indigenous people in an approach that regards the region as a cultural–ecological system.

Incorporating social measures into environment monitoring and management programs is increasingly recognised as important for successful environmental outcomes. However, social measures lack consistency and may under-report key issues. This is increasingly being recognised and considered by national and state government as well as agencies working at regional and local levels. The national and state environmental reporting frameworks are incorporating new innovative valuation methods to include new measures of environmental health that consider the multiple services nature provides to economies. The Ramsar Convention establishes a strong foundation to develop integrated reporting of the multiple values of wetlands at local, regional and national scales. At the regional scale, the Eastern Cape York Water Quality Draft Plan incorporates multiple values of water assets including biophysical and cultural values, however these are still reported as separate entities and are provided at a regional scale. This project builds on and contributes to the early efforts of ecosystem service reporting and wetland typology development at various scales to deliver an integrated reporting system that incorporates ecological and cultural wetland values to support sustainable use of wetland resources.

Ecosystem services and cultural ecosystem services

The ecosystem services (ESS) concept has gained popularity as an integrated way to manage diversity for sustainable development (Hirons et al. 2016). ESS can also offer a useful intercultural framework to enable Indigenous and non-Indigenous partners to monitor and manage the range of values in a given environment and ensure the benefits of environmental management programs are appropriately negotiated. It has also gained traction with policy makers, practitioners and researchers seeking to improve and strengthen environmental decision-making with political, social and economic resolution (Blicharska 2017, Daily 1997). ESS is widely understood as the resources, processes and conditions through which natural ecosystems confer benefits to humans (Daily 1997) and make life on earth possible (Daily 1997, Diaz et al. 2015, Bennett et al. 2015). However, the values placed on the environment by groups, disciplines, communities, and cultures define the services that are prioritised, valued and ultimately measured and addressed in management (Chan et al. 2012). While the ESS concept is highly effective in describing the dependent condition of human wellbeing on nature, research into each of the ESS categories of regulating, provisioning and cultural services highlights the need to recognise and clarify the multiple roles that humans have in the ecosystem services framework as co-producers and beneficiaries of services (Jones et al. 2016). In particular, cultural ecosystem services recognise the 'ecosystem's contribution to the non-material benefits that come from the human-ecosystem relationships (Fish 2016). Central to the evolving thinking on cultural ecosystem services (CES) is co-creation, of the inter-dependency and mutually reinforcing relationship between human cultural practice and ecosystems (Jackson and Palmer 2015; Castree 2001, Robinson thesis). A key gap in scientific assessment and environmental management programs is the absence of the non-tangible and secondary material benefits of CES. CES is central to ESS because of the link between cultural values, methods of valuation and the consequent decision-making that influences ecosystems and human wellbeing (Hirons 2016). A research framework that recognises the interdependencies of ecosystem services and human wellbeing that support the deployment of multiple methods is key to greater understanding of how policies, cultural institutions, technologies and human action can affect provision of services and vice versa (Blicharska 2017, Bennett et al. 2015, Jax et al. 2013, Jackson and Palmer 2015).

1.7 Project outcomes

Feral pigs are a significant threat to wetland ecosystem ecology and biodiversity in tropical Queensland (Mitchell 2010). Their ecological impacts on wetlands function is well documented (see Alexiou 1983, Fordham et al. 2006, Doupe et al. 2010, Mitchell 2010); however, their effects on ecosystem services is not well understood, in particular effects on Indigenous values and the impacts of changing wetlands function on Indigenous values and wellbeing. This project addresses this gap in knowledge in wetland management planning with the use of both ecological measures and Indigenous values for local and regional level reporting.

The NESP project 2.5 team consists of ecologists and human geographers collaborating with Traditional Owners and land managers to develop an integrated monitoring and reporting system on the impacts of feral pig damage on wetland ecosystem services. The team worked with Traditional Owners from southern Aurukun and Coen to measure the biophysical and cultural impacts of feral pig management on a range of values. The project team conducted social and ecological research in the Archer River basin to further the development of a waterhole typology-based impact assessment. The wetland typology conceptual model establishes a framework to develop quantitative indicators to monitor and report on wetland biophysical values that compare impact within similar landscape features. We integrate cultural ecosystem services research, using both quantitative and qualitative methods with Aurukun Traditional Owners, to develop measures of wetland cultural values that can be related to the waterhole typology values. The large collaborative team worked hard to integrate a wide range of values associated with feral animal management in tropical ecosystems, with a strong emphasis on embedding cultural values and supporting Indigenous-led management and planning.

The Queensland Government wetlands group at DES has visualised the conceptual understanding of feral animal impacts on aquatic systems (Figure 2, Figure 3, Figure 4 and Figure 5).

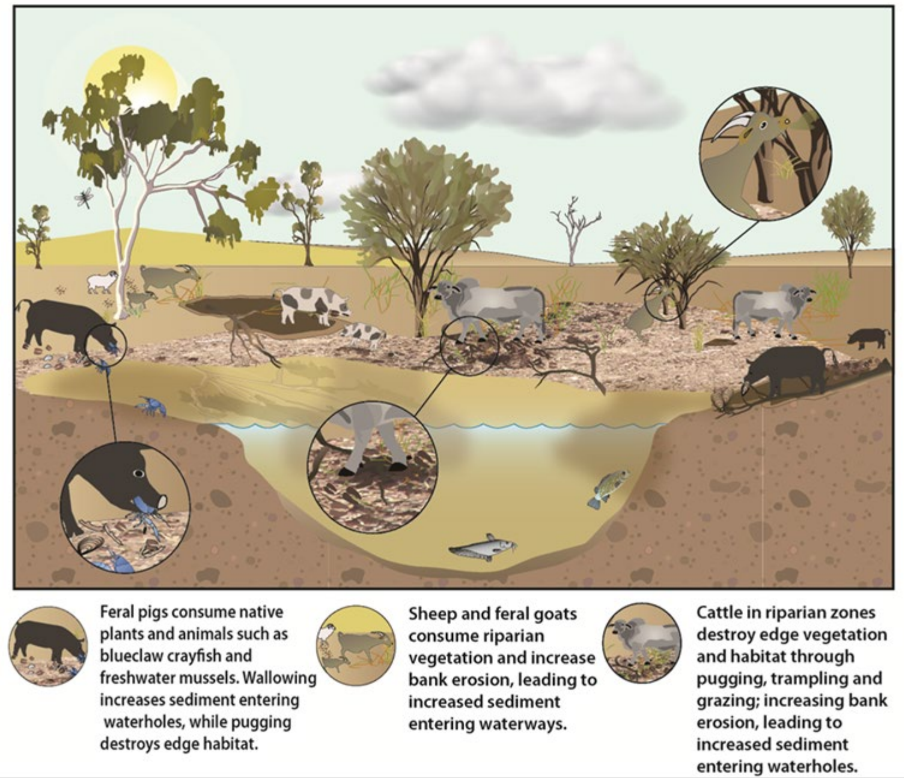


Figure 2. Impacts of feral pigs, sheep, goats and cattle on different elements of the ecosystem.

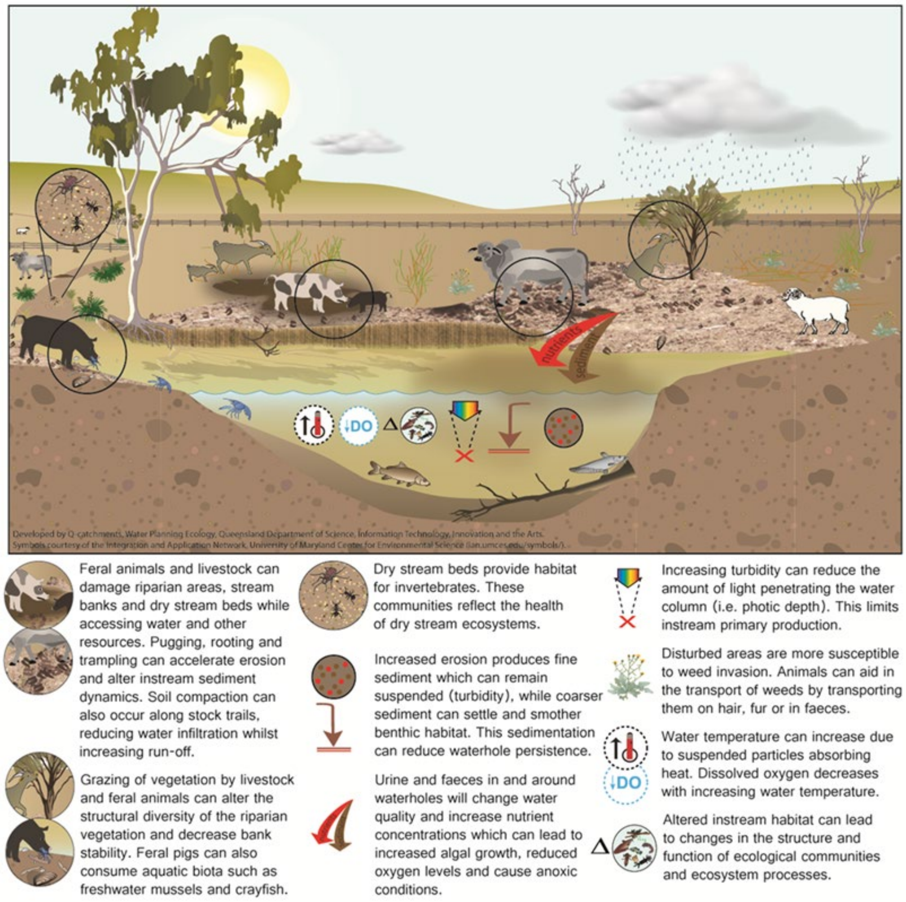


Figure 3. A more detailed conceptual model of feral animal impacts on waterholes.

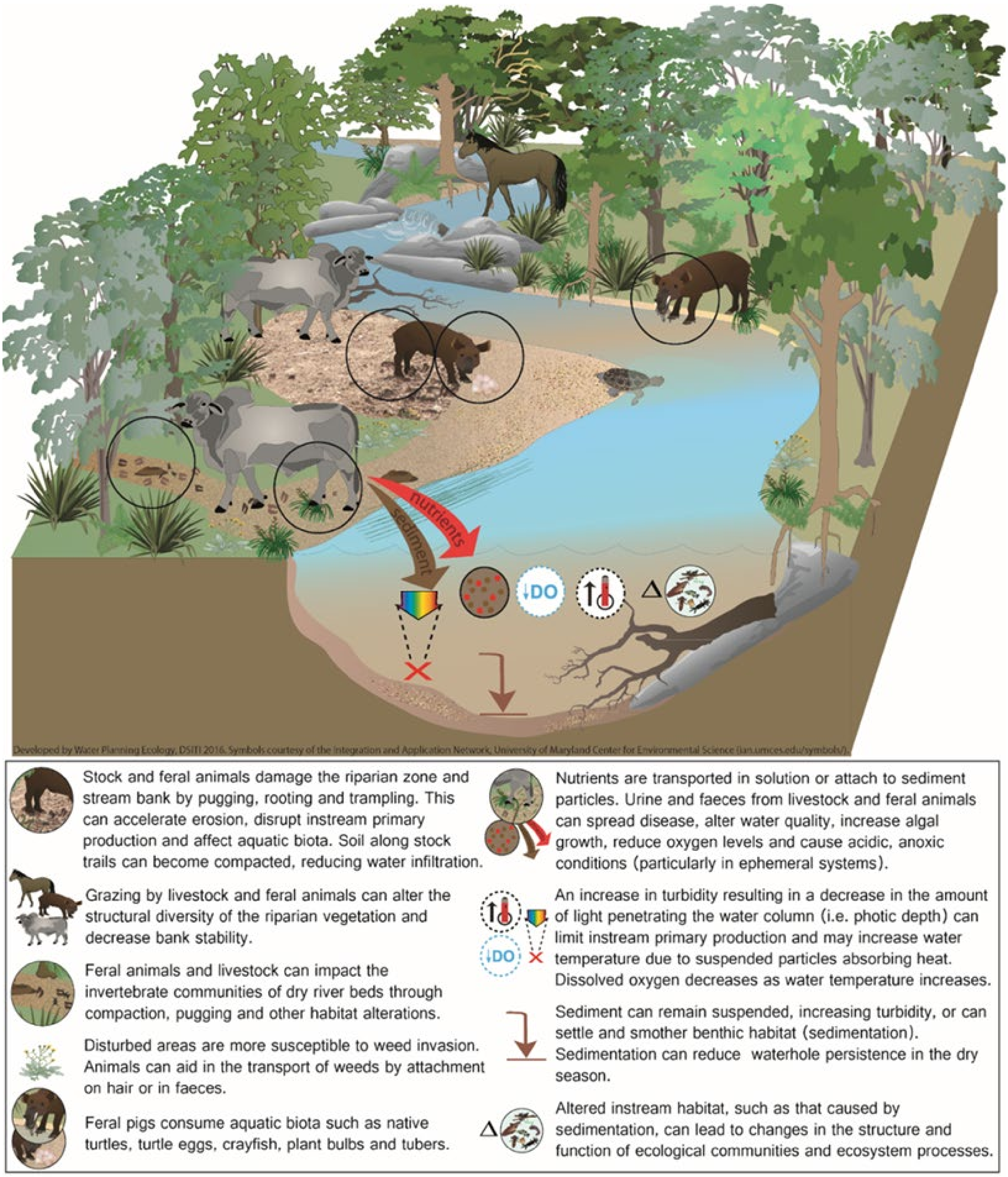


Figure 4. Impacts of feral animals on in-stream habitats.

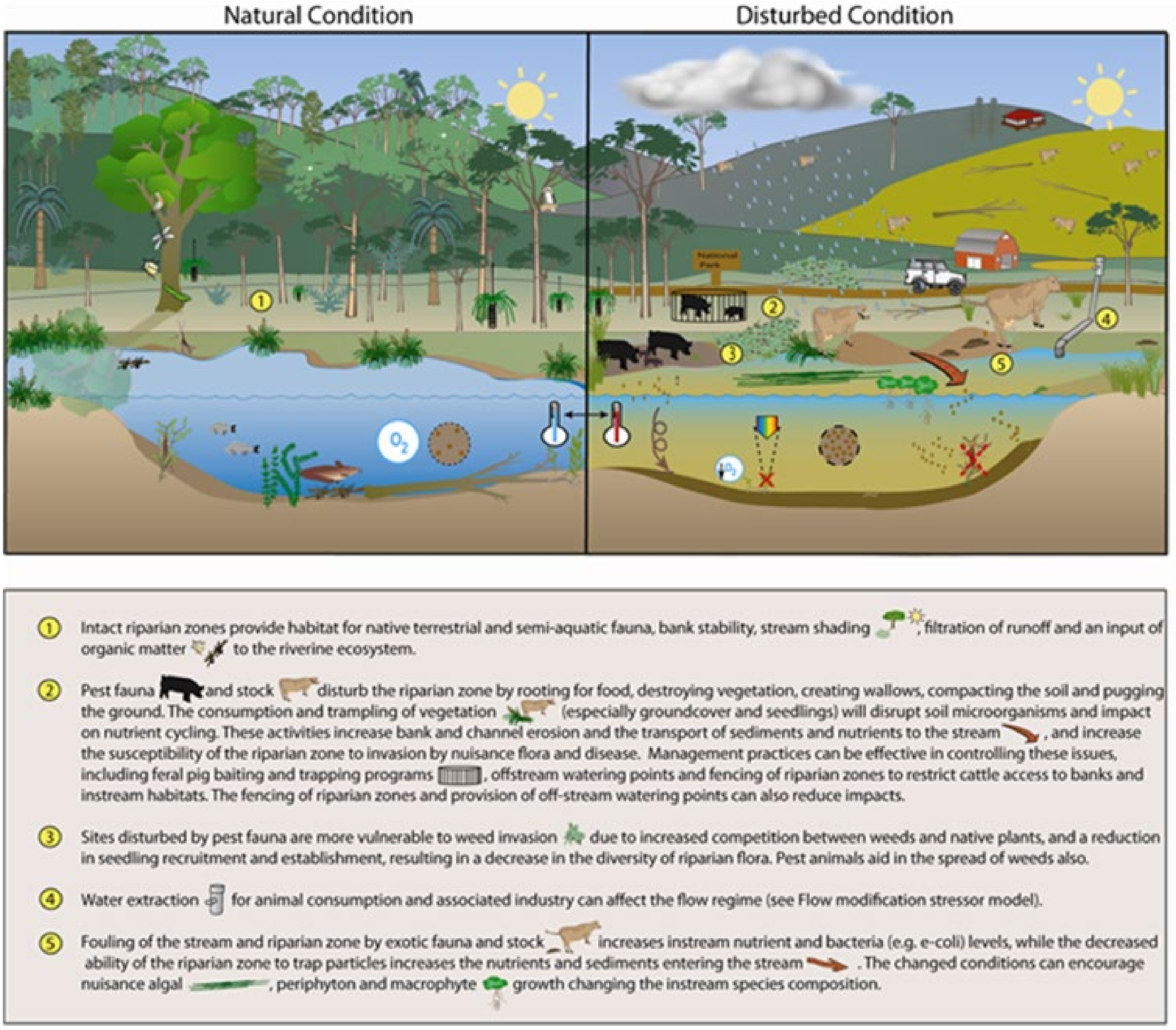


Figure 5. Intact vs degraded systems.

1.8 Animal and human ethics

Animal ethics – CSIRO Animal Ethics Committee. Project Approval No 2017-20

Human ethics – CSIRO Human Ethics Committee. ‘Cultural values and measures in assessing success for feral animal management in northern Australia (086/16)’

1.9 Project factsheets

nespnorthern.edu.au/wp-content/uploads/2018/11/Feral-animal-management-project-update-Oct-2018.pdf

nespnorthern.edu.au/wp-content/uploads/2016/11/Defining-metrics-of-success-for-feral-animal-management-across-northern-Australia-16Jan2017WEB.pdf

1.10 Impact stories

nespnorthern.edu.au/wp-content/uploads/2021/05/Using-AI-to-protect-baby-turtles-from-feral-pigs-impact-story.pdf

nespnorthern.edu.au/wp-content/uploads/2020/08/Managing-feral-pigs-on-Cape-York-impact-story-2019.pdf

nespnorthern.edu.au/wp-content/uploads/2019/06/Reconnecting-with-Country-through-collaborative-research-impact-story-Jun-2019.pdf

2. Extensive baseline data set for the Archer River basin for assessing change under future investment strategies

2.1 Introduction

A baseline ecological data set was collected for the Archer River basin using systematic survey methods conducted by experienced field ecologists from CSIRO, JCU and DES. A methods alignment workshop was completed with project collaborators at the beginning of the project to develop a sampling regime that would enable the team to assess the most appropriate methods for assessing impact on multiple values. Methods were aligned with other major water resource assessment activities conducted across Queensland and were guided by the Water Resources assessment team, the Wetlands Info team, and the Queensland Herbarium.

In this section we summarise the key results from each of the methods applied in this project.

2.2 Measuring physical disturbance to wetland sediments as indicator of feral pig damage (DES)

2.2.1 Overview

Feral pigs damage the ecological and cultural values of wetlands by their rooting, digging and wallowing behaviour. Direct measures of pig damage can be made for a wetland site using observations along transects within a wetland parallel to the edge of wetted areas. Our research has shown that the intensity of rooting, digging and wallowing, collectively termed pig damage, limits the diversity and the number of invertebrates that live on the ground around wetlands. Pig damage, as described here, can therefore be used as a convenient and easy to measure indicator of pig impacts to wetland ecosystems.

2.2.2 Methods

Measures of pig damage are made using transects 200 m long along the zone parallel to the water's edge. Transects continue until the total circumference of the wetland or a maximum of four transects is complete. When no water is present, transects can be undertaken along the edge of fringing terrestrial vegetation, determined by changes in vegetation and topography. Measurements of pig damage are made along the transects for adjacent 10 m × 10 m quadrats. Each quadrat is assessed by observing rooting damage, tracks and wallowing. Quadrat measures use the categories: none (0 = no visible damage), light (1 = presence is visible but no detectable impact; <15% area), moderate (2 = obvious but small; 15–50% area), or severe (3 = obvious presence and widespread damage; >50% area). Damage measurements are assessed by averaging 20 quadrats/transects and highest transect score used as overall damage for a wetland.

2.2.3 Conclusions

Physical damage to wetland sediments is an easy to measure indicator of the impact that feral pigs have on wetland ecosystems. It indicates the level of impact at individual wetlands and, when combined with understanding of a wetland's social, economic and environmental values, it can identify priority wetlands for targeted management, such as fencing.

2.3 Terrestrial invertebrates as indicators of feral pig damage (DES)

2.3.1 Overview

Our research shows that the intensity of pig damage limits the diversity and the number of invertebrates that live on the ground around wetlands. This confirmed pigs as a threat to wetland biodiversity. As our study identified, pig damage limits rather than determines invertebrate diversity and abundance. More research is warranted into covariates that also influence this fauna. Likely candidates include wetland type, hydrological history, and the structural characteristics of the exposed wetland sediments.

2.3.2 Methods

Six replicate pitfall traps were positioned in the exposed wetland sediment of each site and set for approximately 24 hours. Specimens were identified in the laboratory using taxonomic keys with a stereomicroscope. Taxa from each site from each sampling run were standardised as catch-per-unit effort. Invertebrate taxon richness and abundance were calculated, respectively, as the number of taxa present and summed abundance of all taxa, per sample. Quantile regression was used to estimate the effects of feral pig damage as a limiting factor to invertebrate metrics.

2.3.3 Conclusions

The confirmation provided by this study – that pig damage intensity limits wetland biodiversity – justifies the adoption of measures of pig damage as a monitoring tool to evaluate the success of pig management, such as by wetland fencing or by general measures to reduce pig abundance.

2.4 Diatoms as indicators of current and historic water quality (DES)

2.4.1 Overview

Diatoms are single-celled algae from the class Bacillariophyceae. There are thousands of species, and water chemistry determines which ones occur in a wetland, meaning they have been used around the world as bioindicators of water quality. Diatoms live in glass houses. Each cell produces two chambers called frustules made of transparent silica. Ornate patterns in the silica are species specific, allowing their identification from frustules. Being akin to glass, diatom frustules are often preserved in wetland sediments, so by extracting them from sediment cores, and identifying the species composition, it is possible to use diatoms to reconstruct past water chemistry. This helps reconstruct the environmental history of wetlands and identifies changes in response to climate variability of disturbances such as, potentially, changes associated with the first arrival of pigs at a wetland.

2.4.2 Methods

Water samples were collected from each site and samples were filtered or frozen to enable diatom sampling to be done along with water quality metrics.

2.4.3 Conclusions

Diatoms are bioindicators of wetland water quality, both today and in the past. They can be used to identify impacts and set restoration targets for wetland ecosystems. Freshwater diatoms on Cape York are very sensitive to water quality (Negus et al. 2019), but further research is needed to identify the details of water quality responses of Archer River wetland diatoms and to link these to past and current pig impacts.

2.5 Paleo-insights into wetland pig damage from sediment core analyses (DES)

2.5.1 Overview

Pigs cause damage to wetlands but there is limited data on the state of wetland ecosystems prior to pig introduction as a reference baseline for quantifying ecological impact. Therefore, it is difficult to quantify the importance of this damage at local to regional scales. Palaeoecological studies, like this pilot study at Blue Lagoon in Cape York, allow reconstruction of past wetland ecosystems, and biomarkers of pig presence provide a time stamp that permits interpretation of how wetlands changed with the arrival of pigs.

2.5.2 Methods

Wetland sediments accrue over time and preserve records of the past ecological, chemical and climate history of the wetland and its setting. Palaeoecological studies use sediment cores (Figure 6), age the sediments to relate depth below ground surface to time of deposition, and then investigate changes over time in proxies – indicators of past conditions. Examples include diatom and pollen fossils (which indicate past water chemistry and catchment vegetation communities), charcoal (which indicates fire history) and chemical biomarkers (which indicate changing chemical environments in wetlands).

Figure 6. Picture of the wetland core and wetland from where it was extracted.

2.5.3 Conclusions

This pilot study has demonstrated the great potential of using pig biomarkers in palaeoecological studies of wetlands. Future research can use this technique to identify when pigs first occupied wetlands and the effects they have had on wetland ecology. This will provide baseline data to inform pig control and wetland restoration efforts. We showed that pigs leave biomarkers in Archer River wetland sediment records because chemicals such as sterols and bile acids characterising pig faeces are preserved (Figure 7). This provides an excellent basis for future studies into pig impacts on wetlands.

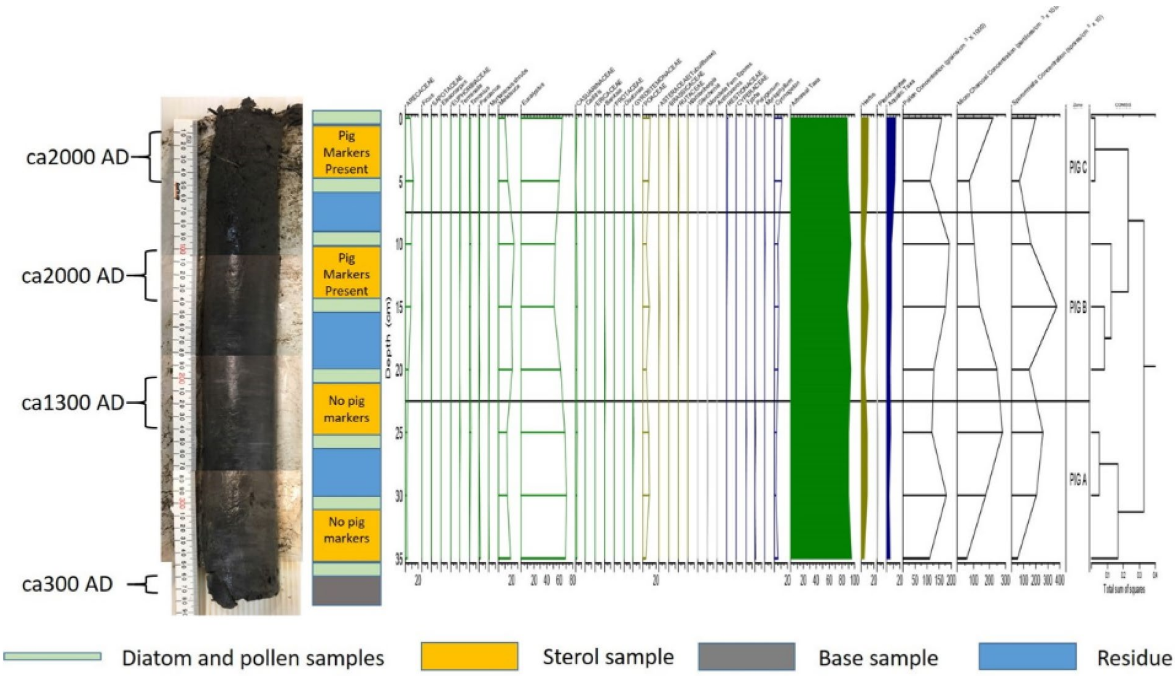


Figure 7. Results from the sediment core sample extracted from a study site wetland on Cape York Peninsula. The example demonstrates how the sediment core is segmented by age and pig markers are detected in the upper sample but not the lower sample providing evidence of time of arrival for this species.

2.6 Damage from pigs limits the number of invertebrates and the diversity of invertebrates living on exposed wetland sediments (DES)

Pigs are widespread and cause significant damage to the ecological and cultural values of wetlands by their rooting, pugging, and wallowing behaviour (Figure 8). We measured the impacts of feral pigs on the number and diversity of ground surface invertebrates (insects, spiders and allies) living on exposed wetland sediments (parts of the wetland that were not inundated with water at the time of sampling), using pitfall trap samples.

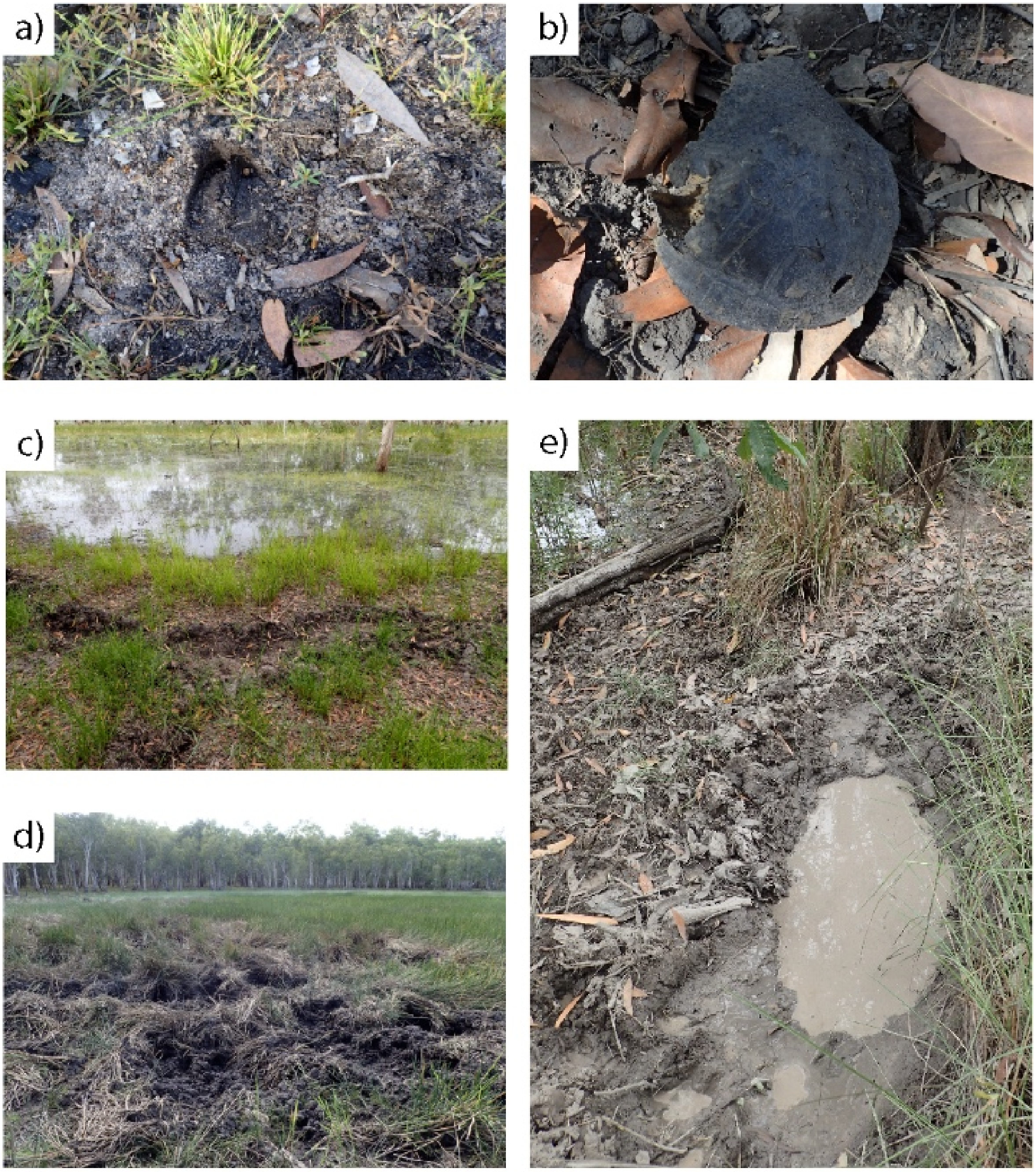


Figure 8. Examples of the physical damage caused by feral pigs to exposed wetland sediments : (a) pug mark; (b) predation on freshwater turtles; (c) moderate rooting and pugging; (d) severe rooting and pugging; and (e) wallow and pugging.

These were collected from 21 sites over three occasions in the Archer River catchment, north Queensland, Australia (Figure 9).

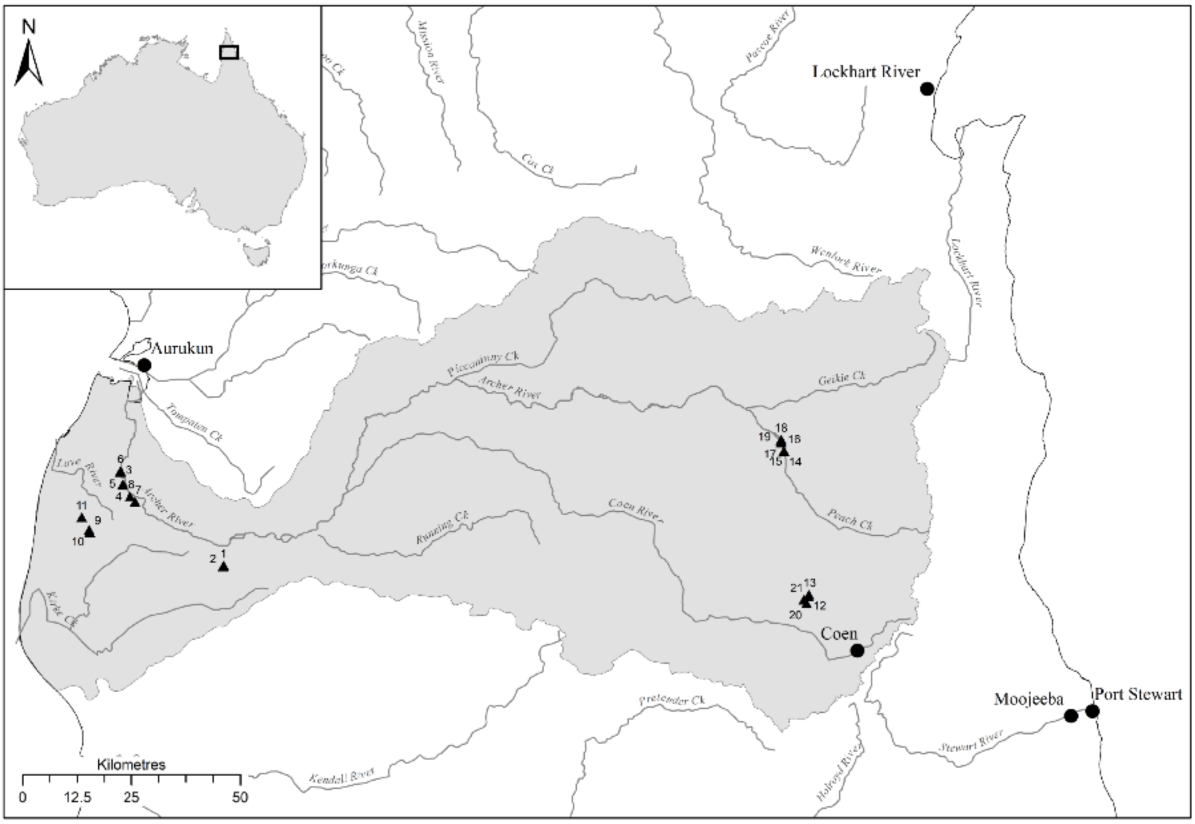


Figure 9. Map of the sampling sites in the Archer River catchment, Queensland, Australia.

The intensity of physical feral pig damage at the sites was recorded from survey transects along the margins of the wetlands. This showed that physical pig damage to exposed wetland sediments varied between sites. This negatively impacted ground invertebrates in this environment, where there was a diverse invertebrate fauna. Both the diversity of invertebrate types (richness) and how many there were (abundance) were significantly limited by physical pig damage, as was variability in their overall community composition. Thirty-one types of invertebrates (66%) showed a decrease in occurrence, abundance, or both, at sites with high levels of pig damage relative to sites with low levels of pig damage. Certain families of spiders and beetles, snails, and freshwater crabs were among those more common when pig damage was low. Direct feeding by pigs and the destruction of habitat from their rooting, pugging and wallowing are the likely mechanisms by which pigs impact these invertebrates.

2.6.1 Damage control by fencing wetlands

How can this pig damage to wetland invertebrates be prevented? General pig control measures such as culling, baiting and trapping can reduce overall pig populations, but they do not eliminate the substantial physical damage to wetlands that can occur from just a few individual pigs, and the resulting impacts to ground-dwelling invertebrates. Exclusion fences are used as a potentially effective technique to prevent this damage to important wetlands.

To test fence effectiveness, we measured the physical damage caused by pigs to multiple wetlands in the Archer River catchment that had previously been either fenced using a typical cattle exclusion fence, a specific pig exclusion fence or had no fence. This showed that wetlands with well-designed and well-maintained functioning pig exclusion fences had no physical pig damage. This was significantly less damage than in all other arrangements assessed. In contrast, wetlands with compromised pig exclusion fences, resulting from damage or poor fence maintenance, had physical pig damage similar to or worse than wetlands with no fences (Figure 10). Compromised pig exclusion fencing of wetlands can thus be worse than having no fencing at all. This is possibly because damaged fences allow pigs access to wetlands but then make it more difficult for them to leave, in effect concentrating the pig damage.

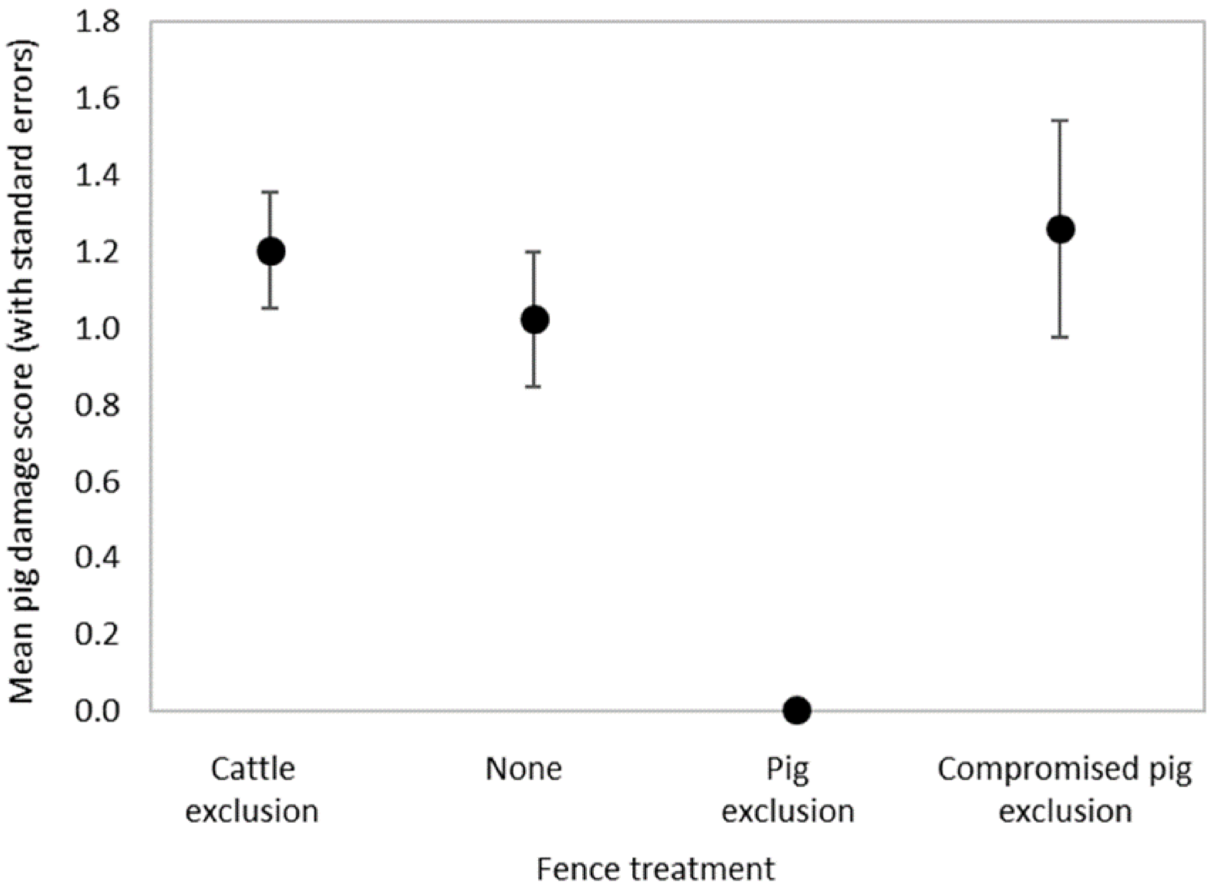


Figure 10. Appropriately designed pig fences can effectively prevent physical pig damage to wetlands but only if they are properly maintained.

2.6.2 Conclusions

There are conservation ramifications from these results as they demonstrate that pigs threaten wetland biodiversity. The significance is difficult to evaluate fully because the taxonomy, ecology and distribution of ground invertebrates of exposed wetland sediments are poorly known, with this being one of the first studies in the world to consider them in this way.

Successful prevention of pig damage to wetlands and resulting biodiversity loss can be achieved by using exclusion fences, but these require ongoing and effective fence monitoring and maintenance regimes (Figure 11). The intensity of pig damage and the richness and abundance of ground invertebrates provide useful monitoring indicators to evaluate the effectiveness of such pig control measures wherever pigs damage wetlands.

Figure 11. Conceptual model representing the main findings of this report. Pigs damage wetland sediments, which results in loss of ground invertebrate biodiversity. Fences can prevent this but if they are poorly maintained and damaged, they can cause greater damage than not fencing at all.

2.6.3 Publications (DES)

Negus, P.M., Marshall, J.C., Clifford, S.E. No sitting on the fence: protecting wetlands from feral pig damage by exclusion fences requires effective fence maintenance. *Wetlands Ecol Manage* **27,** 581–585 (2019). https://doi.org/10.1007/s11273-019-09670-7

Marshall, JC, Blessing, JJ, Clifford, SE, Negus, PM, Steward, AL. Epigeic invertebrates of pig-damaged, exposed wetland sediments are rooted: An ecological response to feral pigs (*Sus scrofa*). *Aquatic Conserv: Mar Freshw Ecosyst*. 2020; 30: 2207– 2220. https://doi.org/10.1002/aqc.3468

Negus Peter M., Barr Cameron, Tibby John, McGregor Glenn B., Marshall Jonathan, Fluin Jennie (2019) Subtle variability in water quality structures tropical diatom assemblages in streams of Cape York Peninsula, Australia. *Marine and Freshwater Research* **70**, 1358-1377.

Appendix 1**.** Draft paper: Jonathan C. Marshall, Andrew C. G. Henderson, Helen Mackay, Patrick Moss, Peter Negus, Fred Oudin, Justin Perry, John Tibby (in prep) Porcine palaeoinsights: the use of faecal biomarkers in sediment chronologies to characterise wetland ecosystems before and after their invasion by feral pigs.

2.7 Water quality and limnology processes in fenced wetlands (JCU)

Wetlands (palustrine and lacustrine) located on floodplains away from riverine channels support rich aquatic plant and fauna communities (Abrial et al. 2019; Hurd et al. 2016). However, some point after peak flood connection, aquatic organisms occupying these wetlands begin to face a moving land–water margin, until connection is broken, at which point the remaining wetland waterbodies support a non-random assortment of species, including fish (Karim et al. 2012). The duration, timing and frequency that off-channel wetlands maintain lateral pulse connection to primary rivers is an important determining factor in broader coastal ecosystem values and services. In addition to connection, environmental conditions become important including water quality, access to shelter to escape predation and available food resources. Efforts by managers to restore wetland ecosystem values is increasing (Waltham et al. 2020), nevertheless access to data establishing success of these programs is limited, which becomes important when attempting to establish biodiversity returns for the funding investment.

After floodplain wetlands begin receding and progressively disconnect from the main river channel, they become smaller and shallower because of water loss via evaporation, groundwater recharge, or consumption by wildlife. In tropical north Australia, seasonal off channel wetlands are more pronounced owing to high evaporation rates, loss to groundwater, and in many situations waters quickly retract away from the banks and riparian shade (McJannet et al. 2014, Wallace et al. 2015). At that point, it is thought that they become more prone to reduced water quality conditions – most notably reduced water depth and high water temperatures – which is important for fish, for example (Waltham and Schaffer 2018). Fish must exploit available ephemeral aquatic habitats, which can be specific to each wetland depending on orientation, location, depth and vegetation cover in the landscape, in order to survive until monsoonal rain reconnects overbank river networks again.

Across northern Australia, feral pigs contribute wide-scale negative impacts on wetland vegetation assemblages, water quality, biological communities and wider ecological processes. Feral pigs utilise an omnivorous diet supported by foraging or digging plant roots, bulbs and other below ground vegetation material over terrestrial or wetland areas (Doupé et al. 2010). This feeding strategy has a massive impact on wetland aquatic vegetation, which gives rise to soil erosion and benthic sediment re-suspension, reduced water clarity and eutrophication which becomes particularly critical late dry season (Figure 12). The fact that limited data exists on the impact that feral pigs contribute to wetlands, places a strain on the ability for land managers to quantify the consequences of pig destruction.

Strategies focused on reducing or removing feral pigs from the landscape have been employed since their introduction to Australia, including poison baiting, aerial shooting, and trapping using specially constructed mesh cages. Attempts to exclude feral pigs have also included installing exclusion fencing bordering the wetland of interest. While advantages of installing fencing around wetlands has been examined only recently in Australia (Doupe et al. 2009, Doupé et al. 2010, Fordham et al. 2006, Krull et al. 2013), those authors claim fencing might well be less effective, particularly in situations where wetlands would normally dry during the dry season. Fencing is expensive to construct and maintain but at the same time may prevent other non-target terrestrial fauna, such as kangaroos, from accessing wetlands that become particularly imperative late in the dry season as regional water points. Other terrestrial species including birds, snakes and lizards, for example, are generally able to access wetlands, though access for freshwater turtles might be hindered (Waltham and Schaffer 2017). Here we measure the underlying exposure risks to fish occupying wetlands that are impacted by feral pigs, in particular critical water quality conditions such as water temperature and dissolved oxygen.

In a second study, the fish assemblage occupying wetlands impacted by feral pigs and those wetlands that were fenced is examined. In a final study we examine the consequences fencing wetlands has on other conspicuous aquatic species that use floodplain wetlands, but that also move across floodplains during the dry season.

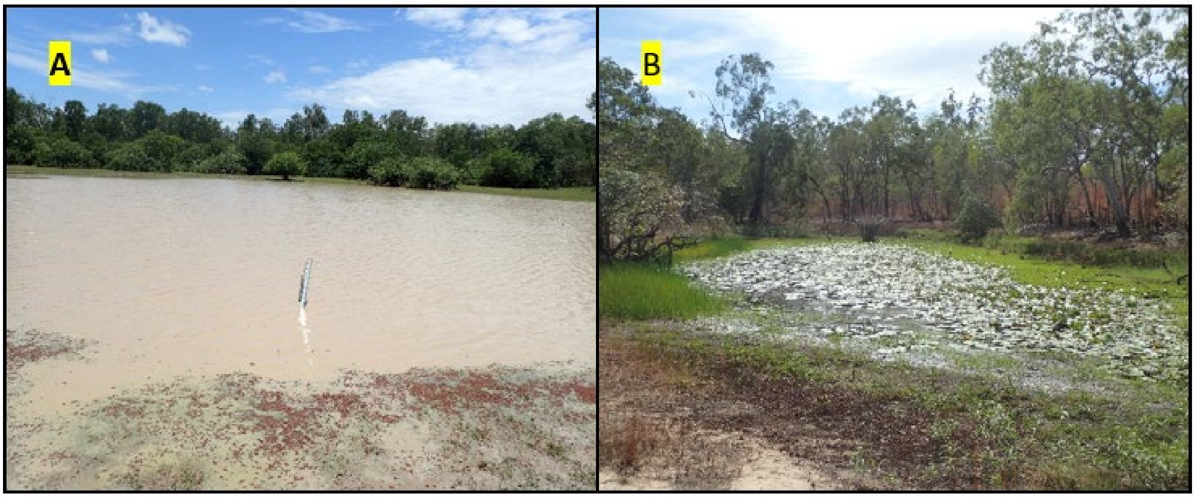


Figure 12. a) example of wetland fenced preventing pig access (photo taken November 2016); b) wetland without fencing and consequent pig disturbance (photo taken November 2016).

2.7.1 Reducing the risks of breaching thermal tolerance for fish through pig exclusion

Acute thermal and asphyxia exposure risks for freshwater fish occupying three tropical wetland typologies were examined (Figure 13). Field water quality data revealed that fish in pig-impacted wetlands had the highest exposure risks, because they are shallow and heavily damaged by pig activities. In contrast, deeper permanent and pig-managed wetlands (the exception is dissolved oxygen which still reached critical conditions because of aquatic vegetation respiration) provide the best opportunity for the same fish species to survive in a heavily pig-impacted tropical landscape.

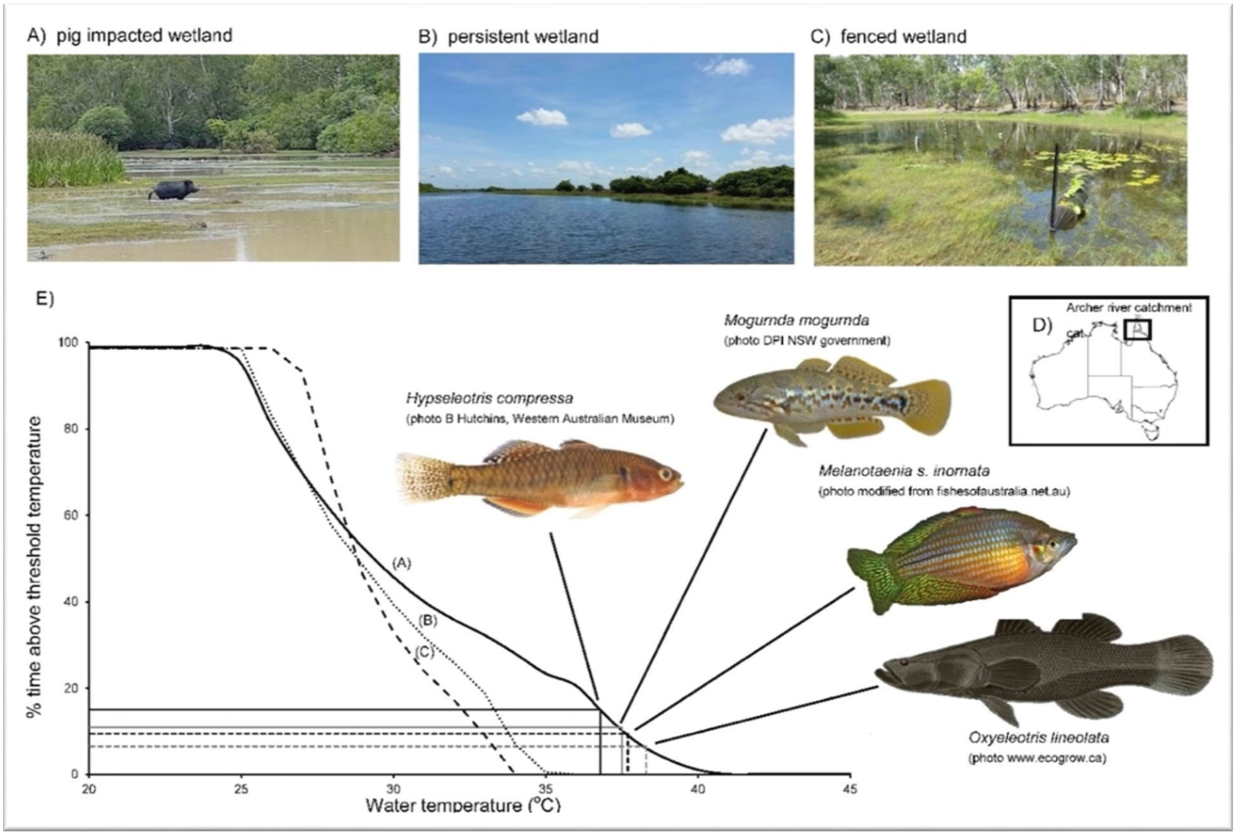


Figure 13. The 3 wetland typologies – (a) pig-impacted wetlands that are shallow, typically <0.5 m deep, without submerged aquatic vegetation, turbid and eutrophic; (b) permanent wetlands that are deeper (typically <2 m deep), steep sides limiting pig access, clear with submerged aquatic vegetation present; and (c) fenced wetlands preventing pig access that are deeper (typically <2 m deep), clear with submerged aquatic vegetation present – dominant in the Archer River catchment (d); (e) frequency distribution for surface (0.2 m) water temperature logged in the 3 wetlands between 12 and 22 November 2017. Threshold lines are minimum acute effects temperature for subset of freshwater fish present in wetlands to illustrate percentage of time above the water thresholds.

2.7.2 Fish assemblage structure in fenced wetlands

Efforts to protect and restore tropical wetlands impacted by feral pigs in northern Australia have more recently included exclusion fences, an abatement response proposing fences improve wetland condition by protecting habitat for fish production and water quality. Here we tested: 1) whether the fish assemblages are similar in wetlands with and without fences; and 2) whether specific environmental water quality conditions influence fish composition differently between fenced and unfenced wetlands. Twenty-one floodplain and riverine wetlands in the Archer River catchment (Queensland) were surveyed during post-wet (June–August) and late dry season (November–December) in 2016, 2017 and 2018, using a fyke soaked overnight (~12–14 hrs). A total of 6,353 fish representing 26 species from 15 families were captured. There were no multivariate differences in fish assemblages between seasons, years and for fenced and unfenced wetlands (PERMANOVA, pseudo-F <0.58, $P<0.68$). Late dry season fish were considerably smaller compared to post-wet season: a strategy presumably to maximise rapid dispersal following rain. At each wetland a calibrated Hydrolab was deployed (between 2 and 4 days, with 20 min logging) in the epilimnion (0.2 m), and revealed distinct diel water quality cycling of temperature, dissolved oxygen and pH (conductivity represented freshwater wetlands), which was more obvious in the late dry season survey because of extreme summer conditions. Water quality varied among wetlands, in terms of the daily amplitude and extent of daily photosynthesis recovery, which highlights the need to consider local site conditions rather than applying general assumptions around water quality conditions for the types of wetlands examined here. Although many fish access (fenced and unfenced) wetlands during wet-season connection, the seasonal effect of reduced water level conditions seems to be more important compared to whether fences are installed or not, as all wetlands supported few, juvenile, or no fish species because they had dried completely regardless of whether fences were present (Figure 14).

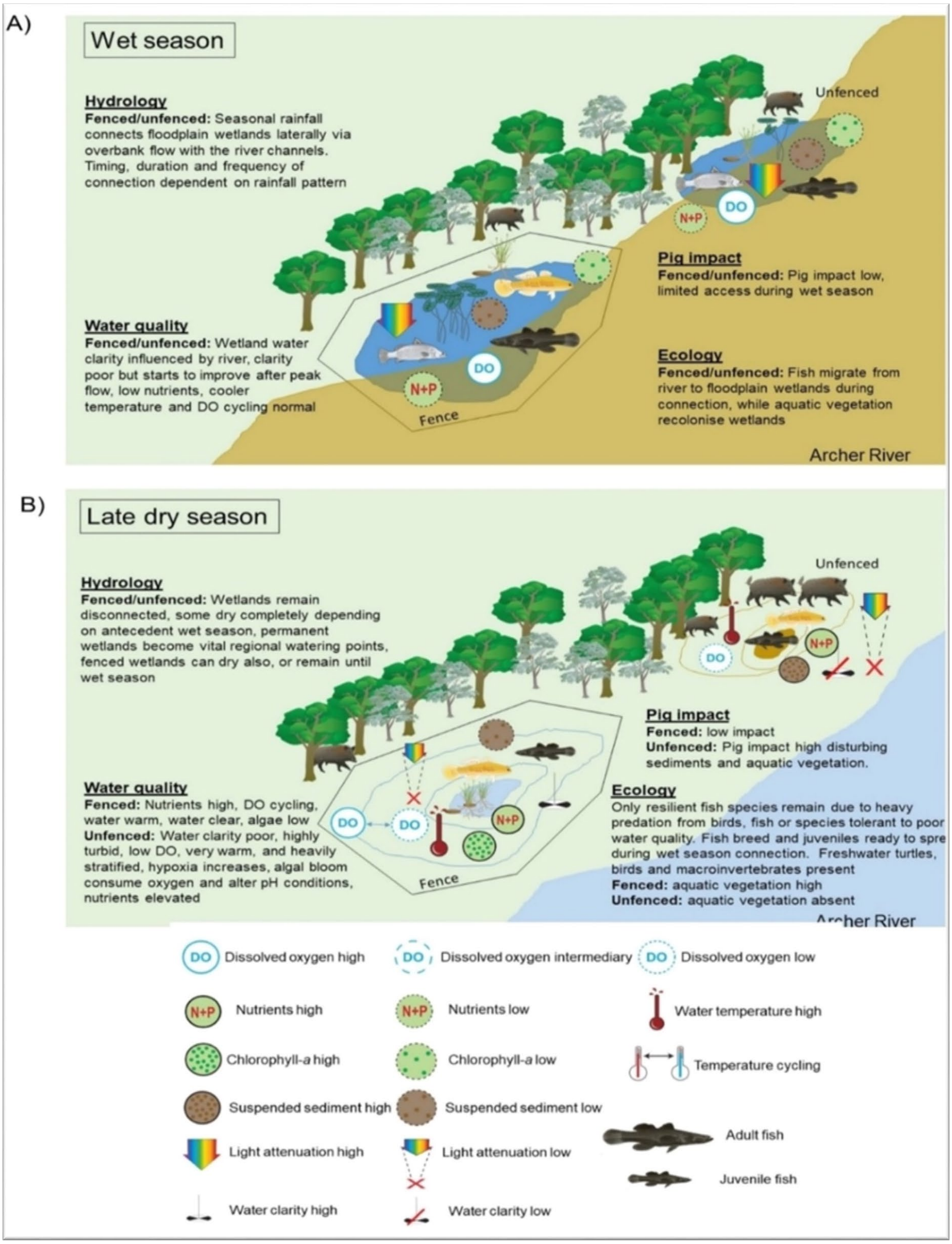


Figure 14. Conceptual diagram of wetland ecosystem conditions during (a) wet season, and (b) late-dry season. During the wet season, the lateral connection between the Archer River channel and wetlands occurs, during which fish can access wetlands and water quality is generally best because feral pig impact is minimal regardless of fencing. The dry season results in water retracting from the land margins, allowing pigs to access unfenced wetlands. At this stage, water quality conditions are poor in unfenced wetlands with high turbidity/nutrients and temperature, and dissolved oxygen is generally critical for fish. Fenced wetlands become shallower too, though temperature and dissolved oxygen cycling is reduced, turbidity is low, while nutrients can be also high. Regardless of fencing, fish community is reduced to a few resilient species dominated by juveniles ready for rapid dispersal when wet seasons commences again.

2.7.3 Simple modification to fences increases freshwater turtle movement on floodplains

Globally, freshwater turtles are at risk of extinction because of high rates of land use change, contributing to poor habitat quality or the habitat is lost completely; nests are continuously predated by animals, and turtles are hunted directly by predators or humans for consumption or changes in hydrology, either through direct water extraction or regulation and climate change (Ocock et al. 2018, Van Dyke et al. 2018). In northern Australia, a number of freshwater turtle species inhabit seasonal wetland complexes and will employ terrestrial locomotion to exploit ephemeral food supplies, to lay eggs or escape drought – accessing terrestrial areas additionally exposes turtles to hazards such as desiccation, exposure and predation by other terrestrial fauna (Waltham and Schaffer 2017). Freshwater turtles are an obvious species on coastal floodplains of northern Australia and their cultural value to Indigenous communities as a food source means there is considerable government interest and investment into funding feral pig control programs. The use of wetland perimeter fencing is now widespread in northern Australia, which has contributed to wetland limnology improvement including protecting aquatic vegetation and water quality; however, it raises important secondary consequences relating to whether conservation fences indeed impede turtle terrestrial movement (Doupe et al. 2009).

Our aim here was to evaluate the potential impact that wetland exclusion fencing has on the population demographics of freshwater turtle species inhabiting floodplain and riverine wetland complexes in northern Australia. Specifically, we examined shell morphology in relation to existing fence dimension characteristics from turtle populations occupying fenced and unfenced wetlands to determine the proportion of individuals whose mobility across the landscape would be restricted because of wetland fencing (Figure 15). Extending on these field observations and previous studies, which have shown that vagile turtles will persist in their attempts to overcome barriers to movement between wetlands, we then tested the efficacy of different orientations and simple 'turtle gates' on a widely used style of exclusion fence to greater facilitate unrestricted turtle movement across these potential barriers. The results showed that most freshwater turtles, which cannot normally fit through un-manipulated fences, will prospect and move along a barrier fence until they find a suitable passage opening/gate. The gate designs employed here are easily applied to fences during construction, but also retrofitted to existing fence enclosures, to increase successful land movement by turtles in northern Australia. We advocate that this simple, yet effective, fencing modification is necessary for all existing and future floodplain conservation fencing projects.

Figure 15. Left: female C. rugosa *found in situ on the exterior side of an exclusion fence installed around a wetland on the lower Archer floodplain (17/08/2018). Right: Arrows indicate abrasive injuries as a result of sustained effort to access wetland through small fence mesh panels.*

Each conservation fence program requires a relevant and rigorous scientific monitoring and evaluation program in order to evaluate the efficacy, but more importantly to identify whether additional design improvements are necessary to lessen broader consequences. We advocate here that an easy management response is to ensure the wider diagonal width squares are located along the ground when erecting fences, rather than the small diagonal width squares – which results in an increase in the number of turtles that could pass through the fence when confronted and would conceivably not increase the possible chances of pigs to smash through fences. However, simply removing a small piece of wire to increase openings allows for up to 100% passage rates of turtles that would otherwise be stuck on one side of the fence. Turtle gates may be strategically applied in travel corridors to minimise the need for large-scale clipping efforts around entire wetlands – and gates can be easily retrofitted to existing fence designs. This outcome has enormous positive conservation benefits for freshwater turtles in an already challenging, and changing, floodplain environment.

2.7.4 Conclusions

Floodplain wetlands hold incredible habitat, water quality and cultural values, and need protection and conservation. The impact of feral pigs (and cattle) on these important ecosystems is obvious, with low aquatic plant communities, highly turbid, low dissolved oxygen and they are generally shallow and experience higher water temperature when compared to wetlands that are managed for conservation. Fencing wetlands provides an important means of managing the threat of pigs, which protects local aquatic plants that are necessary to provide thermal refugia for fish. Generally, fencing also protects fish in wetlands, with slightly more fish recorded in fenced wetlands compared to those unfenced – the exception here is that wetlands that are more distant to primary rivers tend to be seasonally ephemeral, so fencing does not increase habitat values for fish. Fencing does become a problem for freshwater turtles that have a diagonal shell size larger than the fencing wire. However, we provide the first evidence that a simple design modification increases the prospects of turtles passing through fences. Overall, for the expense of construction and maintenance, fencing of wetlands is important in aquatic conservation and protection, but slight modifications to the design of fences will maximise the biodiversity return for the investment (Figure 16).

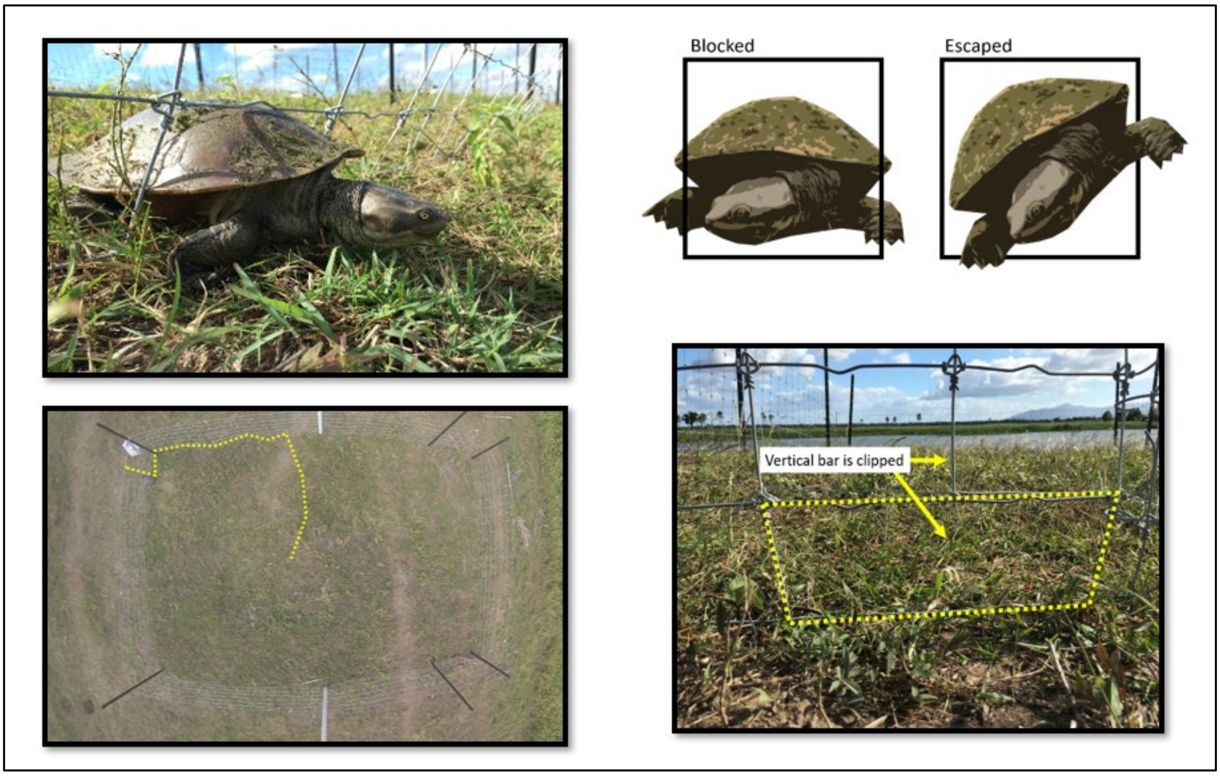


Figure 16. Experimental design for assessing turtle interaction with fences.

2.7.5 Publications

Waltham, N. J., and J. R. Schaffer. 2018. Thermal and asphyxia exposure risk to freshwater fish in feral-pig-damaged tropical wetlands. Journal of Fish Biology 93:723-728.

Waltham, N. J., and J. R. Schaffer. (in press). Feral pig exclusion fencing provides limited fish conservation value on tropical floodplains.

Waltham, N. J., Schaffer, J. R., Perry, J., Walker., S., and E. Nordberg (In review). Simple conservation fence modification increases freshwater turtle terrestrial movement opportunities on floodplains.

2.8 Soil propagules (JCU)

2.8.1 Introduction

Many ephemeral or seasonal wetlands have a diverse and abundant plant propagule bank (Bonis et al. 1995, Brock and Rodgers 1998). Regeneration from persistent soil propagule banks is an important means by which plants can recover from both natural and artificial disturbances by enabling species to tolerate adverse conditions in situ and regenerate rapidly when conditions become suitable. For wetland plants of temporary systems, drawdown and drying out is one such natural disturbance and the presence of a local propagule bank allows the vegetation to recover rapidly when water returns. In such systems, propagule banks may be sensitive to the impacts from stressors such as pigs and could be a useful indicator of wetland health and resilience to both natural and anthropogenic stressors (Skinner et al. 2001).

Pig foraging habits damage vegetation structure, disturb soil and increase water turbidity, the impacts of which are easy to observe (Bengsen et al. 2014). However, there are likely to be other impacts on wetland function that are more difficult to detect such as changes to soil propagule banks. Pigs can greatly increase wetland disturbance levels through their rooting activities as they forage for food and turn over extensive quantities of soil (Wurm 1998) and alter soil properties (Singer et al. 1984). In doing so they can redistribute seeds from deeper in the soil profile to the surface (Bonis and Lepart, 1994) exposing seeds to germination conditions earlier than would otherwise occur. This can disrupt persistent seed banks situated deeper in the soil profile, leading to a shorter-term, homogenous and transient seed bank (Bueno et al. 2011). Conversely, pig activities bury some seeds deeper in the soil (Wurm 1998) and thus seeds may not be exposed to conditions required for germination and seedling growth. Pig activities may also alter seed supply through dispersal of propagules and trampling of young seedlings, ingestion and damage to mature plants, which reduces or prevents flowering and seed set.

Here we examined the germinable propagule bank composition and structure of three ephemeral wetlands in the Archer River basin, Cape York Peninsula, northern Australia. Two wetlands were sampled prior to the construction of exclusion fencing, while the third wetland was sampled after pig and cattle fencing had been in place for 12 months.

2.8.2 Methods

Soils were collected from each wetland (Figure 17) in the Archer River catchment in November (2015) while the wetlands were dry prior to the wet-season commencement. Within each wetland and fencing zone, three depth strata were identified. The marginal or shallow wetland strata at the furthest extent of the most recent inundation event, the medium depth zone (which represented the midway point between the wetland edge and the deepest point of each wetland) and the deep strata in each wetland. The latter was defined as the lowest elevation point which also retained water the longest. Within each depth strata, eight replicate soil samples were collected by pooling five soil subsamples taken to a depth of 10 cm from within a 1 m by 1 m quadrat. Following collection, the soil samples were returned to the laboratory, sorted to remove any large stones and non-viable matter, and stored until commencement of the germination trials.

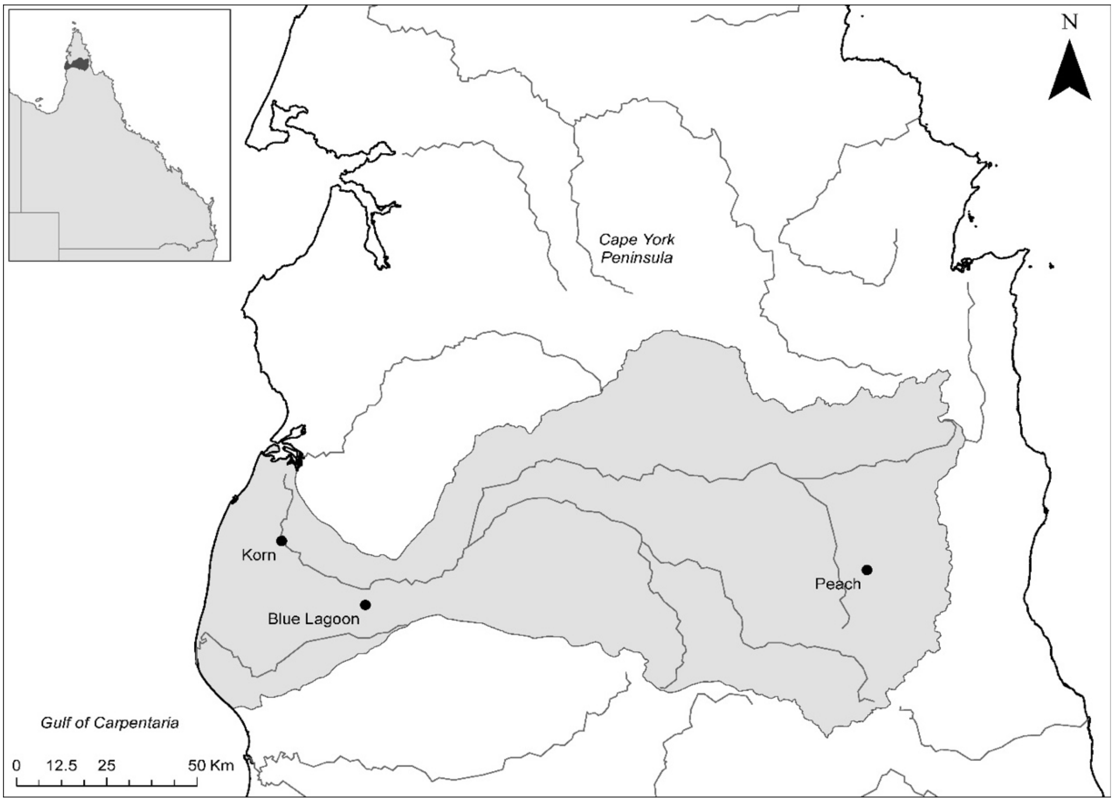


Figure 17. Location of wetlands. Map shows major river channels and Archer River catchment boundary as shaded area on main map.

We used the seedling emergence method under damp soil and submergence (15 cm water depth) to determine the germinable propagule bank. Each soil sample was used to fill two square plastic containers (4.5 litre capacity, 179 × 179 mm by 192 mm height) to a depth of approximately 3 cm. We used the same containers for both the submerged and damp soil treatments. This resulted in a total of 288 containers (3 wetland × 2 management zones (fenced or unfenced) × 3 depth strata × 8 replicates × 2 treatments). The samples were then randomly placed on one of five large tables inside an unheated greenhouse at Townsville (19.3277°S, 146.7565°E). The germination trial was run for eight months from the start of June 2016 until the end of January 2017.

2.8.3 Results

Over 3,000 seedlings from 55 species were recorded from 27 different families. Notably, very few introduced species were recorded with a few widespread introduced annual herbs such as *Emilia sonchifolia var. sonchifolia*, *Scoparia dulcis*, *Tridax procumbens*, and the introduced fern *Pityrogramma calomelanos* but no notable weeds.

Of the 55 species recorded many are considered wetland species that are associated with wet or inundated soils. Members of the family *Cyperaceae* dominated with 16 species, but members of typically wetland plant families such as *Eriocaulaceae* and *Hydrocharitaceae* were also quite common (5 and 3 members respectively). Plant families more associated with terrestrial habitats were *Asteraceae* (5) and *Poaceae* (3) but overall terrestrial species constituted a low proportion of the species richness and seedling abundances.

Annual and short-lived perennial herbs were the most prevalent and species rich growth forms (20 species) but graminoids were also abundant and diverse (19 species recorded, the majority being sedges). The aquatic vegetation was also relatively diverse with 10 submerged and four floating species. Five fern and allied species were also recorded and the remaining species were seedlings of perennial species (*Myrtaceae* sp.) and complex algae (e.g. *Characeae* sp.).

Growth form and habit varied predictably across the depth strata with the deepest strata occupied predominantly by aquatic taxa (submerged and floating species), the medium strata occupied largely by graminoids (grasses and sedges), algae (*Characeae*) while the shallow strata was associated with aquatic emergent herbs and shrub seedlings. Ferns and terrestrial herbs tended to occur across all the depth strata. Growth forms also varied in a predictable manner across the two water-depth treatments with submerged and emergent aquatic plants and algae found exclusively in the submerged treatment, and graminoids, terrestrial annual herbs, terrestrial ferns and shrubs found predominantly in the damp treatments. Floating aquatic plants tended to occur in both watering treatments with species such as *Nymphoides indica* able to germinate and grow both submerged and on damp soils.

2.8.4 Discussion

This study demonstrates the unique and variable propagule bank composition of three wetlands in the Archer River catchment and is consistent with surveys of extant vegetation in nearby catchments (e.g. Doupe et al. 2010). The wetland flora emerging from the soils of the three wetlands examined here was dominated by vegetation species associated with saturated and/or inundated soils and few non-native species were recorded.

The notion exists that because ephemeral wetlands are subject to annual desiccation and rewetting, the impacts of pigs are not considered to be particularly important as drying out effectively ‘resets’ the ecosystem (Doupe et al. 2010). This is reinforced by the fact that with rewetting any remaining turbid water is flushed away and the vegetation returns. We found differences in the propagule bank composition of pig exclusion sites relative to those sites with pig access (cattle fenced). Differences in propagule bank composition between the fencing strategies appeared to be greatest for the deep depth strata. This is consistent with the hypothesis that animal activities disproportionately impact deeper regions of wetlands because animal activities tend to become concentrated in the deeper water zones as the water bodies shrink in size towards the end of the dry season. However, we did not find any evidence to support the notion that pigs acted to reduce spatial variability and homogenise the propagule bank as initially proposed (i.e. there were no differences in multivariate dispersion among groups between the exclusion and accessible wetland halves).

2.8.5 Conclusions

In this study, the differences in propagule bank composition and structure between the fencing strategies was subtle. This is probably because of the long history of impacts from pigs prior to fencing, the proximity of the pig-excluded and accessible wetlands, and the relatively short period fencing has been in place when the soil samples were collected. Bonis and Lepart (1994) reported that seeds banks recovered some of their vertical profile structure within a year of enclosure. Recovery of vegetation, however, will be reliant on a source of propagules (propagule dispersal and in situ propagule banks) and successful seedling establishment through to maturity. While both are potential bottlenecks in recovery, germinating seedlings – even in fenced areas – remain vulnerable to disturbances such as trampling and burying from other animal activities. Mortality at this stage prevents these plants contributing to the future propagule bank and may thus act to deplete the propagule bank over the longer term. Therefore, the time taken for the propagule bank to recover is both habitat and taxon specific but is likely to occur over longer periods than studied here.

Wetland and floodplain propagule banks of temporary wetlands have been extensively studied elsewhere in Australia but remain relatively unknown in northern Australia. This is due, in large part, to the remoteness and difficulties in accessing wetlands in much of the region. Understanding the spatial structure and variability of the propagule bank is a prerequisite to designing appropriate sampling strategies for assessments of propagule banks and for understanding the contribution these reservoirs make to extant communities and their resilience to disturbances in the presence and absence of animal disturbances. Finlayson (2005) noted that fundamental information regarding the ecology of these tropical floodplain wetland systems was lacking. Recent studies have addressed some of these deficits (e.g. Cross et al. 2015) but given the continued pressures from invasive species such as pigs, as well as climate change and land use development, further work is still needed.

2.8.6 Publications

Appendix 1: Draft propagule paper.

2.9 Use of unmanned aerial systems (UAS) to document change in waterhole habitat values over time (CSIRO)

2.9.1 Introduction

Many modern land management organisations have embraced the use of unmanned aerial systems (UAS) – drones – in recent years. Relatively inexpensive commercially available UAS such as DJI Phantom or Mavic are a common choice. Despite many organisations owning and using UAS for land management activities there is no standardised method for conducting repeatable survey and analysis using the commonly available drones. In this project, we sought to develop accessible survey methods that could be applied by land managers to monitor and report on the impact of feral animals. In this element of the project, we developed survey and analytical standards that can be applied in any location assessing changes to habitat values in waterholes.

2.9.2 Methods

For surveys to be repeatable it is important to be able to sample the sites under similar environmental conditions. Here we completed surveys in the early dry season (between May and July) and late dry season (between October and December). For the late dry season survey, we aimed to survey when water holes were at their driest and prior to the first substantial rain. In our study area, late dry season surveys were most consistent in October as intense storms are more common in November and December which rapidly fill up waterholes.

2.9.2.1 Drone surveys

Equipment

We conducted surveys with two different types of done, the DJI Mavic Pro and the DJI Phatom 4 Pro. Surveys were done by trained pilots and used standard controllers and iPads or iPhones to operate the software.

Software

We used commercial drone survey software DroneDeploy (www.dronedeploy.com). We chose DroneDeploy as there are different payment tiers making the software relatively inexpensive. The software operates on commonly used mobile devices (iPhone, iPad and Android mobile devices) and is intuitive and easy to use.

Survey methods

We conducted survey tests at three different heights: 40, 50 and 80 metres. Sites varied in size from less than 1 hectare to >30 hectares. We selected 40 m as a standard height for survey in the development phase; however, work done since suggests 70 m is suitable for habitat assessments. For a moderately sized waterhole (14 hectares) with 70% front overlap, 60% side overlap and a flight speed of 5 m per second, a survey took 26.37 minutes, used two batteries and captured 524 photos (Figure 18).

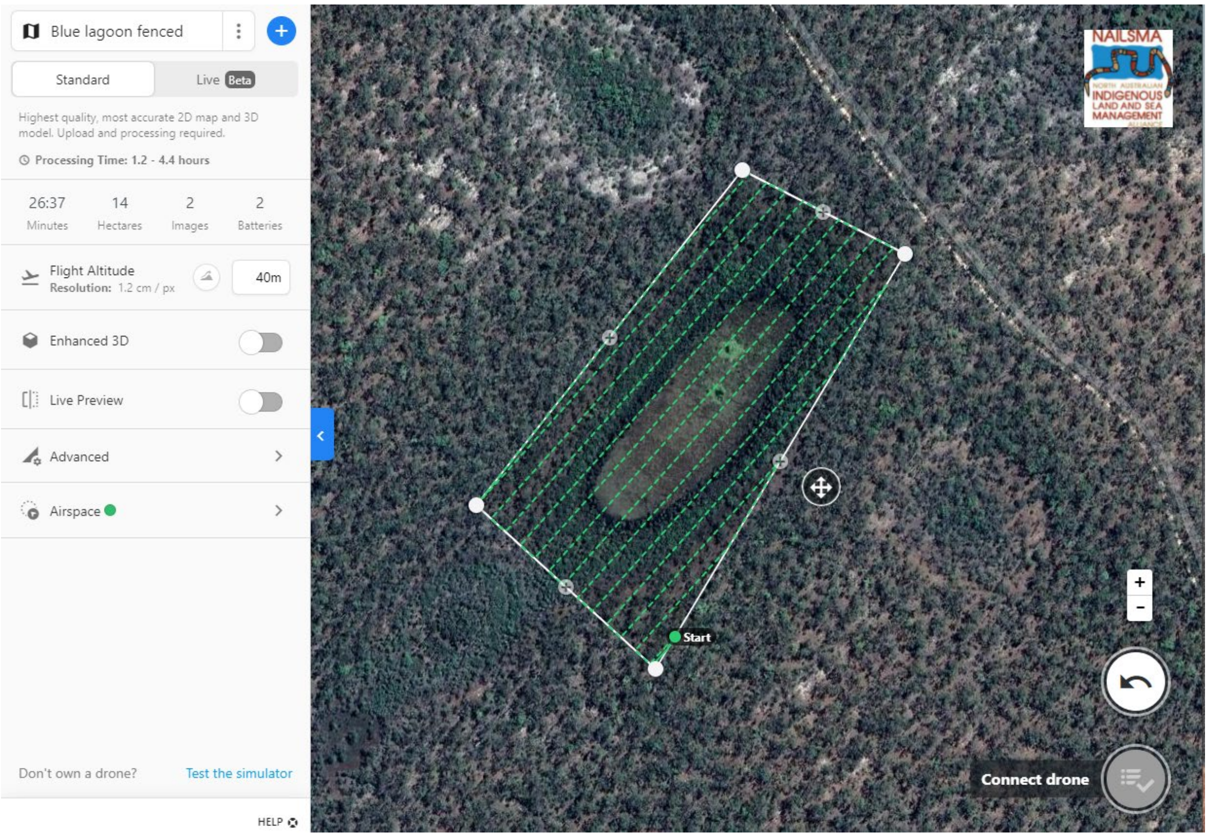


Figure 18. DroneDeploy survey software automatically develops a flight plan.

Using the new method standards, flying at 70 m, 75% front overlap, 75% side overlap and 6 m/s flight times, the survey could be done in 14 minutes with one battery and 294 photos. This dramatically reduces survey time and processing time.

Data preparation

Once a survey or surveys were complete, photos were sorted into folders on a laptop or PC back at the ranger base. Photos were uploaded for each site using the DroneDeploy software (Figure 19). Once uploaded the DroneDeploy software creates a geo-rectified image in the cloud for each survey and automatically emails the user once completed (usually 2 to 3 hours).

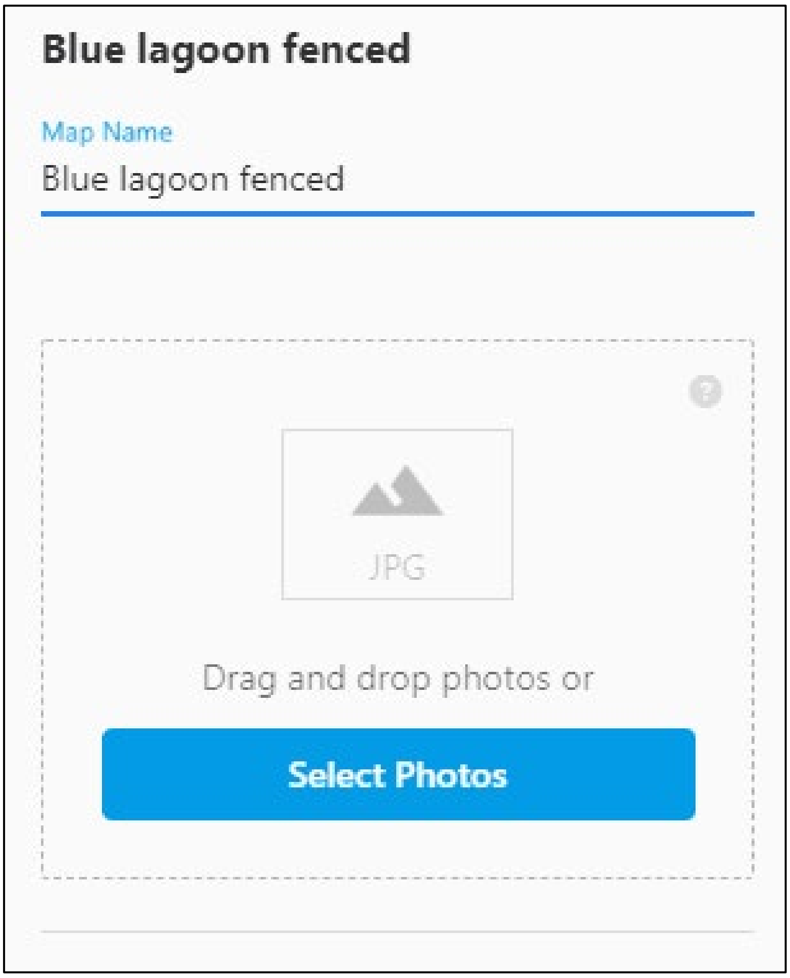


Figure 19. Upload screen in DroneDeploy.

The geo-rectified image can be viewed on the DroneDeploy website and each survey can be viewed through a date picker or compared using a side-by-side slider (Figure 20).

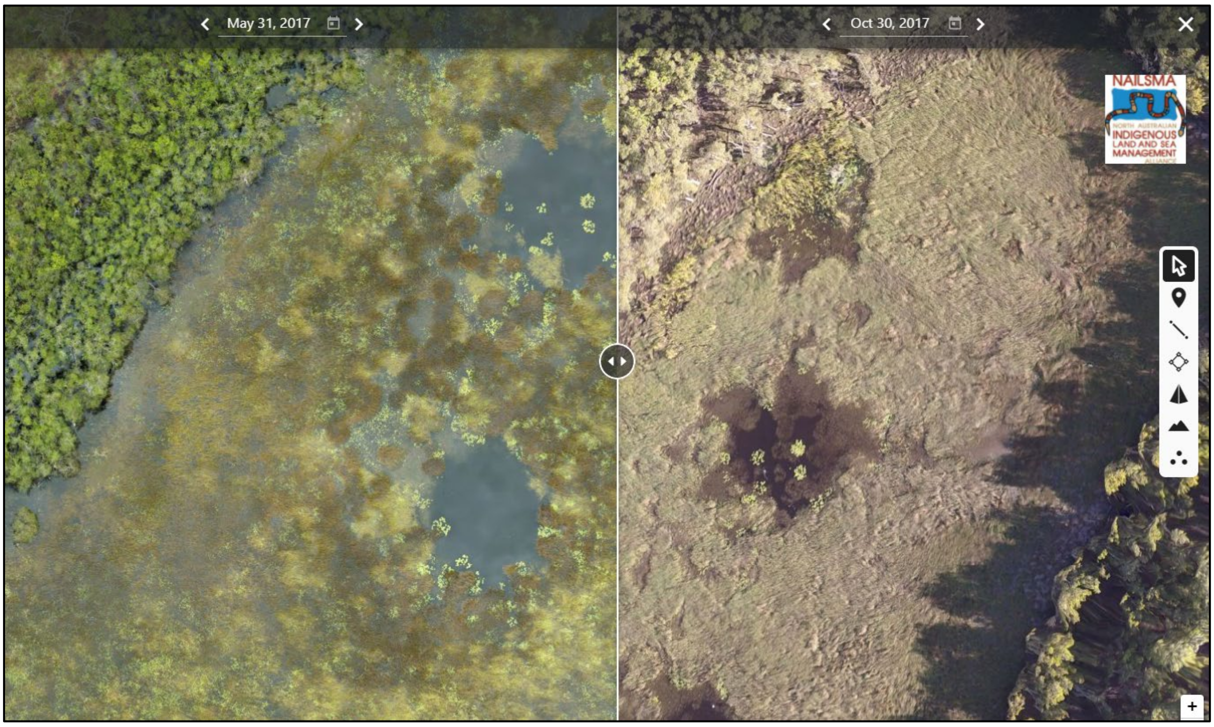


Figure 20. Side-by-side slider visualisation in DroneDeploy software comparing May 2017 survey to October 2018 survey.

To prepare for analysis a survey date is selected in DroneDeploy and exported to the users PC using the export function. The user exports as an ortho-mosaic, geotiff, using the desktop (WGS84) map projection using the max available resolutions (here 1.2cm/px). Once processed an email is sent to the user enabling them to download the ortho-mosaic as a compressed geotiff file.

Analysis

Analysis is conducted using the Healthy Country AI software solution developed by CSIRO and Microsoft (github.com/microsoft/HealthyCountryAI.git) (Figure 21).

For the habitat model, we scored the dominant habitat type for each tile by season and site. We greatly reduced the complexity of the labelling task by limiting the labels to broad habitat types. For this pilot study we tested the analysis using five habitat categories:

- tree
- pugged sedge
- sedge
- water
- grass.

We use a single tag per image for our classification model. This required subject matter experts, in this case researchers who had a good knowledge of the visual characteristics of feral animal impacts for different water hole types from aerial photos. Using this method, it was necessary to make decisions about which habitat type was dominant, reducing the complexity of the labelling task but also reducing the detail of the results and leading to difficult labelling decisions in tiles that had diverse habitat characteristics (e.g equal parts water and sedge).

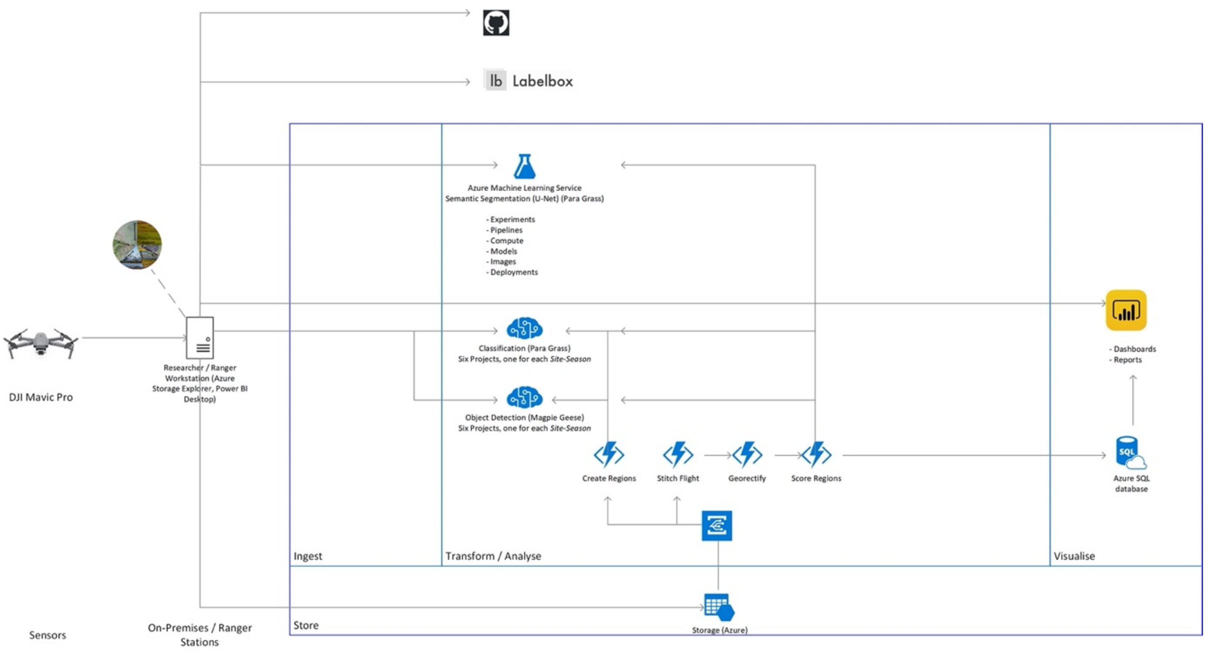


Figure 21. Healthy Country AI software architecture.

The scored habitat data is stored in an SQL database which is linked to a Power BI report. The SQL server contains links to the resized photograph and the scored results of the Custom Vision models (e.g. the percentage of each habitat type) (Figure 22). The proporting of each habitat type is displayed enabling land managers to see how important habitat values (e.g proportion of feral animal pugging) are changing each year. Copy the link below into your browser to view the interactive dashboard.

https://app.powerbi.com/view?r=eyJrIjoiMzEzNWJhNmQtODExZi00ZWE1LTgxMWMtNjI2OWI0MTM4ZjUyIiwidCI6IjJiNzQ1YWMxLTZmNGEtNGUwZS1hOTczLWVkM2YyZjQ3NWUxNyJ9

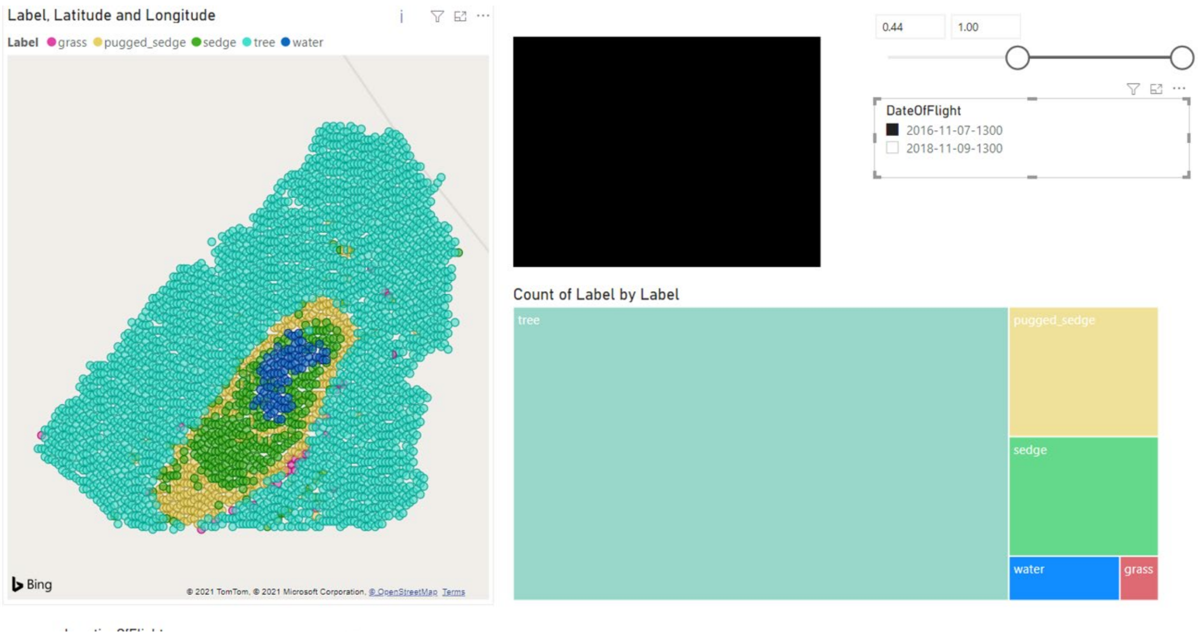


Figure 22. A simple Power BI dashboard visualising the predicted habitat variables.

2.9.2.2 Conclusions

Here we have developed a standardised method for assessing feral pig impact on wetlands across time. This represents a significant step in supporting robust quantifiable metrics that can be collected by land managers with limited technical support. The methods developed here dramatically reduce the time required to conduct wetland monitoring with as little as 15 minutes to conduct a survey over the entire 14 ha wetland. To conduct a survey of this wetland using currently applied field survey methods would take more than a day and would require support from trained field technicians. To operationalise this method, work is required to establish accessible interfaces to the method using cloud-based platforms and to integrate the drone software with the method to reduce processing steps. A significant amount of AI model training is required to increase the utility of this method across seasons and different habitat types and across climatic zones.

2.10 Impacts of pigs on marine turtles (CSIRO)

2.10.1 Intensive nest protection and on-ground surveys

2.10.1.1 Introduction

Marine turtles face a series of threats globally. Their populations suffer from pressures both on land and at sea, ranging from pollution, fisheries bycatch, and challenges from rising sea water, including nest inundation and lack of suitable nesting beaches due to erosion or beach habitat loss (Fish et al. 2005, Fuentes et al. 2010, Whytlaw et al. 2013). In addition, excessive predation rates from native and feral animals (Davis and Whiting 1977, Whytlaw et al. 2013) has led to reduced recruitment and population declines (Engeman et al. 2003, Hamann et al. 2010, Stancyke 1982). Marine turtle populations have declined globally in concert with many anthropogenic practices, in part because marine turtles face threats at all lifestages, from nestlings to adults. Eggs may represent the most vulnerable lifestage for turtles, given their survival is dependent on various external environmental factors. While marine turtles are extremely fecund and can lay multiple clutches of eggs per year (Miller 2017), entire nests, or even nesting beaches, can be destroyed by predators (Engeman et al. 2005, Garmestani and Percival 2005). A variety of native and feral animals, including invertebrates, reptiles, birds and mammals, are known to prey upon marine turtle eggs (Garmestani and Percival 2005, Kurz et al. 2012; Lei and Booth 2017, Stancyke 1982). While native animals have sustainably harvested turtle nests for thousands of years, turtle populations are now at risk due to additional predation pressures from feral animals among other threats (Limpus 2008, Whytlaw et al. 2013). Feral pigs are responsible for high levels of predation in the study area exceeding 90%.

2.10.1.2 Methods

This study was conducted along a 48 km stretch of coastline between the Love and Kirk rivers managed by the APN Aboriginal ranger group, located approximately 30 km southwest of Aurukun, on the west coast of Cape York Peninsula, Queensland, Australia (Fig. 1). The site was chosen for its accessibility and a 6-year history of marine turtle surveys and feral animal control. Nest monitoring took place between June and November 2018. Surveys were done using a purpose-built iPad application, Nestor, designed in collaboration with the APN rangers (Figure 23).

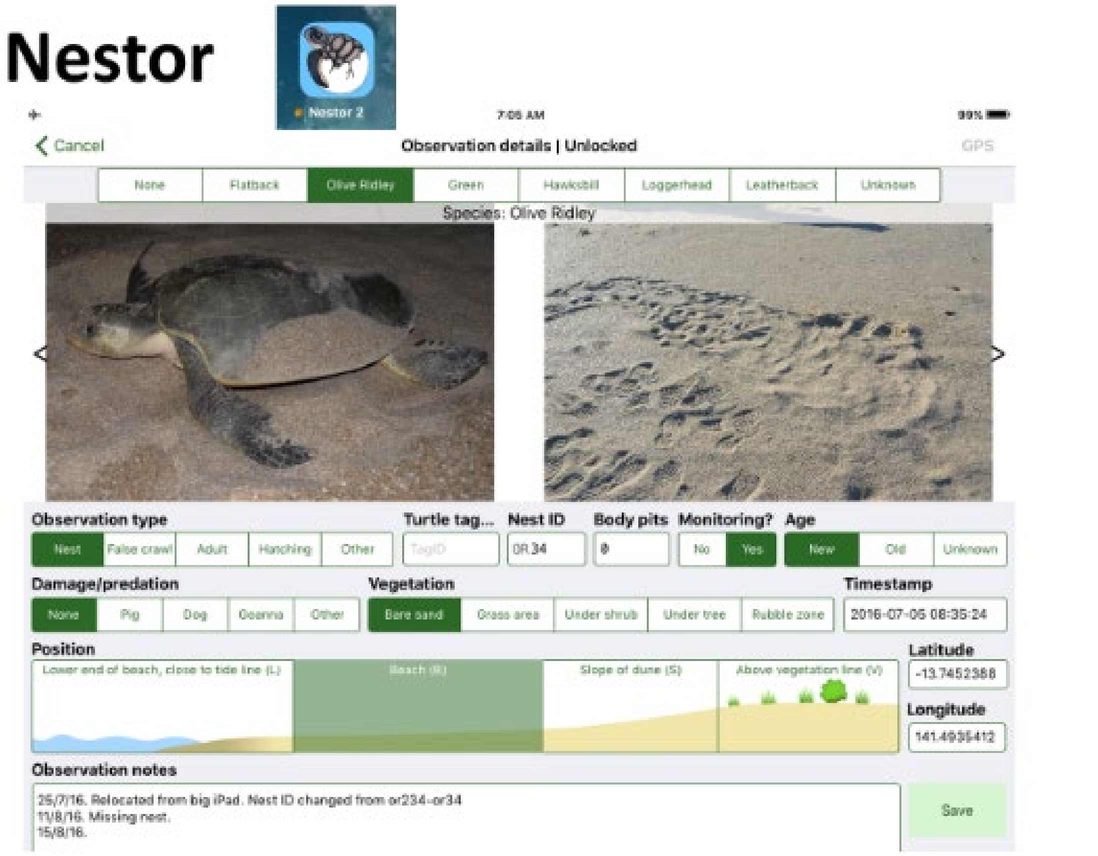


Figure 23. Screenshot of the Nestor iPad application used to systematically collect consistent turtle depredation and nesting data.

Turtle nest monitoring frequency was dependent on the frequency of turtle nesting events. During the peak season (July–September) monitoring took place daily. This was important as challenging weather events (e.g. strong winds/tidal influences) would increase the difficulty of locating new nests over time. During the shoulder periods (June–July, October–November) nest monitoring was reduced to 2–3 surveys per week in concert with lower nesting activity.

Upon locating nests, PVC-coated flower mesh (90 cm wide, with mesh size of 50 mm × 50 mm; Whites) was applied over turtle nests as a predator deterrent. Due to limited resources and differences in vulnerability listing status in Queensland (olive ridley turtles are listed as endangered, flatback turtles are listed as vulnerable; *Nature Conservation Act 1992*; September 2017 list), the application of plastic meshing was only implemented on olive ridley nests due to their shallow nest chambers (compared to flatback nests; Limpus 1971; Santidrián Tomillo et al. 2017) and high susceptibility to predation (Perry, unpublished data). Mesh was cut into 90 cm × 100 cm pieces to fit over each nest and then dug down into the sand around the nest (10 cm deep), centring the mesh over the egg chamber. The mesh was secured around the perimeter with additional sand pegs (up to nine pegs). The perimeter of the mesh was then covered with sand, leaving the centre of the meshing area unburied.

We classified nest predation events into three types: failed, partial or complete predation.

2.10.1.3 Results

We conducted 107 beach surveys during the study period (Jun–Nov 2018). We found and monitored 360 nests from two species of marine turtle (243 olive ridley and 117 flatback). Turtle nests were found along the entire stretch of beach, with olive ridley nests being mostly evenly distributed within the study area. In contrast, flatback nests showed a more clustered distribution with two higher density patches: one in the north and one in the south. Predation attempts were common, with 168 nests (46.6% of all nests) showing signs of digging at nest locations. We documented a total of 142 (58.4%) depredation attempts on olive ridley nests compared to 26 (22.2%) depredation attempts on flatback turtle nests (Fisher's exact test: P = 0.012). For nests that were protected by mesh, goannas attempted to access the nests most (63 times) followed by dingos (26) and pigs (3). Meshing was unsuccessful 14 times, partially successful 30 times, and completely successful 19 times at protecting turtle eggs from goannas. For dingos, meshing protected eggs partially 12 times and completely 10 times with 4 cases of complete depredation. Plastic meshing was not effective at stopping feral pigs depredating turtle eggs (Figure 24).

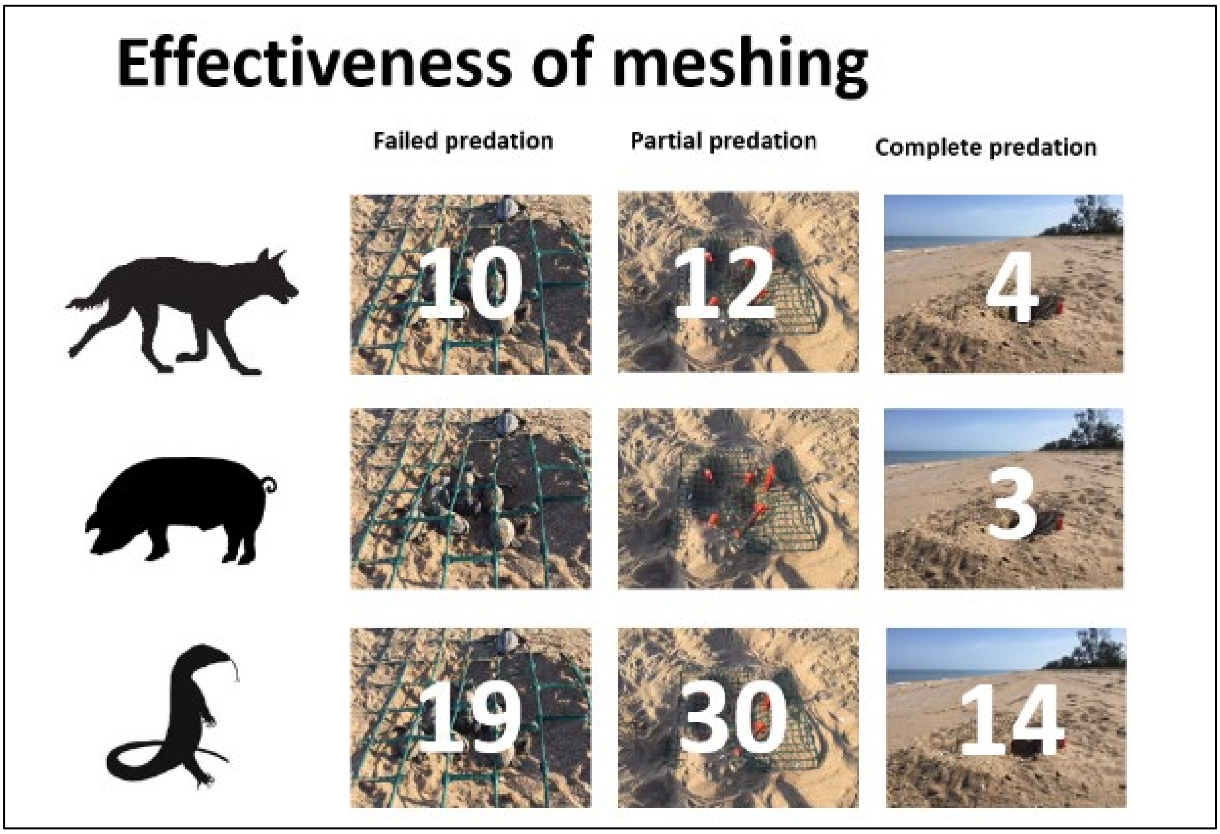


Figure 24. Summary of plastic mesh protection success and failure for dingos, pigs and goannas.

2.10.1.4 Discussion

Our work demonstrates that inexpensive meshing is effective for goannas and dingoes some of the time, but it does not stop feral pigs which, when unmanaged, are responsible for 100% depredation. We also demonstrate that the level of protection may not affect the population viability given that unprotected nests can have similar hatchling success rates. This emphasises the need for a thorough understanding of predator guilds and ecosystem processes, as well as integrating predator management and nest protection strategies to make conservation practices more efficient and effective in the future. The use of more sturdy aluminium cages has proven successful for all predators at beaches south of the study area and warrants further research to quantify success rates and operational challenges for scaling this solution. Given that goannas and dingos have replaced pigs as the primary predator (following intensive baiting at the study site), plastic meshing is a valid management method.

2.10.2 Large-scale (100 km) beach surveys using artificial intelligence (AI)

2.10.2.1 Introduction

The primary challenge faced by APN rangers for protecting marine turtle nests from depredation is the lack of access to beaches throughout the year. One section of beach (~50 km) is intensively managed when the flood plain dries out and the area becomes accessible (usually late July or early August). For the remaining turtle nesting habitat (another 50 km) there has historically been no recorded information as the sites are very difficult to access, even when the landscape is accessible in the late dry season.

The challenge here is to collect enough data to be able to understand nesting density and depredation pressure throughout the nesting season without expending all the available resources to get this critical data.

CSIRO, NAILSMA and APN worked together to develop an operational monitoring system that uses off-the-shelf action cameras with a CASA-approved rig to house the camera, to enable large-scale data collection of high-resolution geo-coded aerial photographs at limited cost and requiring limited training. We coupled the data collection process with an analytical process that leveraged the Healthy Country AI platform to automate the analysis and data visualisation.

2.10.2.2 Methods

We used a Garmin Virb camera on a custom-designed engineer-approved and CASA-approved camera rig attached to the bottom of an R44 Helicopter (Figure 25). Following a short training session in the connection and use of the camera and the Garmin Virb mobile application, APN rangers conducted the surveys across 100 km of beach representing the APN operational area (Figure 26).

Five surveys were conducted over 6 days. Surveys were done in the late afternoon (between 4pm and 6pm) to reduce tree and helicopter shadows and to increase the angle of the sun which highlights nests, animal tracks and depredation events due to increased shadows within sand depressions.

The helicopter flew at ~60m and travelled at approximately 75 knots to ensure overlap between the photos. The Garmin Virb camera stored metadata for each photograph including latitude and longitude, date, time, direction and altitude, which were used in the analysis. On return from each survey, photos were transferred onto an external hard drive and were uploaded onto the Healthy Country AI cloud storage for analysis.

Figure 25. NAILSMA project officer Raphael Clarke fitting the Garmin Virb action camera to the custom-designed camera rig.

Figure 26. APN ranger Gareth Kerindun receiving training from NAILSMA project officer Raphael Clarke to conduct the aerial survey.

2.10.2.3 Analysis

Analysis was conducted using the Healthy Country AI platform developed by CSIRO and Microsoft. https://github.com/microsoft/HealthyCountryAI.git

Description

The Healthy Country AI v2 project is a collaboration between CSIRO, APN Cape York and Microsoft in developing a Turtle Nesting and Depredation Tracking System to detect and monitor the turtle nesting and depredation along the Cape York Peninsula coast. APN Cape York has been working with CSIRO and other partners to protect marine turtles from predators (pigs, dingos and goannas) since 2011. When the collaboration began APN rangers were recording 100% destruction of turtle nests each season from feral pigs. For the past 8 years APN rangers have been doing intensive on-ground surveys during the peak nesting period.

These surveys are in very remote areas and only ~50 km of the 100 km beach can be accessed. The accessible beach is very difficult to access until August due to annual inundation of flood plains. Peak nesting for turtles on this coastline is between June and September. APN Rangers and CSIRO have worked together to build and test the helicopter survey method to provide an alternative monitoring method that is not limited by ground access. The survey method was successful but manual assessment of the photographs (~50,000 per survey period) was not feasible in an operational context.

Survey method

A Garmin Virb action camera was attached to the bottom of a helicopter and set to take 2 photographs per second (triggered by a mobile device from within the helicopter). Surveys were conducted over 100 km of coastline on the west coast of Cape York Peninsula during the peak nesting season for olive ridley and flatback marine turtles. The 100 km stretch of coastline was flown five times in seven days to capture images of new nests and subsequent depredation events. Each image includes date, time, latitude and longitude in the exif file.

Automating the image analysis

The challenge here is to ingest thousands of high-resolution images and automatically detect turtle tracks, predator tracks and depredation of nests.

The architecture developed for Healthy Country AI v2 has the following stages:

- Data ingestion and storage stage (1): Data is ingested and stored in Azure datalake store. The images are stored in raw format, based on survey block mode.
- Transform and analyse stages (2–5): The raw data (photographs) are processed using the metadata and renamed according to survey block and data mode. Each photograph is split into 121 smaller tiles. Each tile is then classified via a trained predictor and based on the classification result, sent to the object detection trainer to identify any tracks available.
- Store prediction results (6): The results are stored in an SQL DB platform and then summarised and aggregated for easy analysis.
- Visualisation (7): To view the results a Power BI report is used.

Details

The captured coastline images are first processed and tiled to produce 121 equally sized tiles of 273 x 364 pixels optimal for detecting turtle tracks, predator, and any depredations. These tiled images are then applied to a trained Terrain Classifier Model to classify as either being:

- beach
- vegetation
- sea.

The tiled images which are classified as 'beach' are applied to the Track Detector Model to identify and detect three main objects:

- turtle tracks
- predator tracks
- depredation*.*

These tagged images are further processed and visualised using Power BI. Both the Terrain Classifier Model and the Track Detector Model were developed using a combination of modelling techniques and Microsoft Cognitive Services – Custom Vision along with Azure Machine Learning Service.

The Turtle Depredation Tracking System consists of two main streams:

1. Deployment Stream (Image Transformation + Inference) where the trained models – Terrain Classifier Model and the **Track Detector Model** – are implemented as a fully functional turtle-tracker detector based on auto-triggering of a set of uploaded images.
2. Training Stream – where new images are ingested to train and publish both the Terrain Classifier Model and the **Track Detector Model** which are then implemented in the **Inference trigger Stream**.

Training Stream

The **Training Stream** consists of five main processes as shown below:

1. Image tagging: the tile images are read from the storage Azure storage container (tiletestoutput) and prepared to be uploaded into a temporary Azure Cognitive Services – Custom Vision project for manually tagging the tile images. This method is the same for both terrain classification and track object detection.
2. Image Preparation: Once the tile images are tagged in the temporary Custom Vision project) the images are downloaded, processed and uploaded into the training Custom Vision project ready to be trained.
3. Training*:* The tiled images (either terrain clarification or track objects) in the training Custom Vision project are trained and given iteration IDs per run.
4. Publish: The best trained iteration in the training Custom Vision project based on the recall value is selected to be published, with publish name and URL end-point.
5. Inference*:* The published model (iteration) of either terrain classification or track object detection URL end-point is used for prediction.

Results

Data stored in the SQL database are visualised using an interactive Power BI dashboard (Figure 27). Rangers and researchers can use the dashboard to filter the location of turtle nests, predator tracks and depredation of nests.

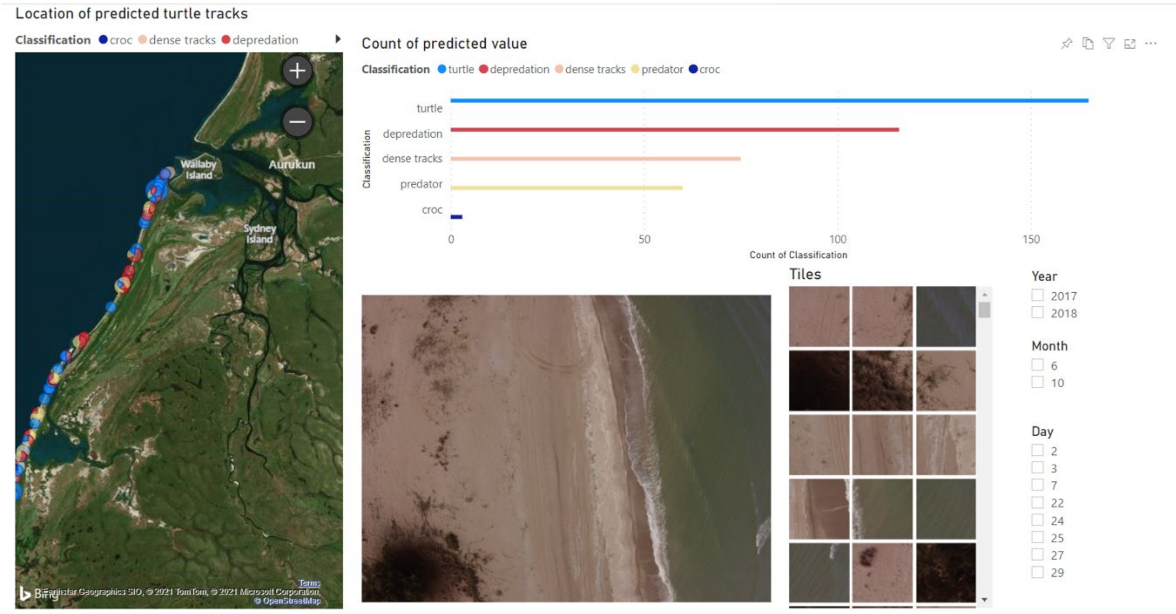


Figure 27. Power BI dashboard used to visualise automated AI analysis from large-scale turtle nest survey.

Management implications

This operational methodology provides a novel monitoring method that enables Indigenous land managers to collect robust and trusted data streams independently. The analysis and subsequent visualisation and summary of the results has enabled rangers to conduct detailed planning accounts for the location of high-density turtle nesting areas and areas of high depredation, contextualised with access constraints. This means rangers have been able to focus their attention on high impact areas to optimise their outcomes with limited resources.

2.10.3 Publications

Nordberg et al. (2019) An evaluation of nest predator impacts and the efficacy of plastic meshing on marine turtle nests on the western Cape York Peninsula, Australia, Biological Conservation,Volume 238

Healthy Country AI open source software – https://github.com/microsoft/HealthyCountryAI

Nestor iPad application – http://itunes.apple.com/app/nestor/id995605741?mt=8&uo=4&at=11l9z8

2.11 Impacts of pigs on terrestrial fauna (CSIRO)

2.11.1 Introduction

Tropical savanna ecosystems are seasonally variable and the annual influence of a short intense monsoon followed by a long hot dry season can drive annual compositional turnover of species between seasons and across years (Andersen et al. 2005). Many species change their behaviours and geographic location to pursue resource availability (Franklin 1999, Coops et al. 2009). For mobile species, it is possible to follow changing resources and retreat to refugial areas, for example, large-scale seasonal annual migration of some species (Baker 1978). For these species, significant landscape-scale modifications such as tree clearing are required to disrupt ecological processes (Andrews and O'Brien 2000) and these large-scale processes have become the focus of global conservation efforts, for example reforestation and habitat corridors (Barrett and Barrett 1997). For species with small home ranges or those with very specific habitat requirements, subtle changes to habitat at very local scales (hectares or square metres) can have a profound influence on species composition and abundance (Read and Cunningham 2010). These impacts manifest at much smaller scales requiring a more detailed understanding of ecological processes to tease apart the impact of natural processes on species distribution and patterns as opposed to threatening processes.

In the largely intact ecosystems of the northern Australian savanna one of the most prominent threatening processes is the impact of invasive mammals such as pigs, cattle (*Bos sp*.) and Asian water buffalo (*Bubalis bubalis*). These species require daily water intake, meaning impacts are centred on natural wetlands and more specifically waterholes within wetland features. The conspicuous impact of pigs, buffalo and cattle on wetland ecosystems consistently places them on top of the threatening process list. However, very little research has been done to link feral pig damage with elements of biodiversity and there is no published research that investigates impacts on vertebrate fauna communities.

Conceptually, birds, small mammals, reptiles and amphibians should respond to altered cover as there are published relationships between cover, structure and vertebrate composition and abundance in this region.

2.11.2 Methods

2.11.2.1 Study sites

Study sites were located within the Archer River catchment, Cape York Peninsula, Queensland, Australia (Figure 21). Twenty-eight sites were established which were surveyed between one and five times, giving a total of 84 separate surveys. Sixteen sites were located within the lower reaches of the Archer River catchment on Indigenous owned land at APN and 12 were in the middle reaches of the catchment on the Kalan Land Trust (Figure 28).

The study area is located within a matrix of tropical savannas characterised by strongly seasonal rainfall patterns: there is a distinct dry season from April to December, with a monsoon driven wet season usually commencing late December to early January. Average annual rainfall across the study area is from 1,000 to 1,500 mm, with most typically falling between the months of December and March (30-year average: bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp?period=jan&area=qd).

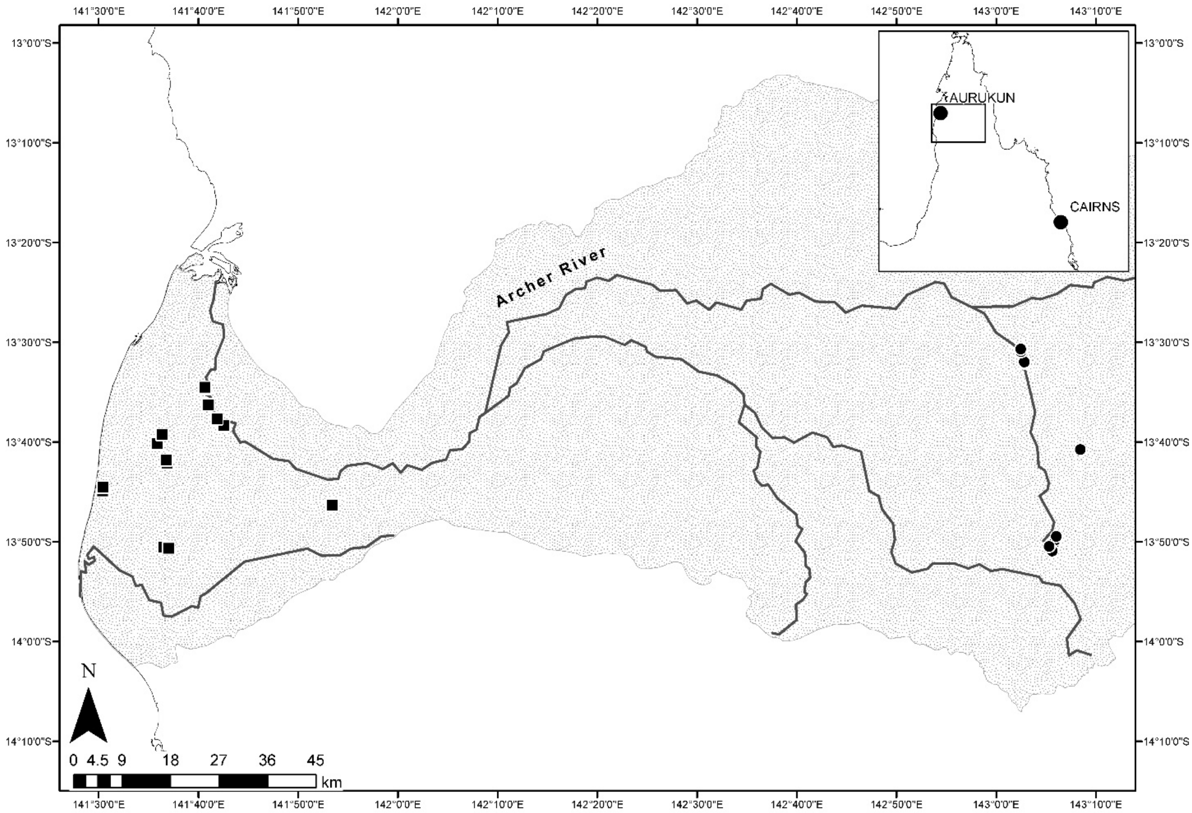


Figure 28. Map showing locations of wetland fauna monitoring sites on Cape York Peninsula. Squares in the west are sites on APN land and circles in the east are on Kalan Land Trust.

2.11.2.2 Sampling

Vertebrates

Sites were samples for vertebrate fauna over a 5-day/4-night survey period using a combination of trapping methods and timed and area-constrained searches. Each of these has potential biases in terms of detectability, which are covered in the discussion.

Pitfall traps (20 L buckets; 400 mm deep) were constructed using 10 m drift fences within 1 m of the water's edge, 2–4 metres beyond the edge of the wet soil, and in the driest (highest altitude) woodland within the treatment. Two funnel traps were placed at each end of the drift fence, set flush with the ground and against the drift fence to reduce the likelihood that animals would avoid the entrance to the funnels.

Twenty small Elliott traps and two cage traps were placed in a 50 x 50 m square if there was sufficient room within the treatment area, or in an irregular shape surrounding the target wetland if there was insufficient space to allow the 50 x 50 m arrangement. All Elliott and cage traps were baited with a mix of peanut butter, oats, vanilla essence and honey and a small handful of dry dog food. All traps were checked at least twice a day, including once in the early morning.

Standardised active searches for amphibians and reptiles were conducting using two methods.

Firstly, we conducted 20 × 1 minute, 1 m^2 visual searches at night. A lightweight, rigid aluminium 1 m^2 quadrant was carefully placed on the ground and thoroughly searched in this methodology. Searches involved kneeling on the ground and observing the ground surface, turning leaves, rustling through ground vegetation and turning clods of mud. Frequently, frogs would hop away when the quadrant was first placed on the ground. Where possible, these were identified and counted as 'in'. The quadrant searches were separated by wandering 10 paces and were not targeted for any particular vegetation cover or ground layer cover. They were designed to be random but trials using randomly placed points in ArcGIS, dividing the billabong perimeter length by 10 to get a distance between samples, proved too inaccurate for the handheld GPS units we were using in the field. The 20 searches were divided into 10 in the wet soil immediately adjacent to the water's edge (when water was present), 5 in a drier zone adjacent to this, and five in the driest zone available within the treatment area. When water was not present, the searches were conducted in the lowest area (10), mid-elevation area (5), and highest elevation area within the site (5).

Second, we conducted 10-minute spotlight searches, twice (different nights and rotated by time), using Led-Lenser head torches to detect animal 'eye shine'. Although eye shine was the primary target of this methodology, any vertebrates observed (e.g. by hearing them hopping off, or seeing the animal without seeing its eye shine), were also recorded. This methodology focused on species close to or on the ground, that is, it did not target arboreal frogs and nocturnal mammals and birds, although these were recorded if observed. For this methodology, distance to the animal at first detection was estimated using paces, which were calibrated for each observer against a tape measure. This methodology gave us a frequency of distance to detection by species.

To sample bird communities, eight 10-minute bird counts were conducted within a 1 ha area centred on the water's edge in the vicinity of the Elliott traps, or, if no water was present at the time of the survey, in a 1 ha area centred around the Elliott trap array. Timing of bird counts was rotated to reduce early morning (i.e. favourable condition) bias.

Results from all survey methods were pooled by treatment and species. For the overall species by site table, surveys from each location were pooled. The methods listed above are for each survey. Since some sites had more survey than others, the total numbers obtained for each species were averaged across the surveys.

Our drift fence and funnel arrays are designed to reduce visual sampling bias between treatments but may also be inherently biased. Because they rely on animals moving in order to be caught, to allow direct comparison between treatments assumes equal degrees of movement in open (pig-damaged) areas versus complex vegetated areas. This assumption may or may not be valid because, for example, animals in thick vegetation may feel more secure and thus move less, or they may feed more readily causing them to move more. Our drift fence/funnel methodology may also be less effective at catching certain species versus others. For example, striped rocket frogs (*L. nasuta*) which can jump metres, and are large, versus *Crinia* spp. which are small and although they may be able to jump or climb over the drift fence, are assumed to not do so readily.

2.11.2.3 Analysis

All sites were assigned to various categories as follows:

1. A typology category was assigned to each wetland in the manner of (Glanville et al. 2019). This used factors such as permanence of the water, influence of the ocean, and vegetation characteristics to group wetlands. Eight typologies were represented in the wetlands sampled for this study. Brief descriptions, from Glanville et al. (2019) are as follows:

   1 – Permanent or near-permanent waterhole proximal to shade and preferred consumptive plant species
   3 – Permanent or near-permanent waterhole proximal to shade and other plant species
   4 – Predictably intermittent waterhole proximal to shade and preferred consumptive plant species
   6 – Predictably intermittent waterhole proximal to shade and other plant species
   7 – Unpredictably intermittent waterhole proximal to shade and preferred consumptive plant species
   9 – Unpredictably intermittent waterhole proximal to shade and other plant species
   10 – Permanent or near-permanent waterhole proximal to preferred consumptive plant species
   19 – Oceanic influenced waterhole

2. Regional ecosystem (RE) classification (Accad et al. 2006; Sattler and Williams 1999), cross checked against floral community properties observed in the field. Some mapped RE categories did not match the vegetation communities observed on the ground. In these instances, RE classifications were chosen that better matched the actual community.

   3.3.10 – *Melaleuca argentea* and/or *M. fluviatilis* +/- *M. leucadendra* open forest or *Melaleuca saligna* open forest fringing streams and creeks

   3.3.14 – *M.saligna* +/- *M. viridiflora*, *Lophostemon suaveolens* woodland on drainage swamps

   3.3.20 – *Corymbia clarksoniana* +/- *Erythrophleum chlorostachys* +/- *M.viridiflora* woodland on alluvial plains

   3.3.43/3.3.10 – *M.viridiflora* +/- *Xanthorrhoea johnsonii* low woodland on fans and alluvial plains; and see 3.3.10 above

   3.3.49 – *M.viridiflora* low open woodland on low plains

   3.3.63 – *Eleocharis dulcis* dominated closed sedgeland on seasonally flooded marine plains

   3.3.65 – Ephemeral lakes and lagoons on alluvial plains and depressions

   3.3.66 – Permanent lakes and lagoons, frequently with fringing woodlands or sedgelands

3. All sites were given a fencing classification, based on the type of fence in place.

   nil – These sites were unfenced at the time of the survey

   pig – These sites had pig exclusion fences entirely enclosing the area in which the survey was conducted. Fences were constructed using 10 × 10 cm galvanised wire 900 mm high, with a tensioned 9-gauge fencing wire and a strand of barbed wire top and bottom, plus a further barbed wire strand 15 cm above the top of the mesh section.

   cattle – These sites had four strand barbed wire fences entirely enclosing the area in which the survey was conducted, thus excluding cattle, but allowing entry and exit to the wetland by pigs.

4. Fences sometimes failed to perform their exclusion function (Negus et al. 2020). This was usually because of tree falls over the fence. Because of this, a damage score was calculated and sites of differing pig or cattle damage, and both pig and cattle damage combined were classified into four classes:

   no damage ('0')

   >0 ≤1 = light ('1')

   >1 ≤2 = moderate ('2')

   >2 ≤3 = severe ('3')

Also, some sites were inaccessible at times because of weather conditions and traditional land access issues. For this reason we analysed sites using aggregated data from each site, divided by the number of visits. We also undertook the same analysis using just one visit's data from each site, for each of summer and winter.

For analysis of species composition we excluded rare taxa because their presence or absence may be a matter of chance and their inclusion may generate noise, potentially masking patterns in the analysis (Clarke and Warwick 1994). We defined rare taxa as those detected in less than 5% of surveys from any site and time, and species contributing less than 1% of the total number of individuals in any single sample. This definition of rarity provides a useful compromise between acknowledging that globally rare species may contribute to some sites in large numbers, while not being ubiquitous across the landscape (Clarke and Warwick 1994).

For the analysis we aggregated data for certain species:

- species that are visually and functionally indistinguishable (*Crinia deserticola* + *C. remota* = CRINSP; *Uperoleia lithomoda* + *U. mimula* = UPERSP) when we knew both species were in a given waterhole because their calls had been heard
- species that we know to be present in an area but which frequently jumped away before definitive identification was possible (*Litoria inermis* + *L. latopalmata* + *L. pallida* = LITOSP)
- species where field identification characters can be difficult to determine without capture and careful examination (*Melomys burtoni* + *M. capensis* = MELOSP, *Rattus sordidus* + *R. tunneyi* = RATTSP).

Variation between sites in species composition was examined by multidimensional scaling (MDS) in two dimensions, derived from Bray-Curtis association (dissimilarity) indices using square-root transformed species abundance, and presence/absence for each class of vertebrates (mammals, birds, reptiles, amphibians). MDS graphs give a visual representation of similarity between sites based on their species composition.

For each vertebrate class we undertook analysis of similarity (ANOSIM) to identify site groups based on species composition. ANOSIM statistically compares pair-wise R values, to measure similarity between sites. R is distributed around zero with zero indicating completely random grouping, while the higher the value for R the greater the separation of replicates between groups (Clarke and Gorley 2006). For the purposes of reporting overall richness and abundance, we used all species that were able to be identified to species.

Because the responses of fauna had potential to also be influenced by other unmeasured stressors, particularly as the study was conducted at multiple wetlands with no prior data on patterns in their faunal variability, we used quantile regression to estimate the effects of feral pig damage as a limiting factor to fauna metrics (Cade and Noon 2003; Brooks and Haeusler 2016). The quantile regression approach followed Steward et al. (2018) to determine linear regression functions between the limiting factor and the proportion of the measured response data points (equivalent to the quantile) that fall below the regression line (Brooks and Haeusler 2016). A quantile (tau) of 0.85 was adopted as the maximum quantile for 37 samples based on the power recommendations of Rogers (1992), where: maximum quantile < 1 – (5/number of sites). We calculated linear quantile regression functions to describe the lowest significant quantile regressions between taxon richness and square root (x + 1) abundance with pig damage score, up to a maximum of tau=0.85, using the rq function within the quantreg package using R software (R Core Team, 2013).

2.11.3 Results

Approximately 250 species of vertebrate fauna were recorded. This comprised 19 species of mammal, 165 birds, 40 reptiles and 24 amphibians.

Very small species (*Crinia* spp.; SVL <10 mm) were rarely recorded record during the 10-minute spotlight searches. Larger species such as rocket frogs and some tree frogs (e.g. *Litoria inermis*, *L. nasuta*, *L. rubella*; SVL usually ~40 mm), tree frogs (e.g. *L. infrafrenata*; SVL usually ~120 mm) and cane toads (*Rhinella marina*; SVL up to 160 mm) were recorded by eyeshine at distances from 3 m to 42 m.

Insufficient numbers of mammals were observed or captured to test for differences in community response between the sites. Mammals are not reported on any further except as reporting species and abundance.

For our nMDS on amphibian, reptile and bird abundance, we found no clustering based on the factors related to pig and cattle scores at the sites. Rather, clustering of sites was strongly associated with landscape variables. Firstly, location was a good predictor of similarity between sites. The closer two sites are, the more likely they are to be similar to one another. Secondly, species similarity was influenced by waterhole and vegetation types (corrected regional ecosystem classification) (Figure 29). This clustering suggests non-independence, and this is almost certainly the case with some of the waterholes, especially with highly mobile species like birds. However, less mobile species such as small frogs also clustered in a similar manner (Figure 29, top right).

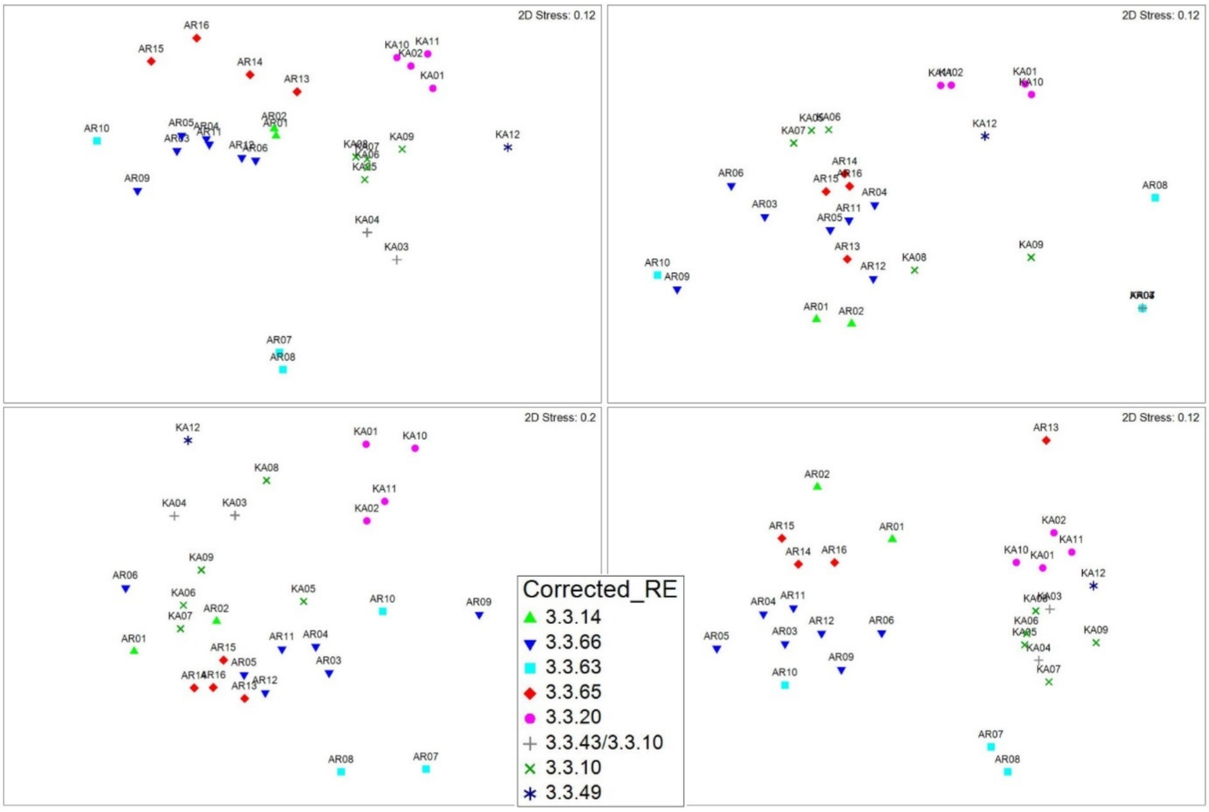


Figure 29. All nMDS plots, square-root transformed data, using Bray-Curtis similarity index; all fauna, both seasons, standardised by number of surveys per site (top left). Single summer surveys; amphibians only (top right), reptiles only (bottom left), birds only (bottom right).

For our analysis of similarity (ANOSIM), there were no significant differences between sites based on factors of damage class or fence type, but there were significant differences between sites based on landscape factors such as the wetland typology, RE classification and broad location (Table 1).

Table 1. Showing differences in sites based on factors. Significant correlates of the fauna communities (amphibians, reptiles, birds and all species combined) are in bold.

	Amphibians		Reptiles		Birds		Combined	
Factor	R statistic	P value	R statistic	P value	R statistic	P value	R statistic	P value
Damage class	-0.096	NS	-0.023	NS	0.14	NS	0.004	NS
Typology	**0.8**	**< 0.01**	**0.331**	**< 0.01**	**0.728**	**< 0.01**	**0.588**	**< 0.01**
RE	**0.579**	**< 0.01**	**0.504**	**< 0.01**	**0.769**	**< 0.01**	**0.855**	**< 0.01**
Location	**0.257**	**< 0.01**	**0.304**	**< 0.01**	**0.646**	**< 0.01**	**0.617**	**< 0.01**
Fence	0.08	NS	0	NS	0.054	NS	0.03	NS

None of the quantile regression models (tau=0.5, 0.80, 0.85) were significant for richness ($p<0.05$) or for abundance ($p<0.05$) (Table 2, Figure 30). This indicates that the richness and abundance of terrestrial fauna were not limited by the intensity of pig damage to wetland margins.

Table 2. Quantile regression analysis results (tau=0.85) for a) taxon richness and b) square root (x + 1) transformed taxon abundance. Neither was significant (p>0.05).

Coefficients	Value	Standard Error	t value	Pr(>|t|)
a) Richness				
Intercept	15.4	3.86	3.98	0.00
Pig damage intensity	-0.07	2.18	-0.03	0.97
b) Square root (abundance + 1) (tau=0.85)				
Intercept	15.4	3.59	4.28	0.00
Pig damage intensity	-0.07	2.21	-0.03	0.97

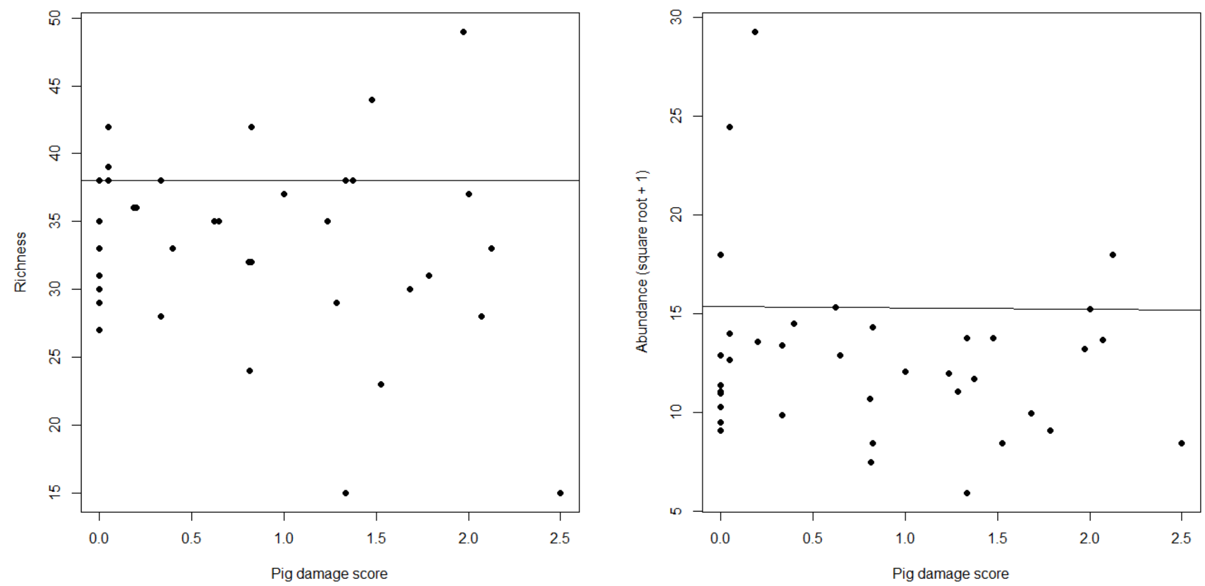


Figure 30. Quantile regression results for (a) fauna taxon richness and (b) fauna square root (abundance + 1) in relation to pig damage intensity. Neither of the tau=0.85 quantile regressions (solid lines) were significant (p>0.05).

Abundance and richness by waterhole type

The abundance and richness of all taxa was driven by waterhole type with type 1 (permanent or near-permanent waterhole proximal to shade and preferred consumptive plant species – Figure 31) supporting the greatest diversity and abundance (11,922 individuals from 152 species – Figure 32 left) compared with the less productive ephemeral type 9 (unpredictably intermittent waterhole proximal to shade and other plant species – Figure 31 right) supporting far fewer species (69) and abundance (487) (Figure 32 right).

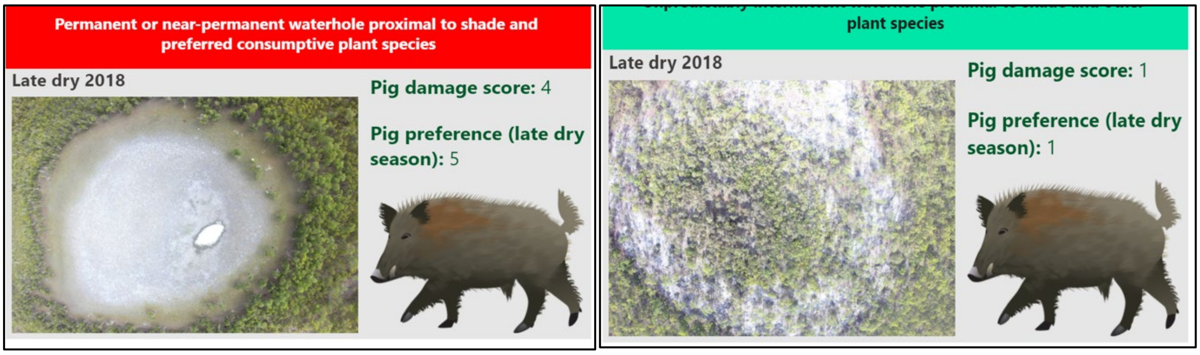


Figure 31. Example of late dry-season state of waterhole type 1 (left) and waterhole type 2 (right) without feral pig exclusion fencing. Note that type 1 is permanent or semi-permanent and should be dominated by preferred consumptive food plants (e.g. Elocharis *sp.). Here pig damage is high and no cover remains.*

Figure 32. Terrestrial vertebrate abundance and richness for waterhole type 1 (left) and waterhole type 9 (right).

The pattern repeats across the taxa when comparing late dry-season results. Bird abundance is more than 50 times higher and richness more than twice as high in type 1 compared to type 9 (Figure 33). No mammals were recorded in type 9 in the late dry season and over 12 different species were recorded in type 1, relatively high richness for Australian savanna ecosystems (Figure 34). Amphibians were more than twice as diverse in type 1 and almost five times more abundant (Figure 35). Reptiles were twice as diverse and around three times more abundant in type 1 (Figure 36).

Figure 33. Bird abundance and richness in type 1 (left) and type 9 (right).

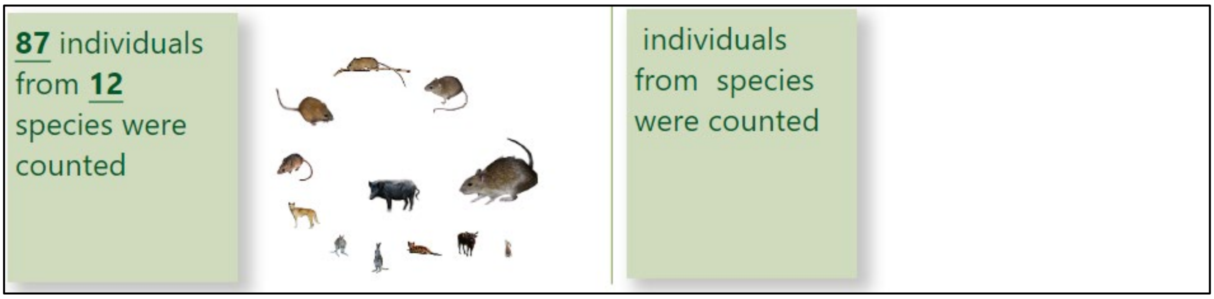


Figure 34. Mammal abundance and richness in type 1 (left) and type 9 (right).

Figure 35. Amphibian abundance and richness in type 1 (left) and type 9 (right).

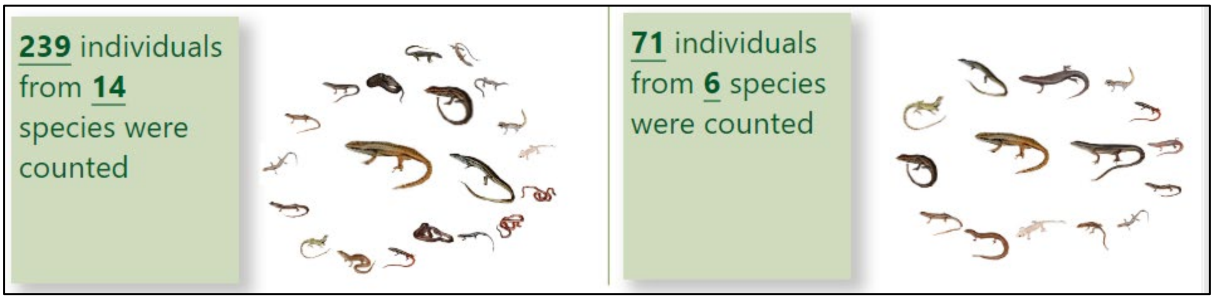


Figure 36. Reptile abundance and richness in type 1 (left) and type 9 (right).

The richness and abundance for each taxa above reflects the difference between these two types in the late dry season when conditions are at their most harsh. However, when considering the same waterhole type comparison in the early dry season, when water is not a limiting factor, type 9 remained depauperate demonstrating the inherent differences between these two sites. Abundance across all species was six times higher and richness was 1.5 times higher in site 1 compared with site 9 in the early dry season (Figure 37).

Figure 37. Early dry-season terrestrial vertebrate abundance and richness for waterhole type 1 (left) and waterhole type 9 (right).

2.11.4 Discussion

Vertebrate fauna

Our analysis of vertebrate fauna composition in wetlands impacted by feral pigs within the Archer River catchment indicated that controlling for natural species turnover is required before pig impact can be quantified.

For all taxa our data suggest that presence of pigs and cattle and the damage they cause is not a significant influence on vertebrate community composition when compared to other environmental factors. Geographic location, vegetation type, and the type of waterhole were more important predictors of species composition and abundance than feral pig impacts. This result seems counterintuitive given the extreme visible impact evident at sites where pigs are present. Our hypothesis is that the extreme natural variation in resources between wet and dry seasons presents a far greater insult than any damage caused by pigs. For amphibians, all the species are r-selected characterised by explosive, early wet-season breeding and relying on ephemeral waterholes in which to breed. They use mass breeding as a strategy to produce millions of young to compensate for significant mortality due to desiccation and depredation. The depredation by feral pigs during this period is likely to be inconsequential considering the number of young produced. Most of the species are agile as they are adapted for avoiding predatory birds and are likely to be able to escape from foraging pigs. Although commonly stated as a key threat, and demonstrated through photographic evidence, frog depredation by pigs has not been quantified in northern Australia.

Frogs seem obvious candidates for impact by pigs and cattle, because of the damage (‘pugging’) to wetlands that result from trampling and feeding. However, on Cape York Peninsula the frogs are largely adapted to a seasonal boom–bust cycle because most waterholes we sampled dry out completely on an annual basis. There was no significant difference between frog abundance and richness on pig-excluded wetlands compared with pig-impacted wetlands. Frogs were observed in deep pig wallows and in heavily impacted sites emerging or retreating to soil cracks that led to moist soil beneath the drying waterholes.

For reptiles and birds the situation may be similar, perhaps with even less effect because they are generally more mobile than frogs and do not rely on wetlands to breed. In our surveys we found wetland type was the primary driver of compositional turnover rather than feral pig impact.

The fact that we could not detect significant difference in vertebrate fauna communities based on the damage caused by pigs and cattle does not mean that these feral species do not have an effect. Effects on littoral invertebrates at the same study sites have been demonstrated (Steward et al. 2020), and severely pig-damaged wetlands resemble dried concrete at the end of the dry season compared with dried soil, often covered by fallen herbaceous vegetation, for undamaged wetlands. This is likely to support higher soil moisture across the year which we did not measure as part of our surveys.

2.11.5 Recommendations

A deeper analysis of the effects of pig and cattle damage on vertebrate fauna in our study region would require a strengthened study design. We recommend that future research should use waterhole typology mapping (see section 3 below) and field survey to select at least six replicates of the same waterhole type with similar pig damage in proximity prior to treatment. Three of the selected waterholes should be fenced to exclude pigs (treatment) and three left exposed to pig impact. Vertebrate fauna should be sampled in the early dry season and late dry season at all wetlands prior to fences being applied to expose the natural variability between sites. Fauna composition and abundance should be similar between the sites prior to treatment. Once fenced, sites should be surveyed annually in the early dry season and late dry season for at least three years to account for lag effects in species recovery. Careful maintenance of the fencing and detailed assessment of the nature of the damage caused (or prevented) are also required.

In this study we exposed the difficulty of maintaining fences as an experimental treatment in the remote and challenging landscapes of northern Australia. Our fences were in areas that are seasonally inundated via flash flooding, are dominated by woodlands and forests that burn annually, are prone to tidal influence and are impacted by tropical cyclones during the wet season. These factors combine to destroy fences, primarily by causing trees and limbs to fall on wires but also through the deposition of debris during floods and rusting of wires and pickets following saltwater ingress. Any breach in the fence was quickly located and exploited by feral pigs, leading to extensive wetland damage (Negus 2019). Future research should be cognisant of the difficulties of maintaining feral pig exclusion and place a high priority on fence maintenance and repair throughout the year, requiring resourcing for continuous and regular surveillance.

3. Wetland/waterhole typologies for the Archer River basin (DES)

3.1 Introduction

Recent work has generated a waterhole classification scheme (DES 2017) consistent with the national interim Australian National Aquatic Ecosystem Classification scheme. The waterhole classification scheme underpinned the development and pilot implementation of a new waterhole typology for northern Australia. The purpose of the new waterhole typology is to support modelling of the spatial and temporal distribution of feral pigs to identify places and times of maximum vulnerability to control measures. A critical aspect of this waterhole typology is the dry-season location of freshwater 'refuges'. In northern Australia, these refuges comprise such places as permanent wetlands, river waterholes and groundwater-dependent ecosystems. Currently, the necessary mapping information to apply this waterhole typology and to understand water and food availability through space and time, and at scales relevant to pigs, is lacking. This project used a combination of existing Queensland Government data, time-series remote sensing data, and field data from the Archer River generated by project 2.5 (Defining metrics of success for feral animal management in northern Australia).

3.2 Background

The following background information was provided to the Queensland Herbarium at the commencement of this project to underpin the development of data products.

3.3 Attributes and attribute categories

Five attributes of waterholes were identified as relevant to the distribution of feral pigs (Table 3) and three to four categories were identified for each attribute.

Table 3. Attributes of waterholes and attribute categories that correlate with pig presence and density.

Attribute	Attribute category
Surrounding vegetation as a food source	Grass, herb and sedge
	Trees and shrubs
	Unknown
Water permanence in the landscape	Permanent
	Near-permanent
	Intermittent
	Unknown
Accessibility of waterhole	Steep
	Not steep
	Unknown
Available shading	High
	Low
	Unknown
Oceanic influence of waterhole	Yes
	No
	Unknown

3.4 Typology

These five attributes of waterholes were used as the basis for a typology relevant to feral pig distribution (Table 4). Further clarification indicated that the difference between 'intermittent 1' and 'intermittent 2' was the predictability of water availability.

Table 4. Waterhole typology compiled using attributes of waterholes that correlate with pig presence and density.

Oceanic influence	Shading	Permanence of water	Surrounding vegetation	Accessibility
No	High	Permanent, near-permanent	Grass, herb and sedge	High
				Low
			Other	High
				Low
		Intermittent 1	Grass, herb and sedge	High
				Low
			Other	High
				Low
		Intermittent 2	Grass, herb and sedge	Any
			Other	Any
	Low	Permanent, near-permanent	Grass, herb and sedge	High
				Low
			Other	High
				Low
		Intermittent 1	Grass, herb and sedge	Any
			Other	Any
		Intermittent 2	Grass, herb and sedge	Any
			Other	Any
Yes	Any	Any	Any	Any

3.5 Refining attributes

In consultation with CSIRO, four of the original five attributes of waterholes (Table 5) were selected for the final typology product and two to three categories identified for each attribute. The removal of accessibility was based on the mismatch with the proposed mapping scale. The addition of a new attribute category for 'surrounding vegetation as a food source' was based on gathered expert knowledge on the preferred plant species for consumption by feral pigs.

Table 5. Attributes of waterholes and attribute categories that correlate with pig presence and density.

Attribute	Attribute category
Surrounding vegetation as a food source	Preferred flora species (e.g. *Eleocharis* sp.) dominated ecosystems
	Grasses, herbs and sedges
	Other (e.g. trees and shrubs)
Water permanence in the landscape	Permanent and near-permanent
	Intermittent 1
	Intermittent 2
Available shading	High
	Low
Oceanic influence on waterhole	Yes
	No

3.6 Applying a typology for feral pigs

The final applied typology (Figure 38) identifies 19 theoretical types of waterholes and reflects the changes detailed in 'attributes' and a further two types related to inundation.

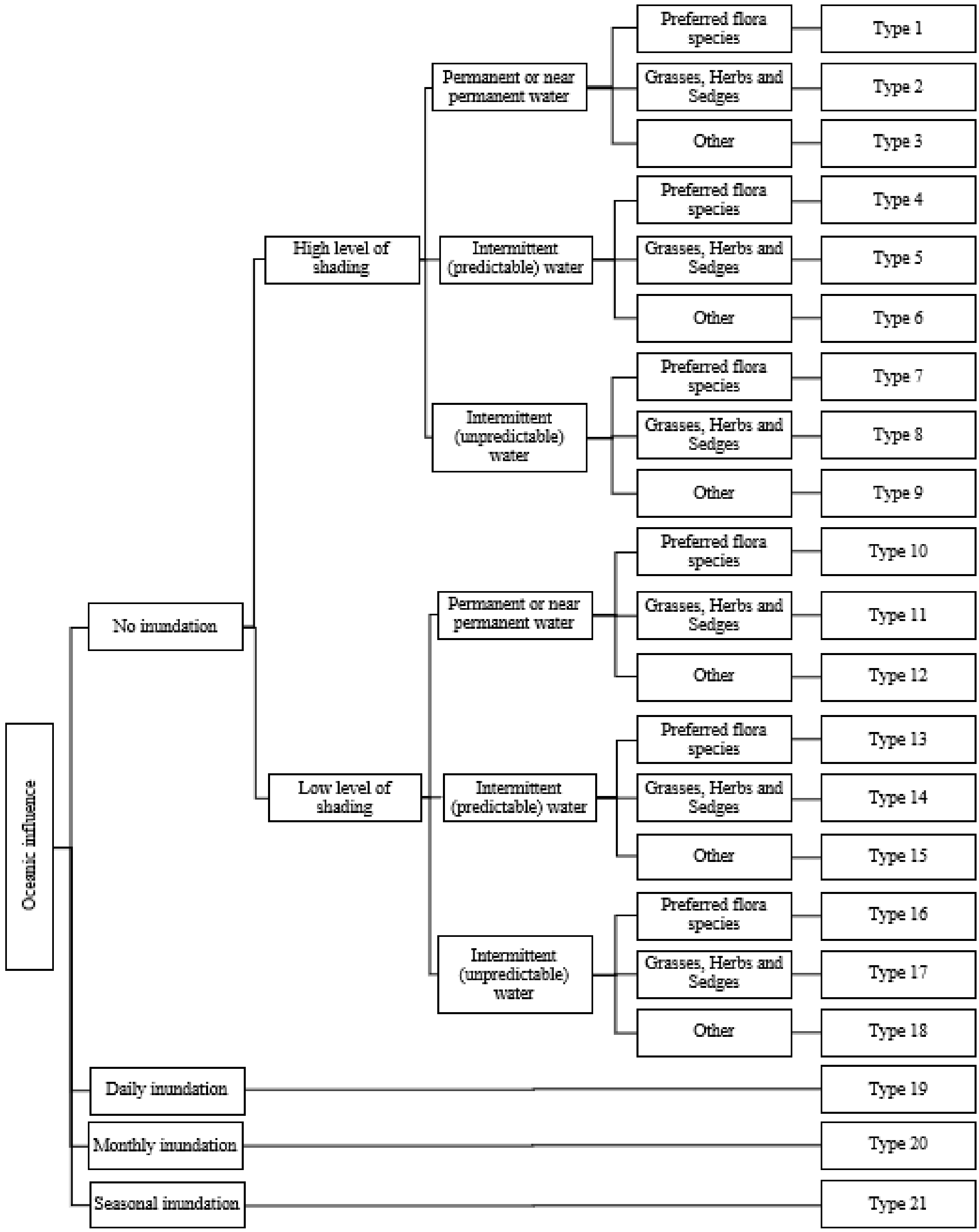


Figure 38. Hierarchical application of attributes for the waterhole typology of northern Australia to support feral animal management.

3.7 Product specifications

3.7.1 Source data

Data was compiled (Table 6 and Table 7) to represent each attribute.

Table 6. Attributes of waterholes, attribute categories, spatial delineation guidance and source data.

Attribute	Attribute categories	Spatial delineation guidance	Source data
Surrounding vegetation as a food source	Preferred flora species (e.g. *Eleocharis sp.*) dominated ecosystems	Select the following regional ecosystems: 3.1.6b, 3.2.27x1a, 3.2.27x1c, 3.3.58, 3.3.63 (and all vegetation communities), 3.3.65 (and all vegetation communities), and 3.3.66.	Biodiversity Of Remnant Regional Ecosystems (V11.1 with manual refinements) Queensland Wetland Data (V4)
	Grasses, herbs and sedge	Biodiversity Of Remnant Regional Ecosystems (V11.1 with manual refinements) Queensland Wetland Data (V4)	
	Other (e.g. trees and shrubs	All remaining areas of the Archer River drainage basin	
Water permanence in the landscape	Permanent or near-permanent	Water detected in at least 30% of clear observations between 1987 and present.	Water detected in between 0% and 5% of clear observations between 1987 and present.
	Intermittent 1	Water detected in between 5% and 30% of clear observations between 1987 and present.	
	Intermittent 2	Water detected in between 0% and 5% of clear observations between 1987 and present.	
Available shading	High	1. Select the following regional ecosystems: 3.2.2a, 3.2.3 (and all vegetation communities), 3.2.4x1, 3.3.50 (and all vegetation	Biodiversity Of Remnant Regional Ecosystems (V11.1 with manual refinements) Queensland Wetland Data (V4) Persistent

		communities), and 3.3.50x1. 2. Select Persistent Seasonal Greenness Cover of 30% over a minimum 10% of the defined area.	Seasonal Greenness Cover Class (V1
	Low	Biodiversity of remnant regional ecosystems (V11.1 with manual refinements) Queensland Wetland Data (V4) Persistent Seasonal Greenness Cover Class (V1	
Oceanic influence on waterhole	Yes	Select tidal flats and beaches (land zone 1), estuary, ocean, and wetlands with tidal water regime.	Biodiversity Of Remnant Regional Ecosystems (V11.1 with manual refinements) Queensland Wetland Data (V4)
	No	All remaining areas of the Archer River Queensland Wetland Data (V4) drainage basin.	

The thresholds presented in the spatial delineation guidance section for the attribute 'water permanence in the landscape' were developed based on expert knowledge of the landscape including benchmarks against known permanent lakes and known predictably intermittent wetlands.

Table 7. Source data.

Source data	Link
Biodiversity Of Remnant Regional Ecosystems (V11.1 with manual refinements that will be incorporated into V12)	https://data.qld.gov.au/dataset/biodiversity-status-of-pre-clearing-and-2017-remnant-regional-ecosystems-queensland-series
Persistent Seasonal Greenness Cover Class (V1)	http://data.auscover.org.au/xwiki/bin/view/Product+pages/Landsat+Seasonal+Persistent+Green
Queensland Wetland Data (V4)	https://data.qld.gov.au/dataset/wetland-data-version-4-queensland-series
Water Observations from Space	https://www.ga.gov.au/scientific-topics/hazards/flood/wofs

3.7.2 Attribution

Source data (Table 7) was analysed to attribute each waterhole with the relevant attribute category (Table 8).

Table 8. Attribute of waterholes, field name, attribute category, and field value.

Attribute	Field name	Attribute Category	Field value
Surrounding vegetation as a food source	SURR_VEG	Preferred flora species (e.g. *Eleocharis* sp.) dominated ecosystems	2
		Grasses, herbs and sedges	1
		Other (e.g. trees and shrubs)	0
Water permanence in the landscape	WTR_PERM	Permanent or near-permanent	2
		Intermittent 1	1
		Intermittent 2	0
Available shading	Shade	High	1
		Low	0
Oceanic influence on waterhole	Tidal	Yes	1
		No	0

3.8 Water permanence in the landscape

Water permanence information was obtained from two sources: analysis of satellite imagery time-series and field observations. First, an analysis of Water Observations from Space was conducted using expert defined thresholds benchmarked against known permanent and predictably intermittent wetlands. The Water Observations from Space product has several limitations: the Landsat satellites used to develop the product observe each place once every 16 days; the Landsat satellites are subject to cloud that further reduce temporal resolution of product; the automated surface water detection algorithm may erroneously detect large buildings, cloud shadow, large uniform black tarpaulins or snow as water; and the algorithm is also designed to locate large areas of water rather than small or narrow water bodies. Second, a total of 2,324 field observations of standing water were collected in 2018 during the driest season. These field observations provide supplementary information on permanent or near-permanent water in the landscape that is below the spatial resolution of the available satellite imagery time-series.

1. Generate a water permanence raster dataset applying the appropriate attribute categories and values to the Water Observations from Space data.
2. Enhance the water permanence raster data set with field observations.
3. Incorporate maximum water permanence information as a new attribute in wetland mapping.
4. Identify locations of water permanence (permanent or near-permanent, or intermittent 1) not captured in wetland mapping, and

    4a. if they meet the requisite mapping scale, incorporate into wetland mapping and attribute with regional ecosystem

    4b. if they do not meet the requisite mapping scale, incorporate into a complementary wetland mapping point dataset and attribute with regional ecosystem.

3.9 Oceanic influence on waterhole

Information on oceanic influence is obtained from the Biodiversity of Remnant Regional Ecosystems (V11.1 with manual refinements). Oceanic influence can be delineated as 'deposits subject to periodic tidal inundation' (land zone 1), estuaries and ocean in the Biodiversity of Remnant Regional Ecosystems data set. In addition, oceanic influence can also be delineated as tidally influenced wetlands in Queensland Wetland Data.

3.10 Surrounding vegetation as a food source

Information on surrounding vegetation as a food source is obtained from the Biodiversity of Remnant Regional Ecosystems (V11.1 with manual refinements) and Queensland Wetland Data (V4). Surrounding vegetation can be delineated based on regional ecosystem and regional ecosystem structure code. Where more than one regional ecosystem occurs within a defined area, the highest category is assigned to the polygon. For example, if two regional ecosystems occur within a defined area and one regional ecosystem is a preferred flora species and the other regional ecosystem is a grass, herb or sedge, the entire feature will be assigned to the preferred flora species category.

3.11 Available shading

Information on available shading is obtained from two types of sources: ecosystem data sets including Biodiversity of Remnant Regional Ecosystems (V11.1 with manual refinements) and Queensland Wetland Data (V4); and remote sensing derived data. Available shading was delineated based on Persistent Seasonal Greenness Cover (V1). This remote sensing derived data set is based on time-series of Landsat satellite imagery with a spatial resolution of approximately 30 metres. This remote sensing data was enhanced based on expert knowledge on available shade by regional ecosystem applied using Biodiversity of Remnant Regional Ecosystems (V11.1 with manual refinements) and Queensland Wetland Data (V4).

3.12 Waterhole typology

The above typology identifies 19 theoretical types of waterholes. The implementation of the above typology identified the presence of all 19 types of waterholes within the Archer River drainage basin (Table 9).

Table 9. Type of waterholes, working description and summary.

Type	Description	Food	Shade	Water	Tidal
1	Permanent or near-permanent waterhole proximal to shade and preferred consumptive plant species	Preferred			
2	Permanent or near-permanent waterhole proximal to shade and grass, herb or sedge plant species	GHS		P/NP	
3	Permanent or near-permanent waterhole proximal to shade and other plant species	Other			
4	Predictably intermittent waterhole proximal to shade and preferred consumptive plant species	Preferred			
5	Predictably intermittent waterhole proximal to shade and grass, herb or sedge plant species	GHS	Yes	Int1	
6	Predictably intermittent waterhole proximal to shade and other plant species	Other			
7	Unpredictably intermittent waterhole proximal to shade and preferred consumptive plant species	Preferred			
8	Unpredictably intermittent waterhole proximal to shade and grass, herb or sedge plant species	GHS		Int2	No
9	Unpredictably intermittent waterhole proximal to shade and other plant species	Other			
10	Permanent or near-permanent waterhole proximal to preferred consumptive plant species	Preferred			
11	Permanent or near-permanent waterhole proximal to preferred consumptive plant species	GHS		P/NP	
12	Permanent or near-permanent waterhole proximal to preferred consumptive plant species	Other			
13	Permanent or near-permanent waterhole proximal to preferred consumptive plant species	Preferred	No		
14	Predictably intermittent waterhole proximal to grass, herb or sedge plant species	GHS		Int1	
15	Predictably intermittent waterhole proximal to other plant species	Other			

16	Unpredictably intermittent waterhole proximal to preferred consumptive plant species	Preferred		Int2	
17	Unpredictably intermittent waterhole proximal to grass, herb or sedge plant species	GHS			
18	Unpredictably intermittent waterhole proximal to other plant species	Other			
19	Oceanic influenced waterhole	Any	Any	Any	Yes

3.12.1 Symbology

The proposed symbology presents three groups of waterholes based on water permanence (Figure 39 and Figure 40).

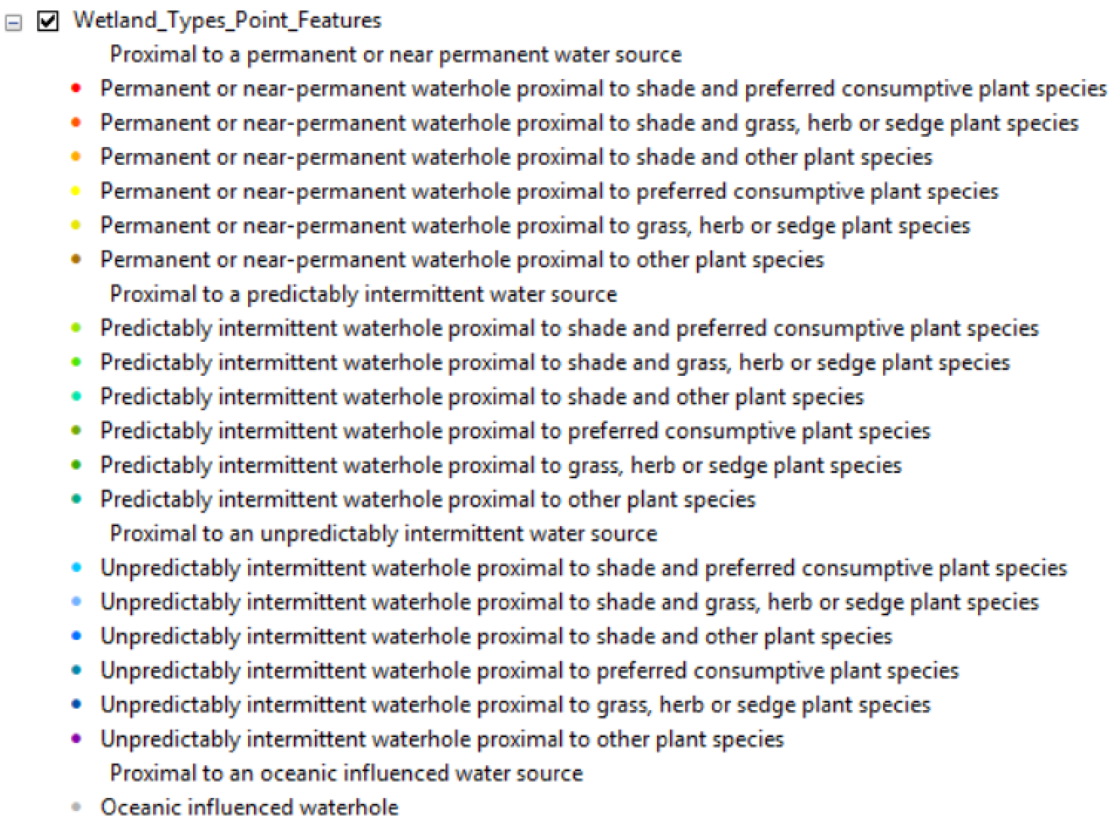


Figure 39. Proposed symbology.

Figure 40. Detailed colour mapping for the product.

In some instances, identified waterhole type may comprise over 80% of the delineated area, 51–80% of the delineated area, or less than 51% of the delineated area. Where the identified waterhole type comprises 51–80% of the delineated area, a hatched pattern is used for data visualisation (Figure 41). Where the identified waterhole type comprises less than 51% of the delineated area, a muted, lighter colour is used for data visualisation (Figure 41).

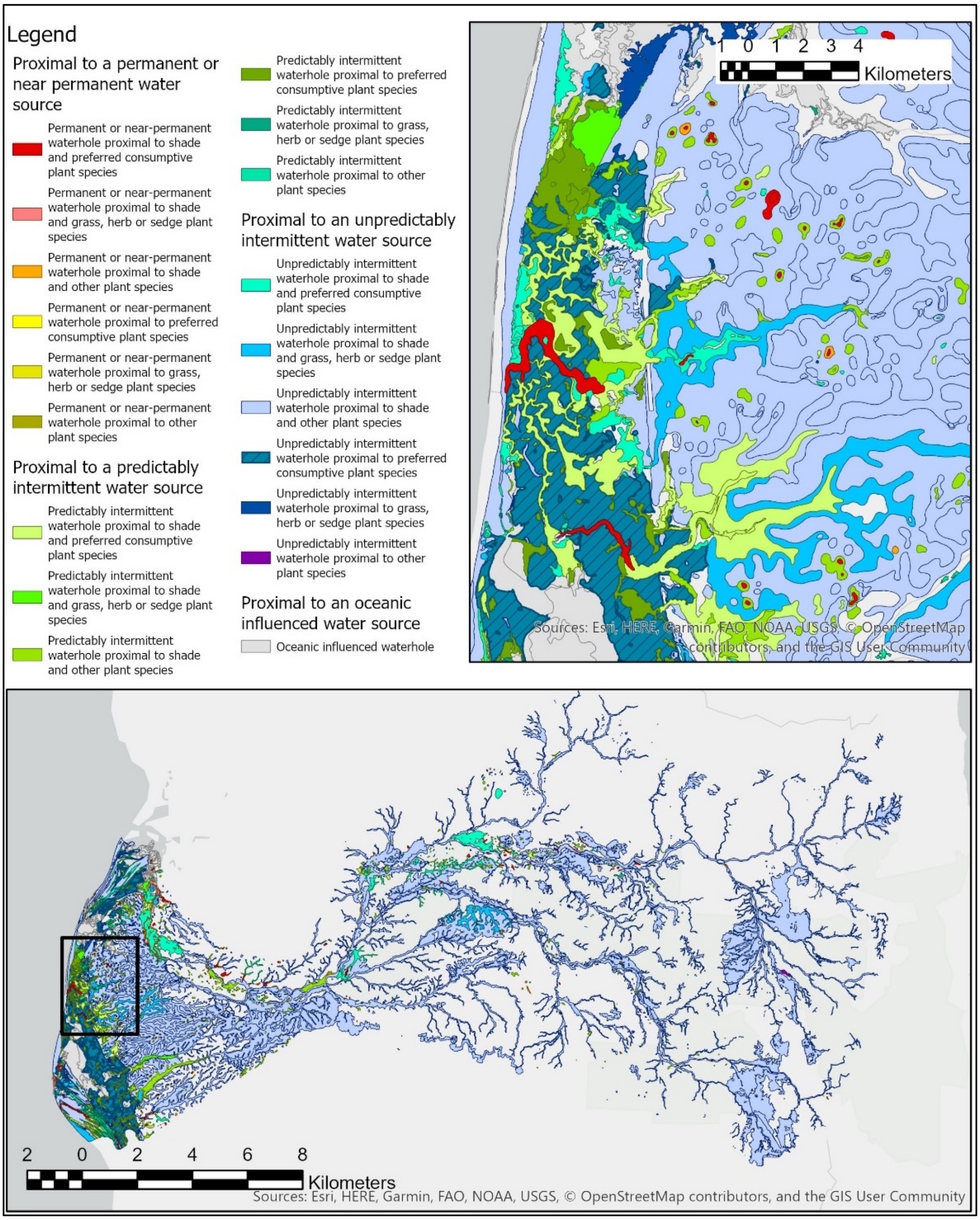


Figure 41. The spatial mapping product for the Archer River basin with a close-up illustrating the waterhole typology resolution with multiple waterhole types.

3.13 Recommendations

It is recommended that an assessment of the final typology presented in this document be reviewed by relevant experts with consideration for the outcomes of the typology's application to the Archer River catchment. For example, regional ecosystems that are tidally influenced are assigned to a single waterhole type. However, expert knowledge indicates that some of these tidally influenced ecosystems (e.g. 3.6.1b) may provide seasonally important habitat and food sources for feral pigs. This knowledge is not captured in the current typology.

3.14 Product disclaimer

This product provides information on the distribution of different types of feral pig habitat across the landscape. These types integrate information on feral pig habitat through time. This product may be used to guide target areas for control activities; however, its use should be supported by an assessment of high-resolution imagery to determine the specific location of feral pig habitat within the mapped area. This product is based on regional ecosystem maps and data (derived from extensive field survey, analysis of aerial photographs, satellite imagery and detailed site data, and assessment of other data such as geology and soil mapping and historical survey plans), wetland maps and data, and satellite imagery. The positional accuracy of this input data, mapped at a scale of 1:100,000, is 100 metres.

3.15 Management implications

Here we define a new method for characterising waterholes within wetlands in the context of feral animal ecological requirements. This provides a framework for site selection that can underpin the development of a robust monitoring program that accounts for ecological gradients which impact species turnover in time and space. We propose that this method is used to underpin future monitoring programs that aim to assess the impact of feral animals on aquatic systems.

3.16 Publications

Appendix 1. K Glanville, J. Perry, T. Ryan, M. Ronan, P. Zivec (in prep) Applying a versatile, comprehensive, attribute-based waterhole classification to ecosystem-based management challenges (journal TBC).

4. A cultural ecosystem service wetland typology to support wetland management on Wik Peoples' traditional lands.

4.1 Introduction

Ecosystem services (ESS) is widely understood as the resources, processes and conditions through which natural ecosystems confer benefits to humans and make life on earth possible (Bennett et al. 2015; Daily 1997; Diaz et al. 2015). In practice the ESS concept has become an integrated tool to guide decisions, largely associated with monetary valuation of ecosystems, to support decision-making for sustainable development (Hirons, Comberti, and Dunford 2016). The ESS concept has been highly effective in describing the dependent condition of human wellbeing on nature, but much is implicitly understood of the multiple roles that humans have in the ecosystem services framework as co-producers and beneficiaries of services (Jones et al. 2016).

Indigenous lands and waters in northern Australia have been managed for thousands of years by Indigenous peoples and hold some of the most biodiverse wetlands in Australia (Moritz 2013). Indigenous peoples have distinct relationships with water that shapes their identity, attachment to place and their custodial roles, as well as their subsistence activities which include hunting and fishing that are place-based and context-specific (Baker, Davies, and Young 2001, Flanagan and Laituri 2004, Jackson, Storrs, and Morrison 2005, Sheehan 2001). Much of these lands are of high conservation value and operate under partnership arrangements between Indigenous peoples and non-Indigenous practitioners (Austin et al. 2019; Moritz et al. 2013). This partnership presents a unique opportunity to combine management values that account for both the conservation and cultural dimensions of natural resources and also fulfil the multidimensional ethical and legal obligations of conservation partners (Duncan et al. 2018).

Increasingly, policy makers, research and natural resource practitioners are recognising the importance of incorporating social measures into environmental monitoring and management programs. A key challenge of adapting current reporting frameworks is the lack of consistency of social measures, which sway the process to under-report key issues. Social dimensions of conservation are often reported against living standards or access to and quality of environmental assets but limited consideration is given to culture (Corrigan et al. 2018; Sangha and Russell-Smith 2017). Recent developments of the ecosystem services framework places culture as an overarching driver of ecosystems services, making a direct link from people's wellbeing to cultural and provisioning services (Daniel et al. 2012; Diaz et al. 2015). In this paper we show how the explicit inclusion of CES to support management of wetlands in Cape York aids a more wholistic integrated approach of human ethics of care to sustain the environment and the services it provides, and the environmental services from which humans benefit.

In this sectopm we present a typology of Indigenous wetland types based on research undertaken with Wik Peoples in Cape York Peninsula. The typology developed from this work is based on the wetland values, uses and cultural practices that Wik Peoples shared with the research team. The typology is being verified with the APN board and Wik Peoples.

4.2 Methods

The fieldwork for this research was undertaken in the years 2017 to 2019 with Wik Peoples on their traditional lands south of the Archer River and north of Kendal River. A mix of informal interview methods was utilised for this research, including semi-structured questions, a rating questionnaire supported by qualitative discussions at waterholes and use of maps. The research consisted of several stages:

- A discussion with rangers and knowledge holders in Aurukun about wetlands, their locations on different traditional lands, past and present uses and values, and changes in the landscape including the effects of pigs. We spoke to knowledge holders and rangers from six homelands.
- Interviews and discussions during family visits to homelands which focused on the importance of water-related places and their uses. Maps were also used to discuss access to wetlands, the management, use and value of different wetlands.
- Documentation of wetland values and uses through a rating system which was accompanied by semi-structured questions.

4.3 Results and discussion

Below (Table 10, Table 11) we present a wetland typology that draws on the ESS concept and is based on Wik Peoples' values and related practices associated with waterholes and water bodies. We reflect on the usefulness of the ESS concept as a land management decision-support tool.

Table 10. Wetland typology categories and examples of services, care and factors that affect delivery of service and care for each wetland type.

Wetland typology category	Service	Care	Factors that affect dimensions of service and care
Domestic or everyday use			Access Seasonality Events
Sacred			
Kinship			
Memory			
Story place			
Ceremony			

Table 11. Examples of the types of factors that affect delivery of cultural ecosystem service and care for each wetland typology category.

Wetland typology category	Factors that affect dimensions of service and care		
	Seasonal and climate change	Events	Access
Domestic or everyday use			
Sacred (access and use prohibited)			
Kinship (inc. fishing, hunting,)			
Memory			
Story place (incl. fishing, hunting, swimming)			
Ceremony (incl. fishing, hunting, swimming)			

For the Indigenous peoples of the Archer River basin, different wetlands provide particular types of services and enable particular types of practices, and each requires the use of protocols that are part of the care practices. In the Indigenous worldview, the knowledge of wetlands and the types of services and practices that are important to those places are historically co-produced by nature, sentient beings of that country and through the 'practice of care' of ancestors and current generations (Cooper et al. 2016; Diaz et al. 2015; Jackson and Palmer 2015). Sangha and Russell-Smith (2017) highlight that connection to, being on, and practicing culture on Country is critical to building and sustaining people's capabilities that are part of the wellbeing benefit of CES.

Wetlands provide multiple CES that can include fishing, maintaining connection with ancestors, practicing lore and passing on knowledge, as well as CES benefits that exist as part of a wider network of wetland services (Cooper et al. 2016). These are not consistently accessed or cared for throughout the year, but are influenced by seasonal factors, community and environmental events or access conditions. For example, seasons affect access to services and benefits, which also bring into effect a variety of 'care practices', such as checking important places in the dry times to ensure they are in good condition and taking children at those times to share the story of those places. Accessibility of wetlands, such as their location and the terrain within which they lie, influences the frequency of access and types of CES that are associated with them. For example, wetlands near the home station are more frequently used for domestic and family activities. Some wetlands are associated with particular resources or ceremonial values and are cared for using protocols that protect particular practices and values. Wetlands provide a location-specific service embedded in a wider system of service and care.

The services, benefits derived, and care practices delivered through wetlands across the landscape create a relational value network between nature, people, descendants and spiritual entities that is in constant motion and responds to human and non-human-induced events and actions. CES is based on an ethics and practice of care that bring focus to peoples' access and presence on Country, responsibility through moral agents, knowledge to act, responsiveness through the right decision-making systems to fulfil those responsibilities and the resources to do so (Robinson 1997). CES is an important consideration in the management and conservation of landscapes (Chan et al. 2012; Fish et al. 2016; Sangha and Russell-Smith 2017). CES and care are based on learning, adaptation and practices and values that reflect the web of diverse relationships and the responsibilities embedded in that cultural landscape (Spiller et al. 2011). (Figure 42, Figure 43 and Figure 44).

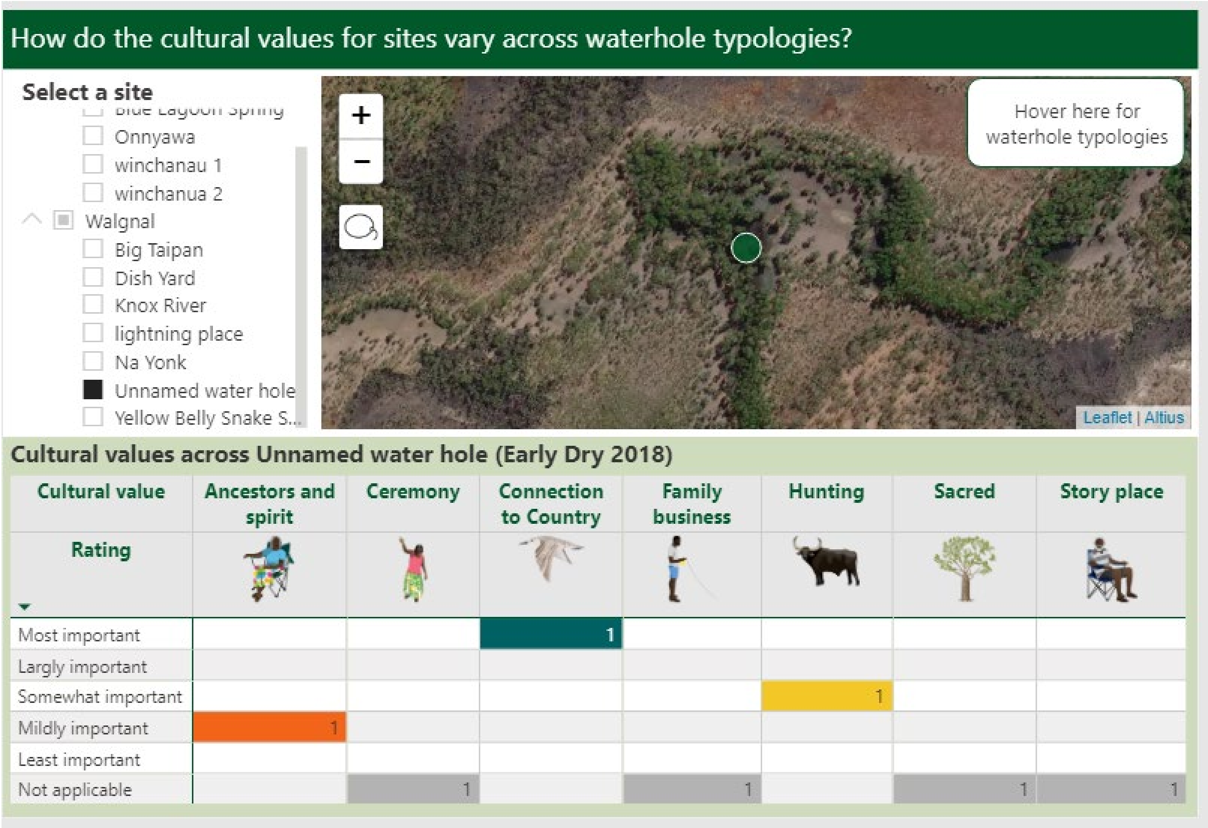
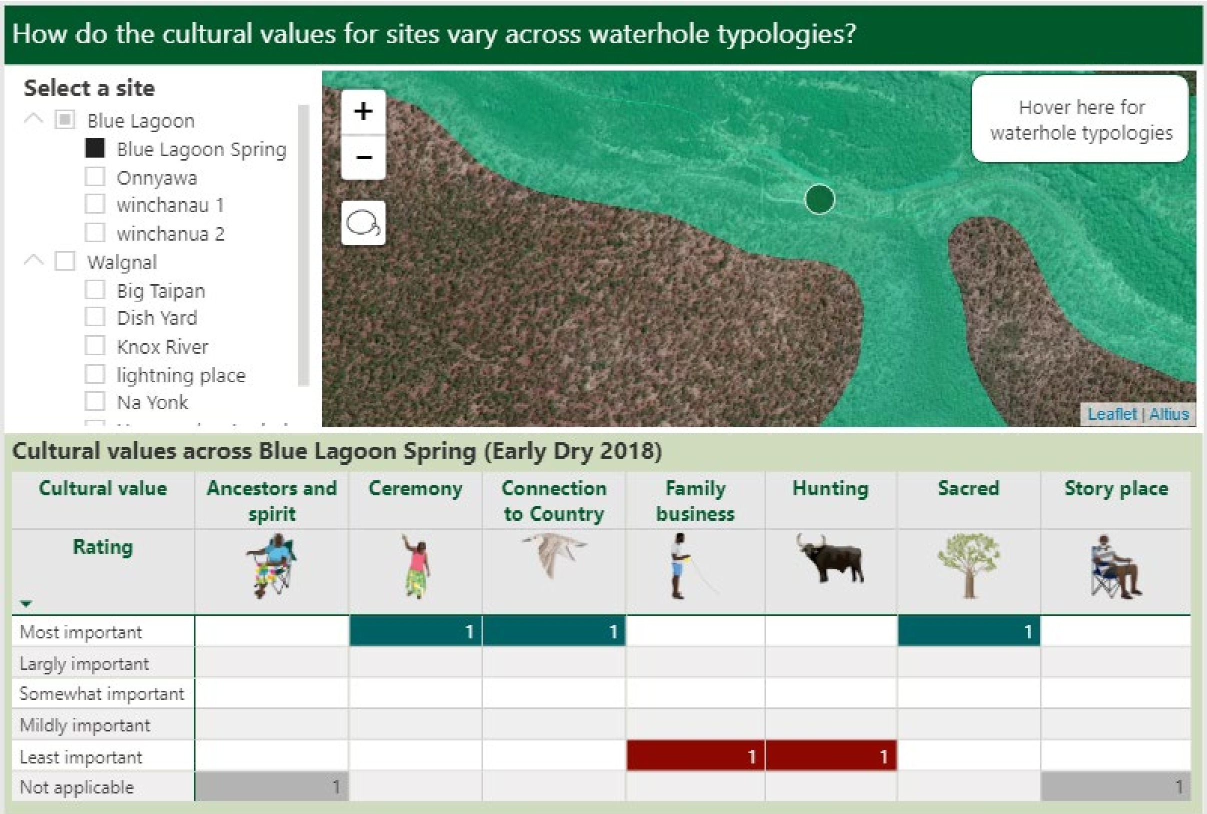


Figure 42. Example of how the typology can be applied at sites.

Figure 43. Data collection at different sites to collect cultural typologies.



Cultural value / Rating	Ancestors and spirit	Ceremony	Connection to Country	Family business	Hunting	Sacred	Story place
Most important		1	1			1	
Largly important							
Somewhat important							
Mildly important							
Least important				1	1		
Not applicable	1						1

Figure 44. An example of a different cultural typology where values of family business, hunting, ancestors and spirits and story place are scored low by Traditional Owners. Sites like these can be visited by outsiders and TOs are open to discussions about alternative use such as tourism or economic development opportunities.

4.4 Publications

Appendix 1. Draft paper: Cultural typologies.

5. Cost–benefit analysis of selected control methods for feral pigs.

5.1 Introduction

Kalan and APN used five methods for controlling pigs.

1. aerial control
2. trapping
3. baiting
4. on-ground hunting
5. fencing.

Controls were conducted to protect important wetlands and to reduce the impacts on marine turtle nesting. In this project we collected data on the costs of fencing and aerial control (culling pigs from a helicopter) compared with changes in total pigs shot, marine turtle depredation and changes in wetland values. Here we outline the methods we developed with APN and Kalan to assess impacts and adapt management based on data collected on control efforts. This included an assessment of the costs of aerial control for each zone. Understanding where money has been spent, particularly when large amounts of money are spent on external contractors – and how this money meets the objectives of management and local employment – is important to be able to adapt management activities that are not leading to the desired impact or supporting local values.

5.1.1 Identifying management zones and values

Working with APN rangers we defined 16 management zones reflecting management intensity, access and varying management aims. Zones were developed to facilitate management planning and development of robust monitoring activities for feral animal management in the Southern Wik homelands between the Archer and Holroyd rivers on the west coast of Cape York Peninsula (Figure 45).

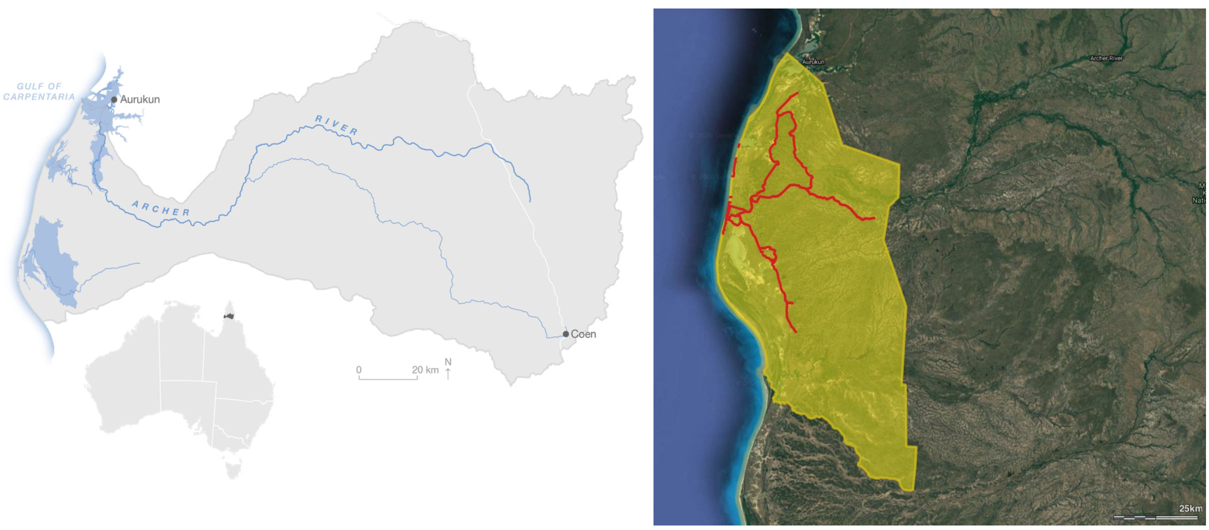


Figure 45. APN management area (yellow polygon, right) in the Archer River basin, Cape York Peninsula (left).

The Traditional Owners of the southern Wik estate have identified multiple objectives for the management of their traditional lands including economic development, maintaining strong cultural connections with their traditional lands and protecting key environmental assets. Land management and cultural activities are applied based on changes in seasons that are informed by traditional ecological knowledge that has been documented for the region. CSIRO and APN worked with Traditional Owners and rangers to develop the Wik seasons operational calendar that informs the management planning in this strategy (Figure 46).

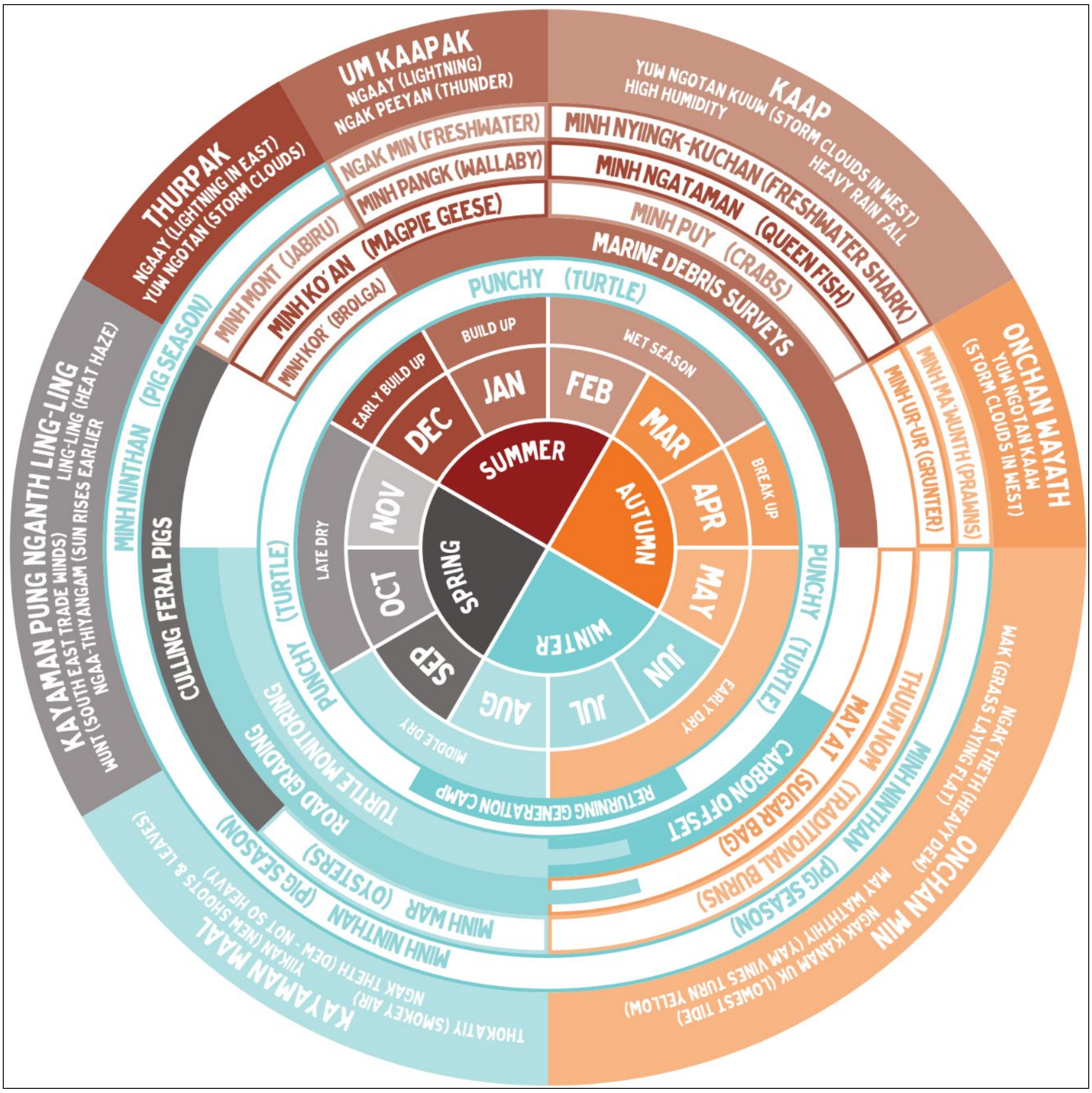


Figure 46. Wik operational seasonal calendar indicating the Wik seasons in the context of major management activities and seasonal indicators. The European seasons and months are indicated against the traditional seasons, but this only reflects the average timing of these. The Wik seasons are not fixed in time but based on environmental cues.

The Wik Traditional Owners and APN have defined specific management objectives for the APN operational area. This includes local objectives that match the aspirations and objectives of Traditional Owners and external goals that meet objectives of state and federal governments and support external funding opportunities that employ local people. The primary objective of APN is to support Traditional Owners to retain connections with their lands and to protect culturally important areas. Feral animal management in the region aligns with nuanced area-specific objectives identified during planning with the different clan groups to account for variable goals, including economic development opportunities and local consumption of feral animals.

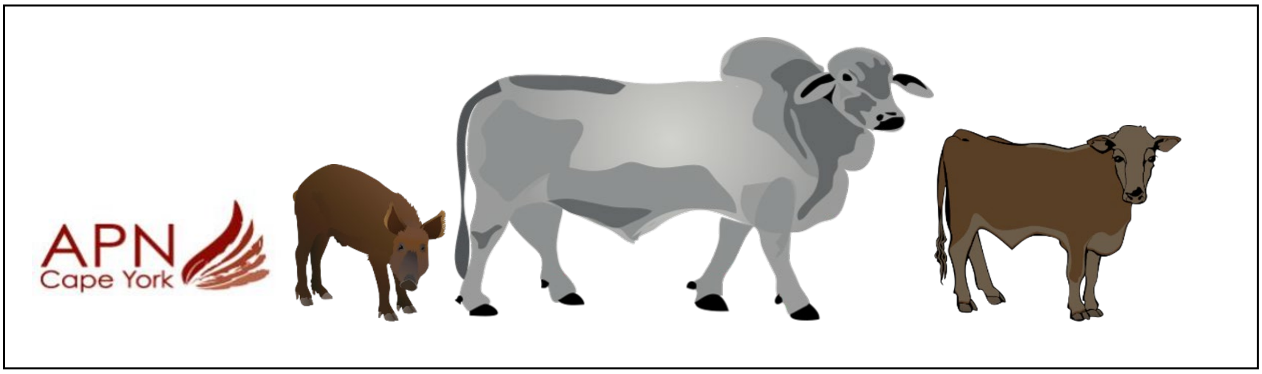
5.2 Local management objectives

- Protect marine turtles to enable sustainable hunting of turtles and sustainable egg collection during peak breeding season.
- Protect freshwater turtles to enable sustainable hunting of turtles at important waterholes in each clan estate. Protect turtle nests during the breeding season.
- Protect wetlands and key cultural foods and sites (water, water lilies etc).
- Reduce grazing pressure on wetlands.
- Traditional Owners want to retain feral pigs and cattle in the landscape for local hunting and consumption. This is generally near outstations.
- For cattle, APN aims to decrease mustering costs and retain higher quality genetics for managed herds, understand seasonal resource-use across seasons to determine strategic watering and fence line placement, and understand seasonal movement to facilitate removal and mustering of unmanaged stock.
- Develop skill sets locally to reduce the reliance on outside contractors to complete management activities (mustering, aerial shooting, trapping, baiting and monitoring).

5.3 External objectives

- Manage threats to nationally listed threatened species. For example, the protection of threatened marine turtles (funded by the Nest to Ocean program) and the protection of threatened star and crimson finches (state and federal threatened species management requirements).
- Manage threats to biodiversity and internationally important wetlands (funded by various environmental funding, non-government organisations and the Queensland Indigenous Land and Sea Ranger program).
- Manage and understand the abundance and distribution of feral pig and feral cattle populations to better respond to disease outbreak (funded and administered by the Northern Australia Quarantine Strategy).

5.4 Feral animal targets



APN is actively involved in managing key threats to biodiversity through the removal and management of feral pigs, cattle, horses and cats. In this document we focus on developing a strategic management plan for feral pigs as this is the focal species for our research collaboration.

The west coast of Cape York Peninsula between the Holroyd and Archer rivers has been documented as supporting the highest densities of pigs in Australia. This region also supports a significant population of unmanaged cattle (estimated to be over 5,000) adjacent to a managed herd of around 1,300 animals in a recently fenced area that is accessible by truck in the dry season from around August to December. Feral pigs have been actively controlled in the region since 2007 with robust monitoring of population numbers and assessments of management effectiveness beginning in 2013. In the following sections we outline a seasonal approach to the management of feral pigs to facilitate annual planning and management activities.

We have identified 16 management zones (Table 12) representing the different management objectives, access in different seasons, and management of threats to environmental and cultural assets (Figure 47). This information is available via an interactive dashboard located in the link below. The dashboard can be operated online or downloaded to a desktop computer and operated offline.

Copy or click the link below into your browser to view the dashboard.

https://app.powerbi.com/view?r=eyJrIjoiYzEzMDU2ZjgtNDY1Yy00MWVhLTllYjQtMWEyZWRmNTZmNGQ4IiwidCI6IjJiNzQ1YWMxLTZmNGEtNGUwZS1hOTczLWVkM2YyZjQ3NWUxNyJ9&pageName=ReportSection1c41c799c92e39603903

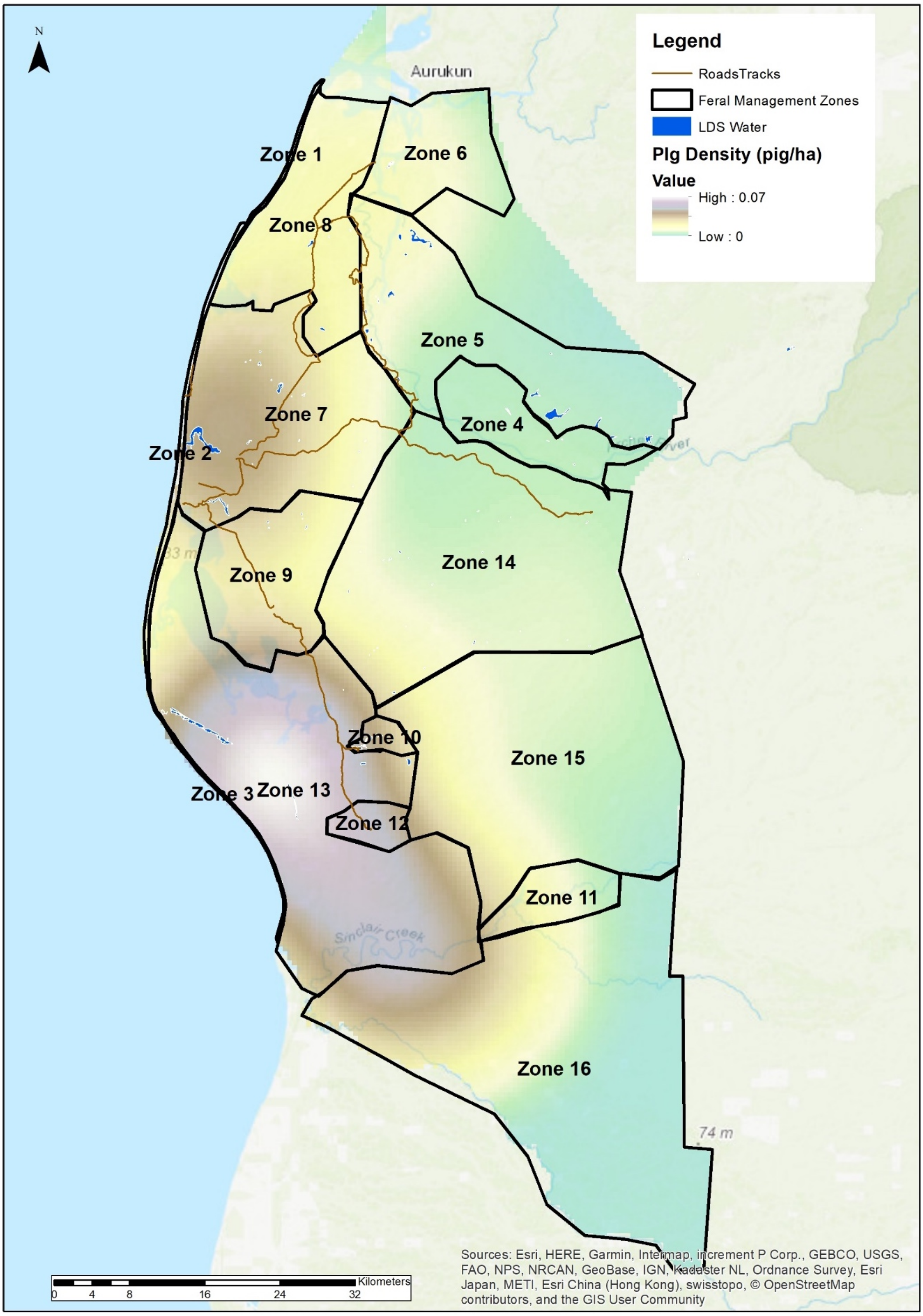


Figure 47. Overview of feral animal management zones in the APN operational area. Detailed information on each zone presented below. Brown line indicates the APN road network.

Table 12. Table of zones and objectives.

Zone no.	Name	Detail	Veg. type	Values	Threats	Management actions	Access	Costs	Pig density	Cattle density
1	Archer River to Love River	Archer River mouth to love river mouth.	Beach	Marine turtles (olive ridley, flatback and hawksbill)	Pigs eat turtle eggs. Aerial survey of area indicates 100% depredation of nests in this zone	Aerial control of feral pigs. 1080 baiting of dune scrubs and beach. Aerial survey of nest depredation.	Late dry season access possible in the late dry season usually between September and November. Boat access from Aurukun.	Expect that costs will predominately be associated with helicopter charter, contract shooters. Around 6000 dollars per day.	High	Low
2	Love River to Kirke River	Main turtle manageme nt area.	Beach	Marine turtle protection. Olive ridley, flatback, hawksbill. Hunting and fishing for Traditional Owners. Camping for Traditional Owners.	Feral pigs eat marine turtle eggs.	Nest protection using aluminium cage. Strategic trapping, hunting or poisoning of individual pigs in response to identified nest predation. Regular monitoring of turtle nests to monitor depredation. Hunting in dense vine thickets. Aerial control.	Via quad bike, or all terrain vehicle from mid dry season. Usually June to December (depending on rainfall). Access via 4wd vehicle to beach entrance from late August to November.	Regular monitoring. Side-by-side vehicle expenses and maintenance Trapping material Poison baits	Moderate	Moderate
3	Kirk to Holroyd	Low turtle nesting density adjacent to the highest densities of feral pigs in the region.	Beach	Limited nesting habitat for marine turtles	Feral pigs eat marine turtle eggs.	Aerial control targeting areas directly adjacent to the beach. Potential for aerial meat baiting.	Very limited access. Possible by ATV in the late dry season but very difficult. Access by helicopter the primary means of access	Significant helicopter costs	Very High	Low
4	Archer River upper dense	Dense inaccessibl e gallery forest on	Dense gallery forest, braided channels	High biodiversity values. Fishing and hunting	Feral pigs dig up yams, freshwater turtles and eat bush foods.	Very challenging for control. Extensive and inaccessible. Aerial control not effective. Could be managed using broad-scale	Not accessible by vehicle.	Prohibitively expensive to access this area	High	Moderate

Zone no.	Name	Detail	Veg. type	Values	Threats	Management actions	Access	Costs	Pig density	Cattle density
		the Archer River.				baiting using aerial poisoned meat baits. .				
5	Archer River freshwater edges	In the open habitats adjacent to the Archer River	Riparian and open woodland. Scattered freshwater water holes	Freshwater ecosystems	Freshwater turtles eaten and nests destroyed. Magpie geese habitat destroyed. Wetland habitat impacts, e.g. Eleocharis and water lilies.	Aerial control. Targeted ground shooting.	Very difficult access via ATV in the late dry season.	Significant helicopter costs	Moderate	Low
6	Watson and Archer rivers salt pans	Open seasonally flooded salt pans.	Salt pans	Estuarine vegetation, Eleocharis channels, freshwater turtles, magpie geese	Feral pigs target seasonally flooded areas destroying water holes and disrupting hanita5 for water birds.	Aerial control	Helicopter or boat	Helicopter costs	High	Low
7	Ootukman and ootukellen, love river flood plain	Major permanent water sources drive the floodplain ecology. Potential for very high pig densities currently suppressed through regular aerial control. Main area that supports commercial cattle herd.	Floodplain, dune scrub, groundwater fed permanent freshwater	Wetlands vegetation. Major breeding area for magpie geese. Major refugee for mammals and birds. Highest known densities of threatened star finch and crimson finch. Major breeding area and dry season refuge for marine turtles. Very important area for hunting geese, turtles, pigs and cattle for Traditional Owners.	Major breeding area for feral pigs adjacent to marine turtle protection beach. Destruction of magpie geese nesting areas, destruction of freshwater turtle breeding. Unknown impacts on nesting and abundance of freshwater turtles.	Aerial control. Mustering. Ground hunting, baiting, trapping.	Access via formed road to wathanin most of the dry season. Good access both north and south through this zone via 4wd vehicle and ATV.		Moderate	Very High
8	Emu foot to	Area behind	Floodplain, dune	Important hunting area	Broad-scale impact from pigs on wetlands and	Arial control. Good potential for intensive	Graded road with good dry season access from around August. King		Very High	Moderate

Zone no.	Name	Detail	Veg. type	Values	Threats	Management actions	Access	Costs	Pig density	Cattle density
	deep water floodplain	mangrove lined saltwater creeks.	scrub and freshwater water holes.	close to Aurukun for cattle and pigs. Adjacent to major olive tidley nesting beach with very high predation	floodplain habitat. Impacting water quality and biodiversity values	baiting in the vine scrub adjacent to nesting beach	tides and late dry season rain cut off access in the late dry season north of the love river crossing			
9	Ootukellen to Kencherang	Area with very little freshwater. Permanent water at Kencherang and Big Lake	Floodplain and woodland transition	Very good cattle grazing wet season to mid dry season	Seasonal impact from cattle and pigs on vast floodplain habitat	Aerial control. Mustering of cattle	Limited access until mid dry season (August/September). Good 4WD access from September to November following grading	Helicopter costs	Moderate	High
10	Ti tree hunting and culture zone	Very important ecological community. Ground water fed system and Significant dry season refuge.	Permanent freshwater waterhole and spring fed system	Very important fishing and hunting area. The most important area in the region for magpie geese breeding.	Very high impact from feral pigs and cattle on freshwater wetlands and Elocharis wetlands	On-ground hunting and aerial control.	Acces via road in the mid to late dry season. Some early access by ATV	Grading, Helicopter.	High	High
11	Sinclair creek ecological zone	Upper catchment north of Sinclair Creek. Low hills expansive homogenous woodlands interspaced with water holes	Permeant freshwater waterhole and spring fed system	Very important ecological system. Likely to contain novel ecosystems and a critically important refugial area.	This is the most important wetland in the region and in areas where pigs can access springs significant and wide spread damage	Aerial control only	Helicopter only	Helicopter costs	Moderate	Moderate

Zone no.	Name	Detail	Veg. type	Values	Threats	Management actions	Access	Costs	Pig density	Cattle density
12	Walgnal hunting and culture zone	Important hunting area with many cultural sites.	Ephemera l water holes near estuarine systems	Very important cultural area. Diverse hunting and fishing sites near the outstation	Impact from cattle and pigs in the area. Limited impact to fishing but could be impacting magpie geese breeding and freshwater turtle abundance.	On-ground hunting. TO's want to retain pigs and cattle near the outstation for local consumption. Avoid aerial control near the house.	Access via road in the mid to late dry season. Some early access by ATV or through helicopter slinging.	Grading, Helicopter.	Moderate	Moderate
13	Kirke to Knox high-density pig zone	The highest densities of feral pigs on APN. Pigs live in dense dune scrub and use permanent water in springs.	Dune scrubs, floodplain, salt pans and water holes	Large coastal vine thicket. Very important vegetation type with permeant ground water.	Un documented impact from pigs and cattle on coastal vine thickets	Aerial control. Very high densities decrease the effectiveness of population control. Consider broad-scale intensive baiting.	Helicopter. Difficult access via ATV	Helicopter costs	Very HIgh	High
14	Upper catchm ent zone	Low feral pig density with Significant congregati on on few late dry season water sources	open woodland s, scattered freshwater waterhole s	large semi-permanent waterholes provide essential dry season habitat for many species. Important recharge zone for ground water dependent ecosystems.	grazing pressure and significant impact to late dry season water holes.	limited aerial control. Consider late dry season aerial baiting at selected late dry season water holes.	Helicopter access only	Helicopter costs	Low	Low
15	Upper Sinclair Creek	Upper catchment no roads	open woodland s, scattered freshwater waterhole s	large semi-permanent waterholes provide essential dry season habitat for many species. Important recharge zone for ground water	grazing pressure and significant impact to late dry season water holes.	limited aerial control. Consider late dry season aerial baiting at selected late dry season water holes.	Helicopter access only	Helicopter costs	Low	Low

Zone no.	Name	Detail	Veg. type	Values	Threats	Management actions	Access	Costs	Pig density	Cattle density
				dependent ecosystems.						
16	No-mans land		open woodlands, scattered freshwater waterholes	large semi-permanent waterholes provide essential dry season habitat for many species. Important recharge zone for ground water dependent ecosystems.	grazing pressure and significant impact to late dry season water holes.	limited aerial control. Consider late dry season aerial baiting at selected late dry season water holes.	Helicopter access only	Helicopter costs	Low	Low

5.5 Seasonal management plan for different zones

Seasonal movement patterns for feral pigs have been explored using GPS tracking data retrieved from collars installed during the Feral IoT project in partnership with CSIRO and APN. These data have indicated that feral pigs have variable movement and respond to available resources across seasons. We used these data and data collected during aerial control operations, using the iPad Application Distance Sampler, to develop seasonal analysis of pig resource use which we use here to inform the seasonal management strategies. We combine modern science and technology with Wik Traditional knowledge to develop a seasonal approach to managing feral pigs in the APN management zones. In this section we identify potential seasonal management strategies in the identified zones.

5.5.1 Seasonal management for zones 1 and 3

(Figure 48 and Figure 49)

5.5.1.1 Um kaapak, Kaap and Onchan wayath. Wet season to early dry season. January to April.

During the wet season and start of the early dry season marine turtles are not breeding so the potential for impact is very low. No management intervention or monitoring required in zones 1 – 3 in these seasons.

5.5.1.2 Onchan min. Early dry season. May to July.

Towards the end of the early dry season (usually the end of June) marine turtles start to nest. During this period an aerial cull can reduce pig populations adjacent to the breeding areas and may remove older boars that are the most likely to target marine turtle nests. During this time feral pigs are largely focused on the Eleocharis channels at the edge of flood plains. This period is also the time when helicopters are used for early dry-season burning, so utilising the helicopter while it is in the area can reduce costs.

5.5.1.3 Kayaman Maal. Mid dry season. August to September.

These seasons represent the peak turtle nesting period for olive ridley and flatback marine turtles. Zone 1 represents very high nesting density and has very high nest depredation. During this period aerial control adjacent to the beach will be beneficial but it is likely that older boars living in dense vine thicket will avoid being shot. Systematic on-ground hunting in the vine thicket could be applied late August and September to target specific animals. This area is a relatively short section of beach and is suited for an intensive baiting program. Setting up and maintaining free feeding grain bait stations at 1 km intervals directly behind the beach in shaded areas from the end of July. Use motion sensor cameras to monitor pig activity on grain stations. When activity increases at grain bait stations and sounders regularly eat the grain, apply 1080 poison. Following successful baiting limited control will be required.

Zone 2 has relatively low turtle nesting densities and is very difficult to access. Aerial control adjacent to the beach may suppress some predation in this zone. Aerial survey data indicates that in the dune scrub adjacent to this beach aerial control puts very little pressure on feral pig populations. Low nesting densities may reflect long-term predation pressure. In the absence of intensive baiting, broad-scale aerial control is not likely to have a large impact in this zone.

5.5.1.4 Kayanman Pung Nganth Ling-Ling and Thurpak. Late dry season. October to December.

Most of the turtle nests will be hatched or depredated by October and limited control or monitoring required.

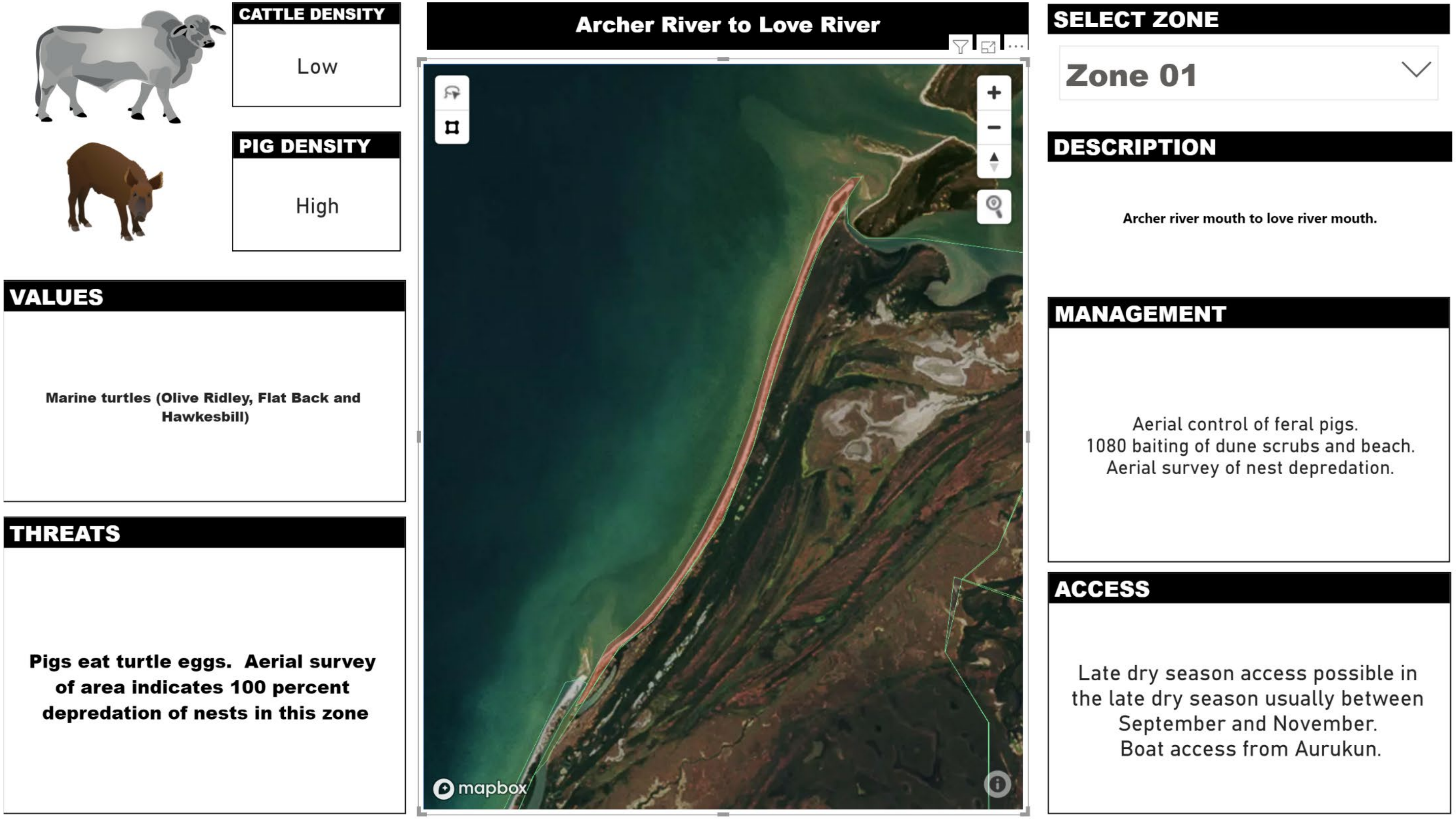


Figure 48. Zone 1 details.

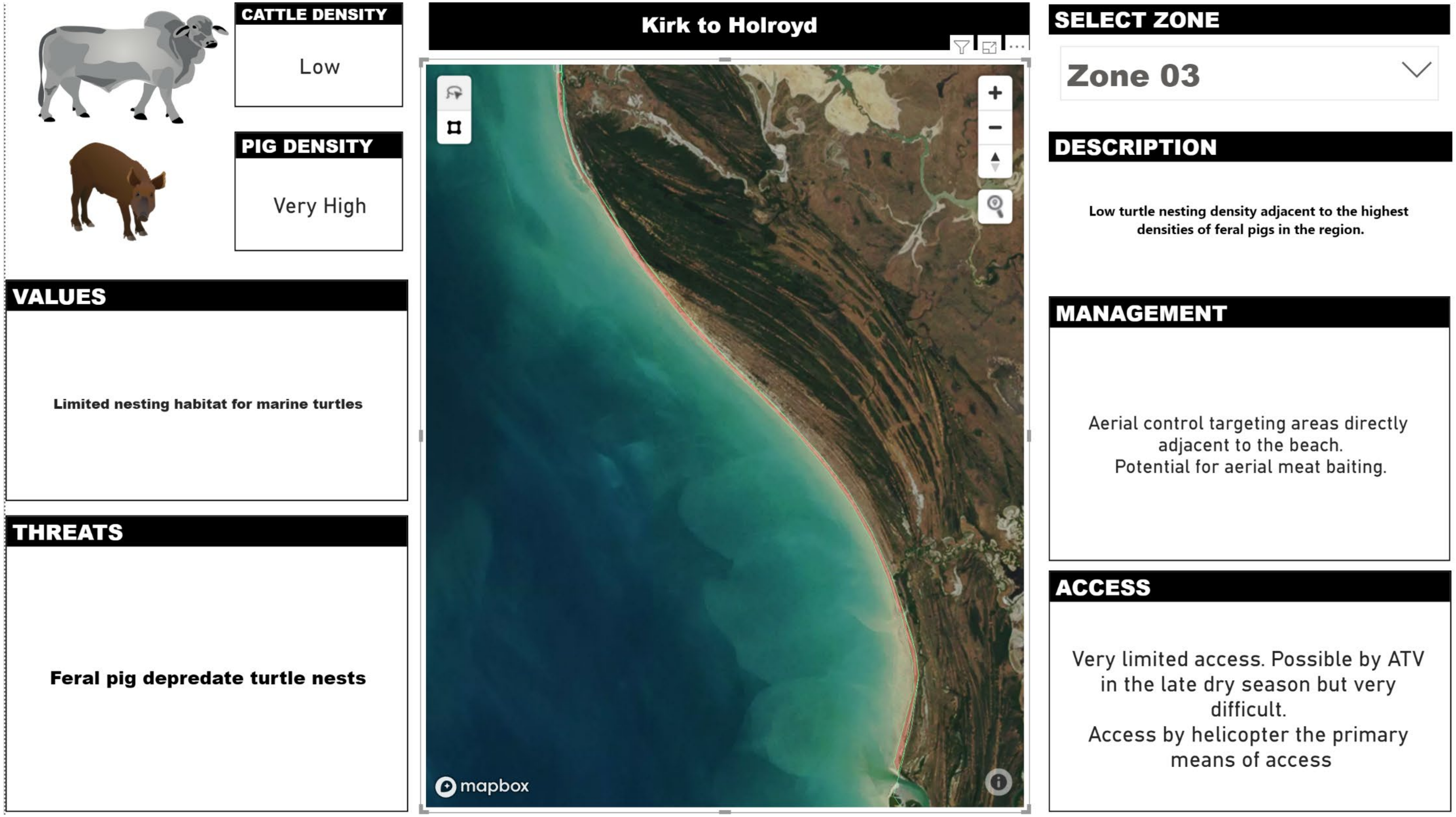


Figure 49. Zone 3 details.

5.5.2 Seasonal management for zone 2

(Figure 50)

5.5.2.1 Um kaapak, Kaap and Onchan wayath. Wet season to early dry season. January to April.

During the wet season and start of the early dry season marine turtles are not breeding so the potential for impact is very low. No management intervention or monitoring required in zone 2 in these seasons.

5.5.2.2 Onchan min. Early dry season. May to July.

Towards the end of the early dry season (usually the end of June) marine turtles start to nest. During this period an aerial cull can reduce pig populations adjacent to the breeding areas and may remove older boars that are the most likely to target marine turtle nests. During this time feral pigs are largely focused on the Eleocharis channels at the edge of flood plains. This period is also the time when helicopters are used for early dry-season burning so utilising the helicopter while it is in the area can reduce costs.

5.5.2.3 Kayaman Maal. Mid dry season. August to September.

These seasons represent the peak turtle nesting period for olive ridley and flatback marine turtles. Zone 2 is the primary nest protection beach and nest monitoring should be done weekly during this period. Conduct aerial control adjacent to the beach. Systematic on-ground hunting should be applied in response to identified pig depredation. Nest protection devices can be applied, e.g. aluminium cages. Pig baits should be laid in areas where pig depredation has been recorded. Free feeding and trapping can also be applied in key water holes and shade near predation areas.

5.5.2.4 Kayanman Pung Nganth Ling-Ling and Thurpak. Late dry season. October to December.

Most of the turtle nests will be hatched or depredated by October and limited control or monitoring required.

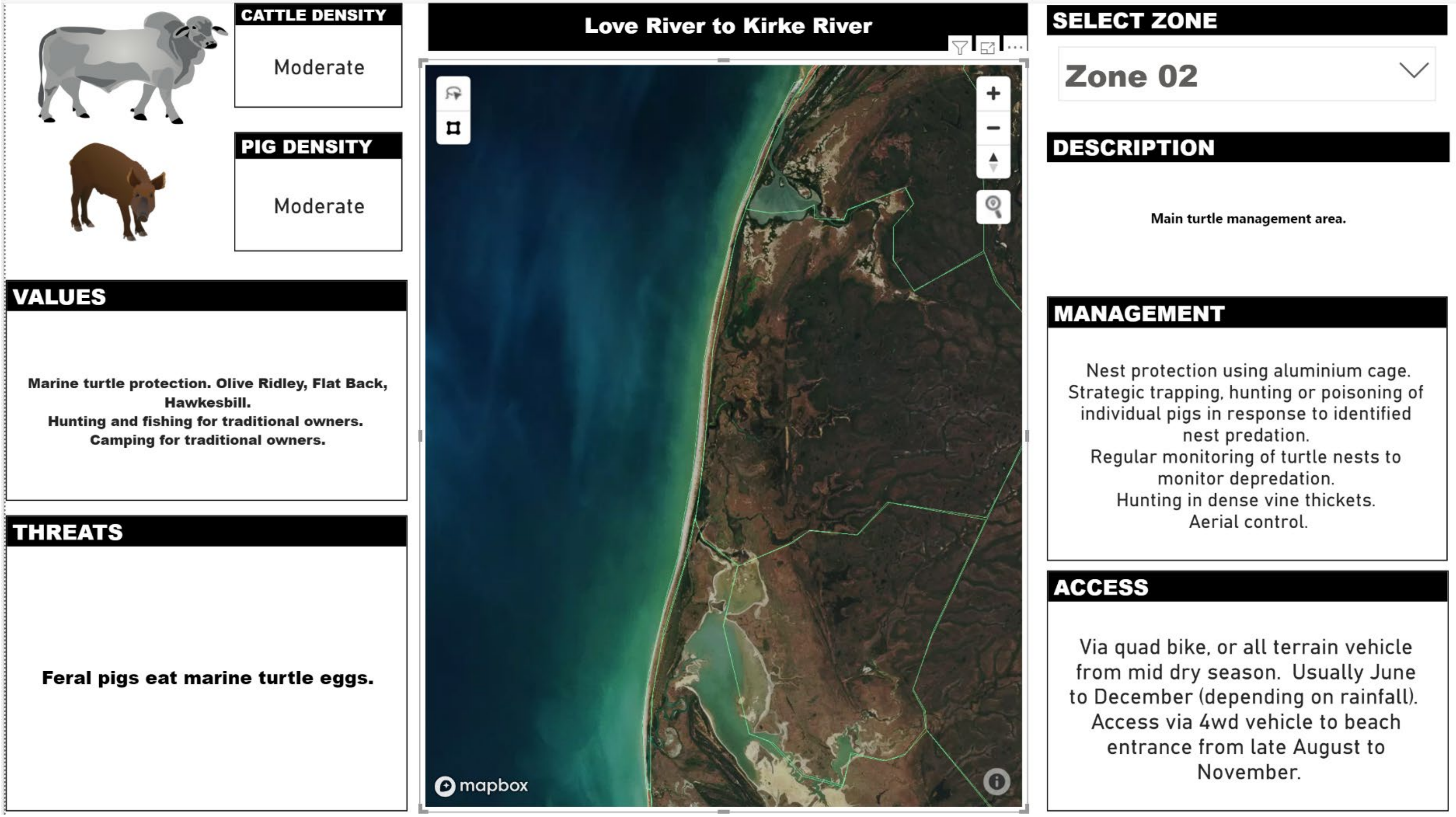


Figure 50. Zone 2 details.

5.5.3 Seasonal management for zones 4 and 5

(Figure 51 and Figure 52)

5.5.3.1 Um kaapak, Kaap and Onchan wayath. Wet season to early dry season. January to April.

These zones are mostly inaccessible, and in the dense forest along the Archer River in zone 4 aerial control is impossible. This represents a major refugial area for feral pigs but access limits any practical control activities. No practical control activities during these seasons.

5.5.3.2 Onchan min. Early dry season. May to July.

No practical control activities during this season. Much of the impact occurs later in the dry season as water drys up. Feral impacts low during this season.

5.5.3.3 Kayaman Maal. Mid dry season. August to September.

On the southern side of the Archer River zone 5 includes large freshwater waterholes that are significant dry season refugia for freshwater turtles. Fencing exclusion can be installed to protect important wetlands. This management intervention is very expensive and difficult to maintain (requiring annual maintenance). Only consider in response to Traditional Owners requesting protection of important wetlands.

5.5.3.4 Kayanman Pung Nganth Ling-Ling and Thurpak, Late dry season. October to December.

Pigs rely on the semi-permanent and permanent waterholes directly adjacent to the Archer River. These are easy to access in the late dry season via the Stoney Crossing. Baiting and intensive hunting around these waterholes can reduce the impact of feral pigs on wetland values (such as freshwater turtles) if pressure is applied regularly.

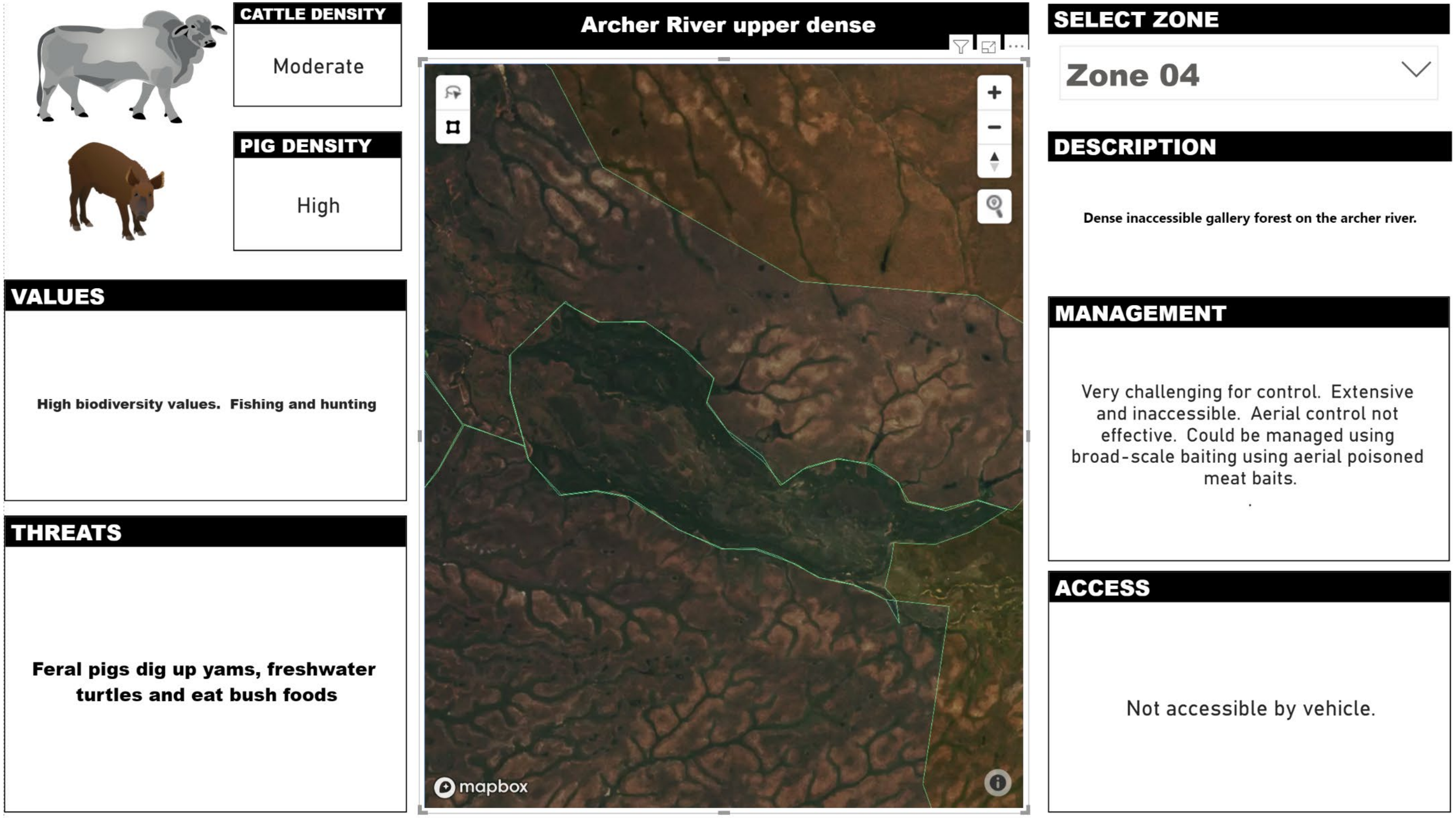


Figure 51. Zone 4 details.

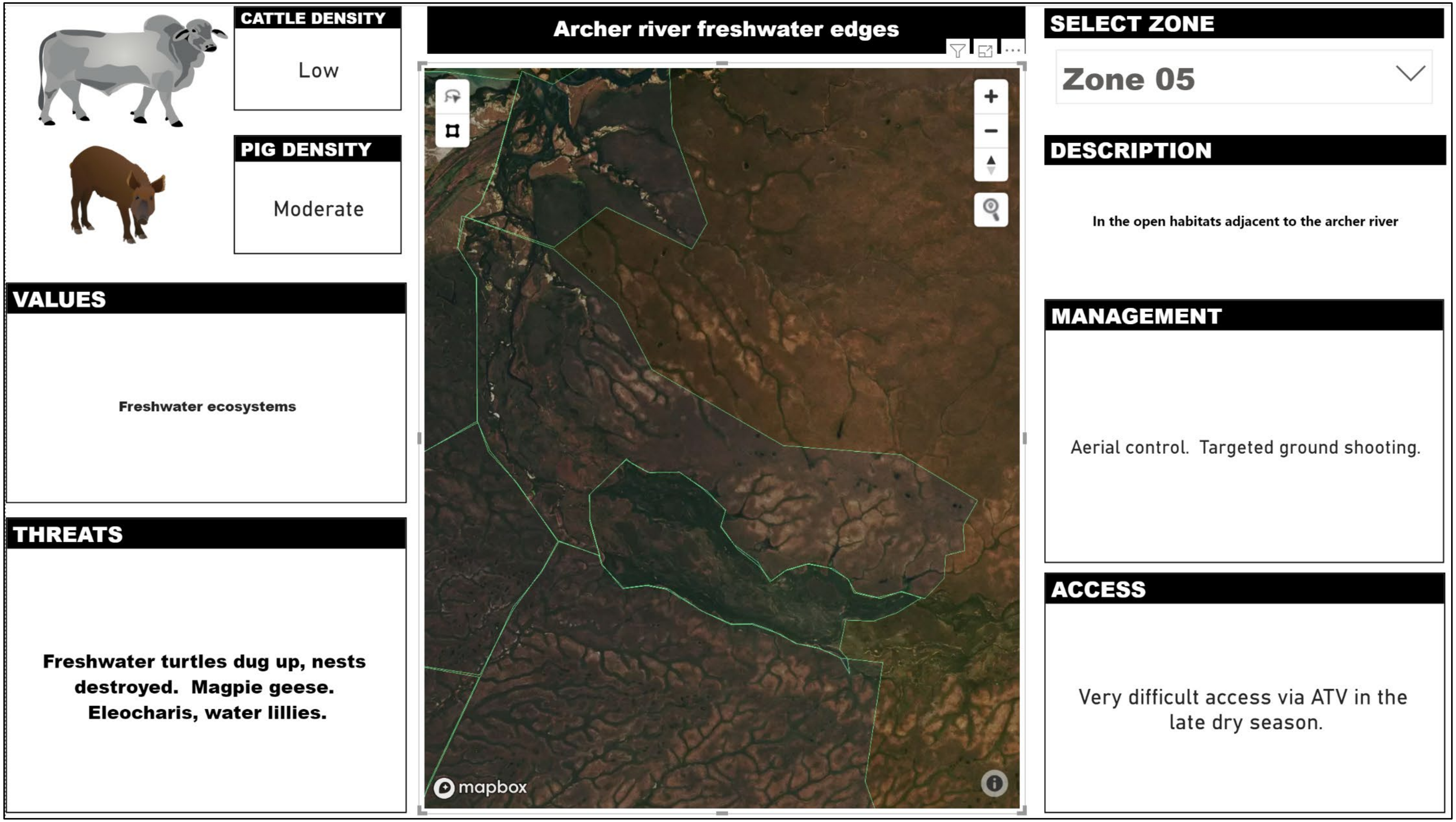


Figure 52. Zone 5 details.

5.5.4 Seasonal management for zones 10 and 12

(Figure 53 and Figure 54)

Zones 10 and 12 are special cultural zones where Traditional Owners do not want broad-scale aerial control to occur. These are areas that are near outstations where people hunt for pigs and cattle. APN should monitor potential impact on freshwater turtles and magpie geese if feral pig populations get too high and advise the Traditional Owners of impacts.

5.5.4.1 Um kaapak, Kaap and Onchan wayath. Wet season to early dry season. January to April.

Research partners could support regular magpie goose nesting surveys. This is a culturally important species that has been shown to be affected by feral pig impact in the Northern Territory.

5.5.4.2 Onchan min. Early dry season. May to July.

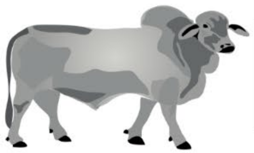
Support Traditional Owners to visit their outstations during this season. Traditional use of Country will put pressure on feral pig populations, and this can reduce impact on key waterholes.

5.5.4.3 Kayaman Maal. Mid dry season. August to September.

Support Traditional Owners to work on their homelands. Hunting and maintenance of cultural assets like wells and springs will put pressure on feral pig populations around important cultural sites.

5.5.4.4 Kayanman Pung Nganth Ling-Ling and Thurpak. Late dry season. October to December.

Late dry-season aerial control on late dry-season waterholes after Traditional Owners have returned to town. Reduce populations for following year.



CATTLE DENSITY

High

PIG DENSITY

High

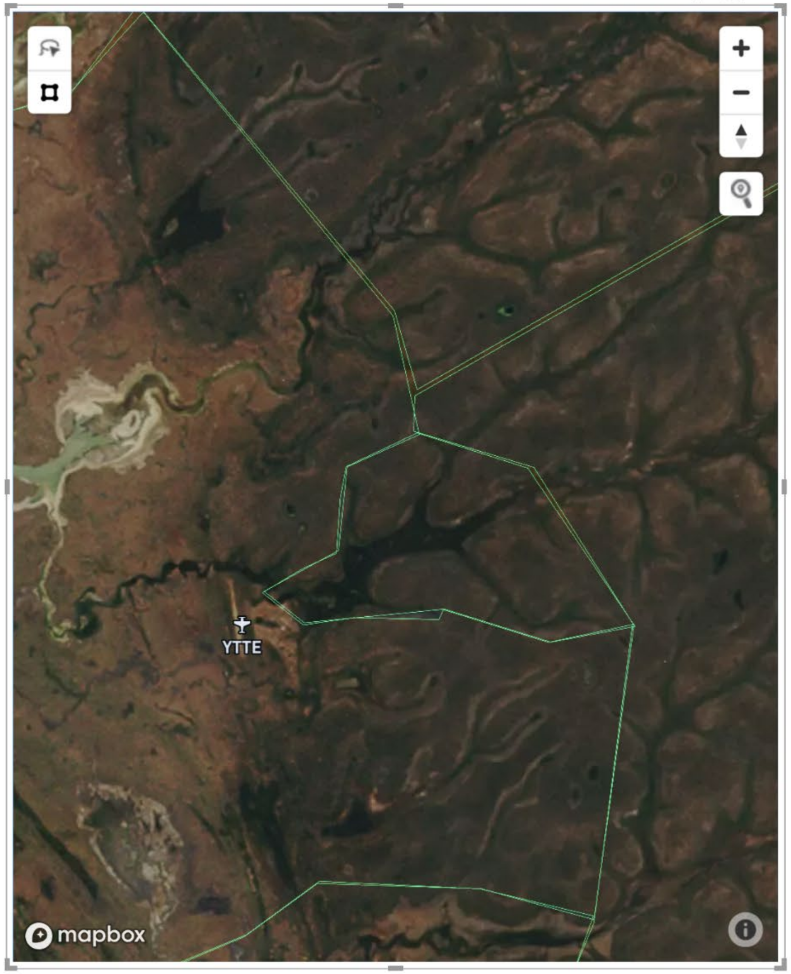
VALUES

Very important fishing and hunting area. The most important area in the region for mapgie geese breeding.

THREATS

Very high impact from feral pigs and cattle on freshwater wetlands and Elocharis wetlands

Ti tree hunting and culture zone



SELECT ZONE

Zone 10

DESCRIPTION

Very important ecological community. Ground water fed system and signicant dry season refuge.

MANAGEMENT

On-ground hunting and aerial control.

ACCESS

Acces via road in the mid to late dry season. Some early access by ATV

Figure 53. Zone 10 details.

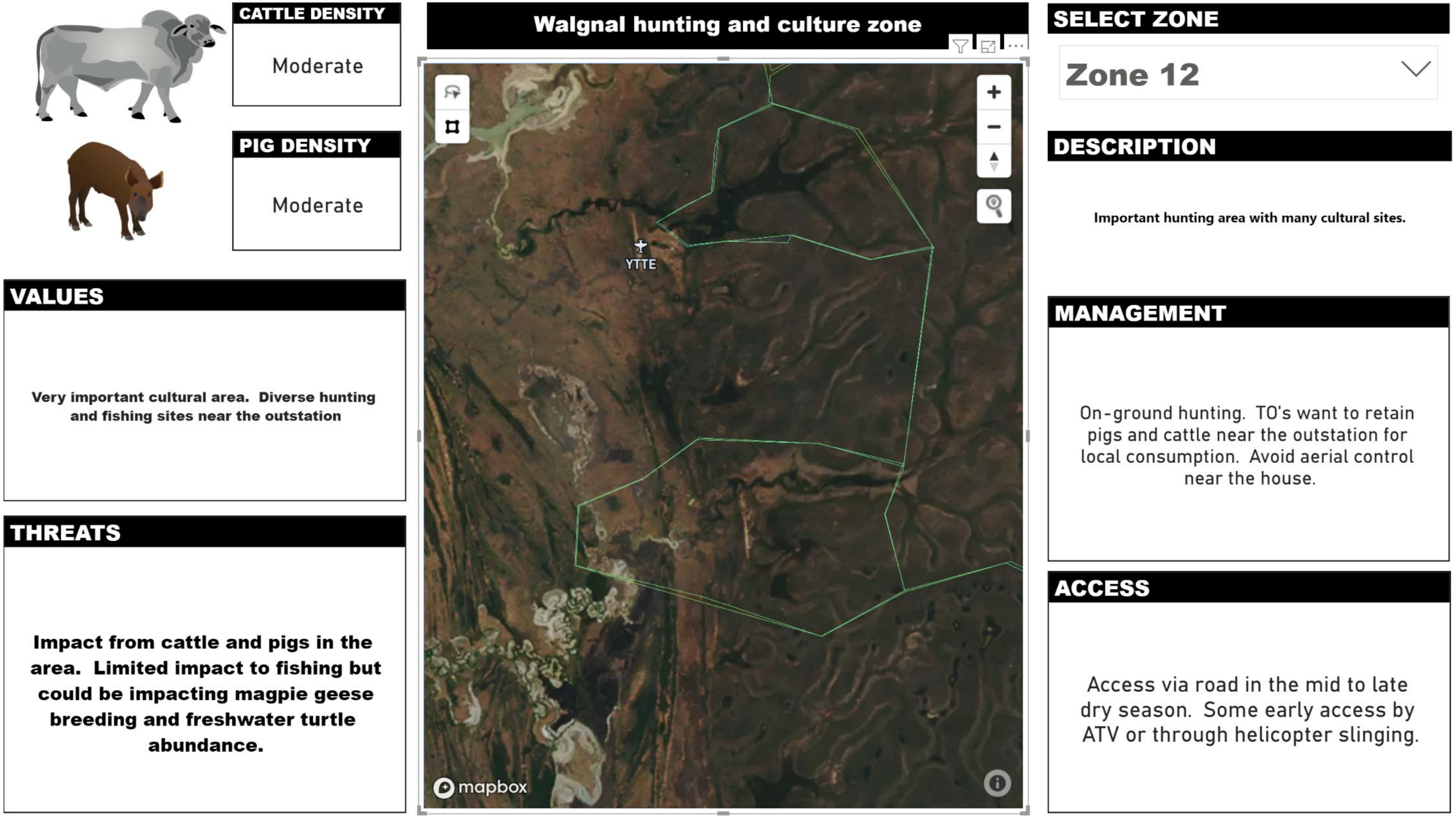


Figure 54. Zone 12 details.

5.5.5 Seasonal management for zones 7, 8 and 9

(Figure 55, Figure 56 and Figure 57)

5.5.5.1 *Um kaapak, Kaap and Onchan wayath. Wet season to early dry season. January to April.*

Floodplains are wet and access is limited. If research partners and funding allow, conducting magpie goose nesting survey would be useful for understanding major breeding areas and recording any depredation by feral pigs.

5.5.5.2 *Onchan min. Early dry season. May to July.*

Limited access during this period. Aerial control activities should focus on Eleocharis channels on the flood plain where feral pigs dig and eat the nutritious bulbs.

5.5.5.3 *Kayaman Maal. Mid dry season. August to September.*

Potential for conducting intensive baiting program in the vine thickets and mangroves adjacent to zone 1. Aerial control should focus intensively on the area adjacent to the beach where feral pig populations are very high near Emu Foot. This area is an important hunting area for people visiting Country for short trips from Aurukun. Substantial aerial control in commonly hunted areas and along roadsides should be avoided.

5.5.5.4 *Kayanman Pung Nganth Ling-Ling and Thurpak. Late dry season. October to December.*

Aerial control or intensive trapping near late dr- season waterholes could be instigated if large-scale population control is required. This requires better knowledge of how sows move through this landscape (GPS data is largely for boars in this area).

CATTLE DENSITY

Very High

PIG DENSITY

Moderate

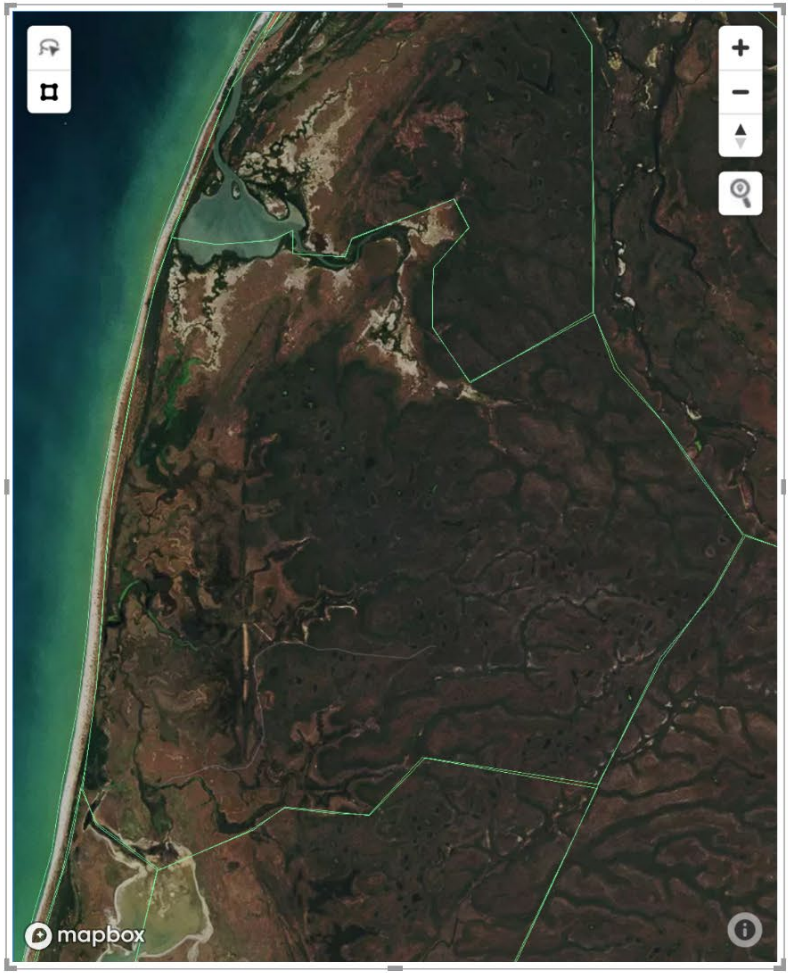
VALUES

Wetlands vegetation. Major breeding are for magpie geese. Major refugee for mammals and birds. Highest known densities of threatened star finch and crimson finch. Major breeding area and dry season refuge for marine turtles. Very important area for hunting geese, turtles, pigs and cattle for traditional owners.

THREATS

Major breeding area for feral pigs adjacent to marine turtle protection beach. Destruction of magpie geese nesting areas, destruction of freshwater turtle breeding. Unknown impacts on nesting and abundance of freshwater turtles.

Ootuk man and ootuk ellen, love river flood plain



SELECT ZONE

Zone 07

DESCRIPTION

Major permanent water sources drive the floodplain ecology. Potential for very high pig densities currently suppressed through regular aerial control.
Main area that supports commercial cattle herd.

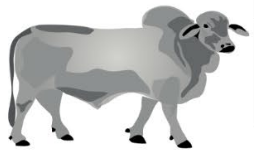
MANAGEMENT

Aerial control. Mustering. Ground hunting, baiting, trapping.

ACCESS

Access via formed road to wathanin most of the dry season. Good access both north and south through this zone via 4wd vehicle and ATV.

Figure 55. Zone 7 details.



CATTLE DENSITY

Moderate

PIG DENSITY

Very High

VALUES

Important hunting area close to Aurukun for cattle and pigs.
Adjacent to major olive Ridley nesting beach with very high predation

THREATS

Broad scale impact from pigs on wetlands and floodplain habitat. Impacting water quality and biodiversity values

Emu foot to deep water floodplain

SELECT ZONE

Zone 08

DESCRIPTION

Area behind mangrove lined saltwater creeks.

MANAGEMENT

Arial control. Good potential for intensive baiting in the vine scrub adjacent to nesting beach

ACCESS

Graded road with good dry season access from around August. King tides and late dry season rain cut off access in the late dry season north of the love river crossing

Figure 56. Zone 8 details.

CATTLE DENSITY

High

PIG DENSITY

Moderate

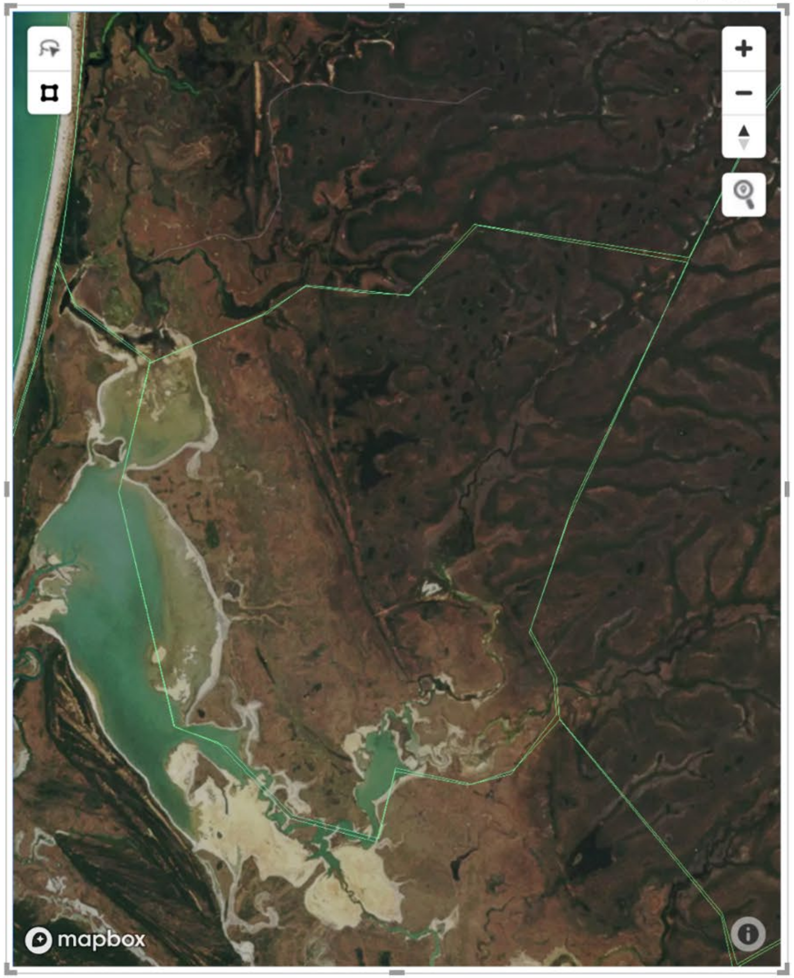
VALUES

Very good cattle grazing wet season to mid dry season

THREATS

Seasonal impact from cattle and pigs on vast floodplain habitat

Ootuk ellen to Kencherang



SELECT ZONE

Zone 09

DESCRIPTION

Area with very little freshwater. Permenent water at Kencherang and Big Lake

MANAGEMENT

Aerial control. Mustering of cattle

ACCESS

Limited access until mid dry season (August/September). Good 4WD access from September to November following grading

Figure 57. Zone 9 details.

5.5.6 Seasonal management for zones 15 and 16

(Figure 58 and Figure 59)

Zones 15 and 16 are very difficult to access and are dominated by homogenous open woodlands. Pigs in these areas rely on late dry-season waterholes to survive. A targeted late dry-season aerial baiting program is likely to have significant impact on feral pig populations in this vegetation type if important late dry-season refuges are identified and mapped, and baiting and control targets these water holes. Tracking data in zone 14 showed that feral pigs in this zone relied on only three major waterholes during the late dry-season period. This indicates that management pressure could be very targeted and at a much smaller scale than previously thought to have significant impact. More data is required to identify the location and movement of major sounders in these zones. This will require tracking. Presently no seasonal management objectives have been defined for these zones due to lack of data and difficultly of access.

CATTLE DENSITY

Low

PIG DENSITY

Low

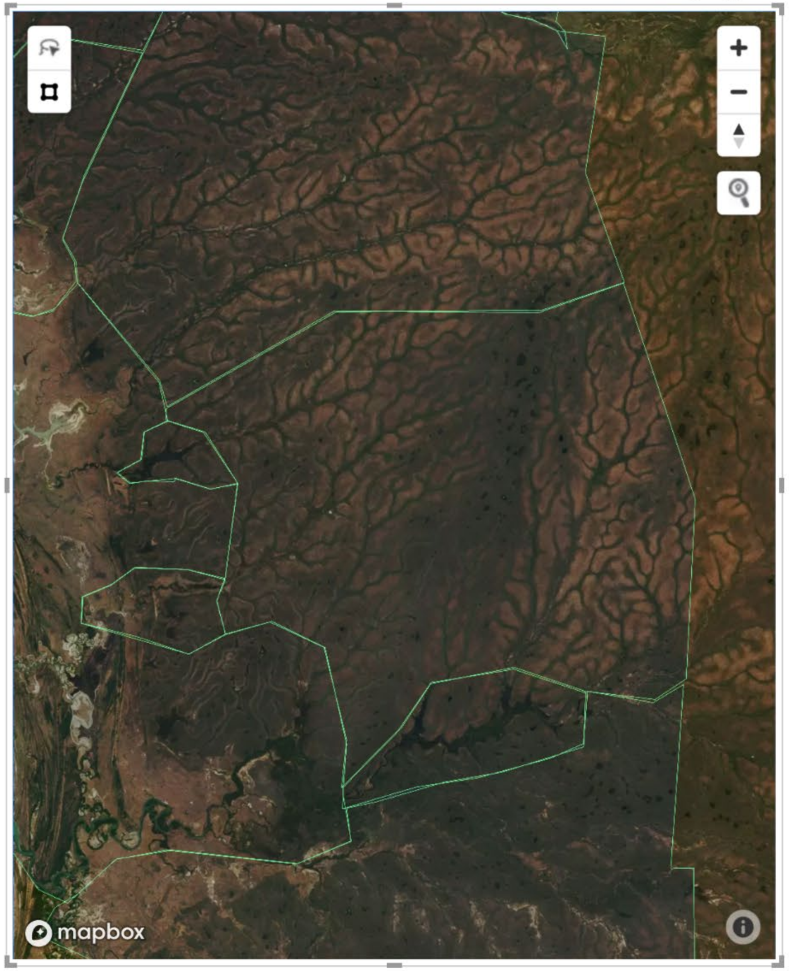
VALUES

large semi-permenant waterholes provide essential dry season habitat for many species. Important recharge zone for ground water dependent ecosystems.

THREATS

grazing pressure and significant impact to late dry season water holes.

Upper Sinclair Creek



SELECT ZONE

Zone 15

DESCRIPTION

Upper catchment no roads

MANAGEMENT

limited aerial control. Consider late dry season aerial baiting at selected late dry season water holes.

ACCESS

Helicopter access only

Figure 58. Zone 15 details.

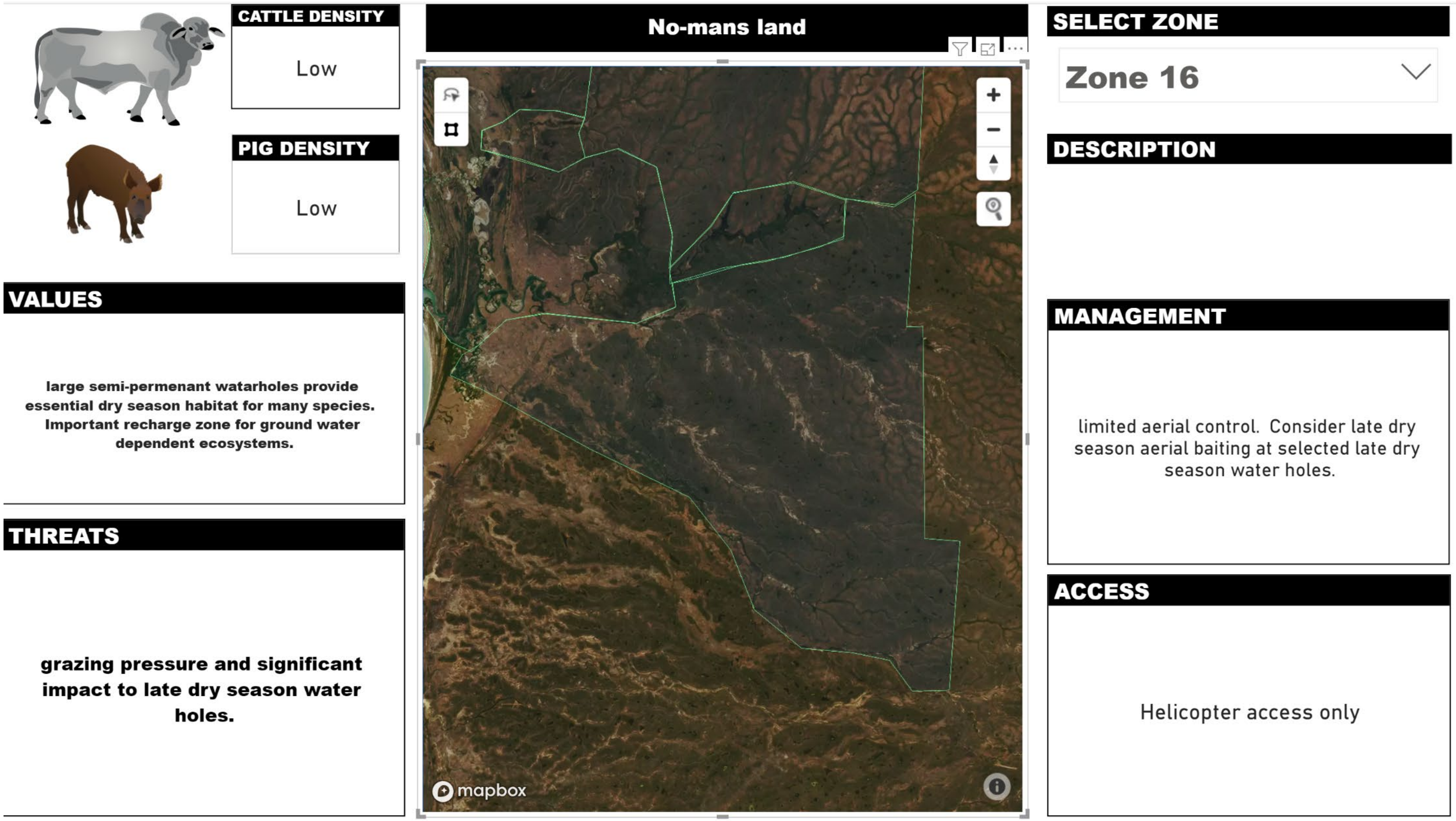


Figure 59. Zone 16 details.

5.5.7 Seasonal management for zone 13

(Figure 60 and Figure 61)

Significant effort and resources have been put into managing feral pigs in this zone. Detailed surveys have indicated that feral pig densities are among the highest in Australia at this location. Despite significant investment and the most intensive and sustained aerial control, the pig populations have not decreased and a minor increase has been observed. Data collection from contract shooters has not been at a high standard since 2018 limiting comparisons in recent years. Any contract shooter should be required to take detailed data so that public funding is not wasted on ineffective control measures. Additionally, funding spent on aerial control does not meet the objectives of APN for local participation and should only be prioritised if there is demonstrated success for other metrics, such as protection of key wetlands and maintaining low predation of marine turtles.

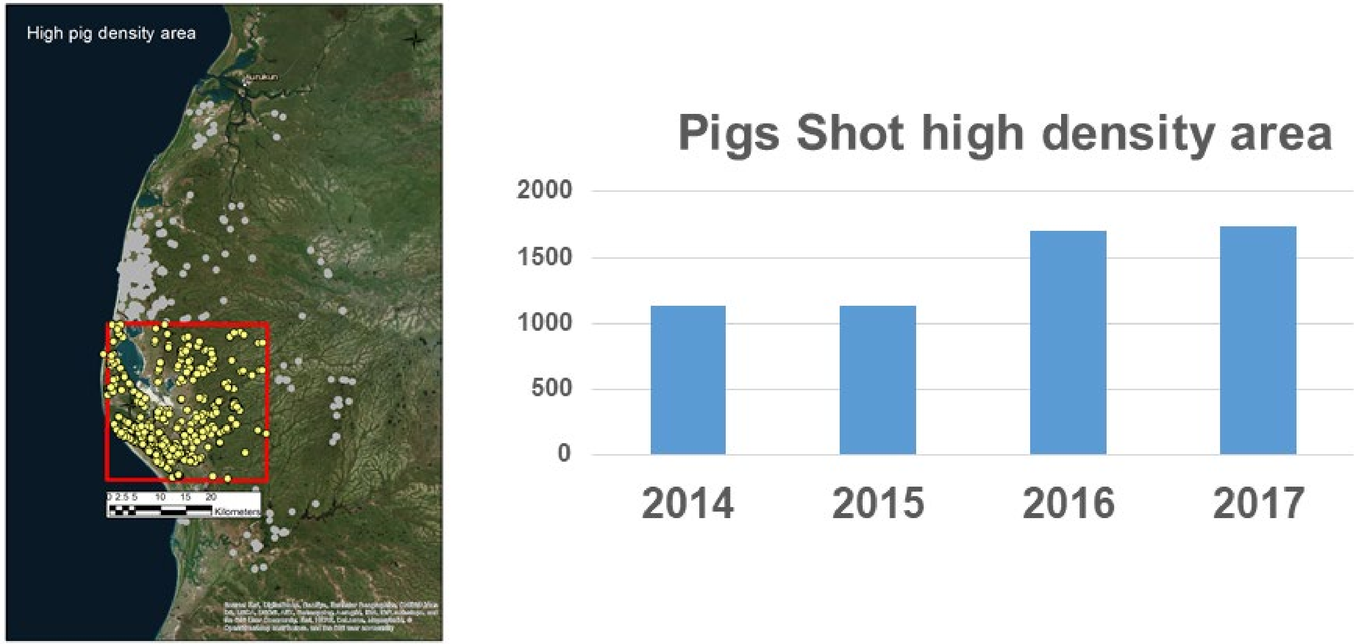


Figure 60. Aerial shooting counts from 2014 to 2017 in the zone 14 high pig density zone.

5.5.7.1 Um kaapak, Kaap and Onchan wayath. Wet season to early dry season. January to April.

Floodplains are wet and access is limited. If research partners and funding allow, conducting magpie goose nesting surveys would be useful for understanding major breeding areas and recording potential depredation by feral pigs of geese nests.

5.5.7.2 Onchan min. Early dry season. May to July.

Limited access during this period. Aerial control activities should focus on Eleocharis channels on the flood plain where feral pigs dig and eat the nutritious bulbs. Aerial control conducted in this region in March illustrated very high abundance despite extensive water in the flood plains. Pig populations in this area are unlikely to travel far due to all food, shade and water requirements being met throughout the year.

5.5.7.3 Kayaman Maal. Mid dry season. August to September.

There is no evidence that aerial control in the high-density area (zone 13) has had any impact on biodiversity values or marine turtle nesting. A more intensive integrated pest control program is required in zone 13 and aerial control effort and resources should focus on zones 1, 2 (beaches) and 7, 8 and 9 (moderate to low density pig areas adjacent to primary turtle nesting habitat).

5.5.7.4 Kayanman Pung Nganth Ling-Ling and Thurpak. Late dry season. October to December.

Intensive aerial baiting could be very successful in this area. During this period there is very limited visitation so impact on Traditional Owners would be limited. Significant consultation required with Traditional Owners if aerial meat baiting is considered.

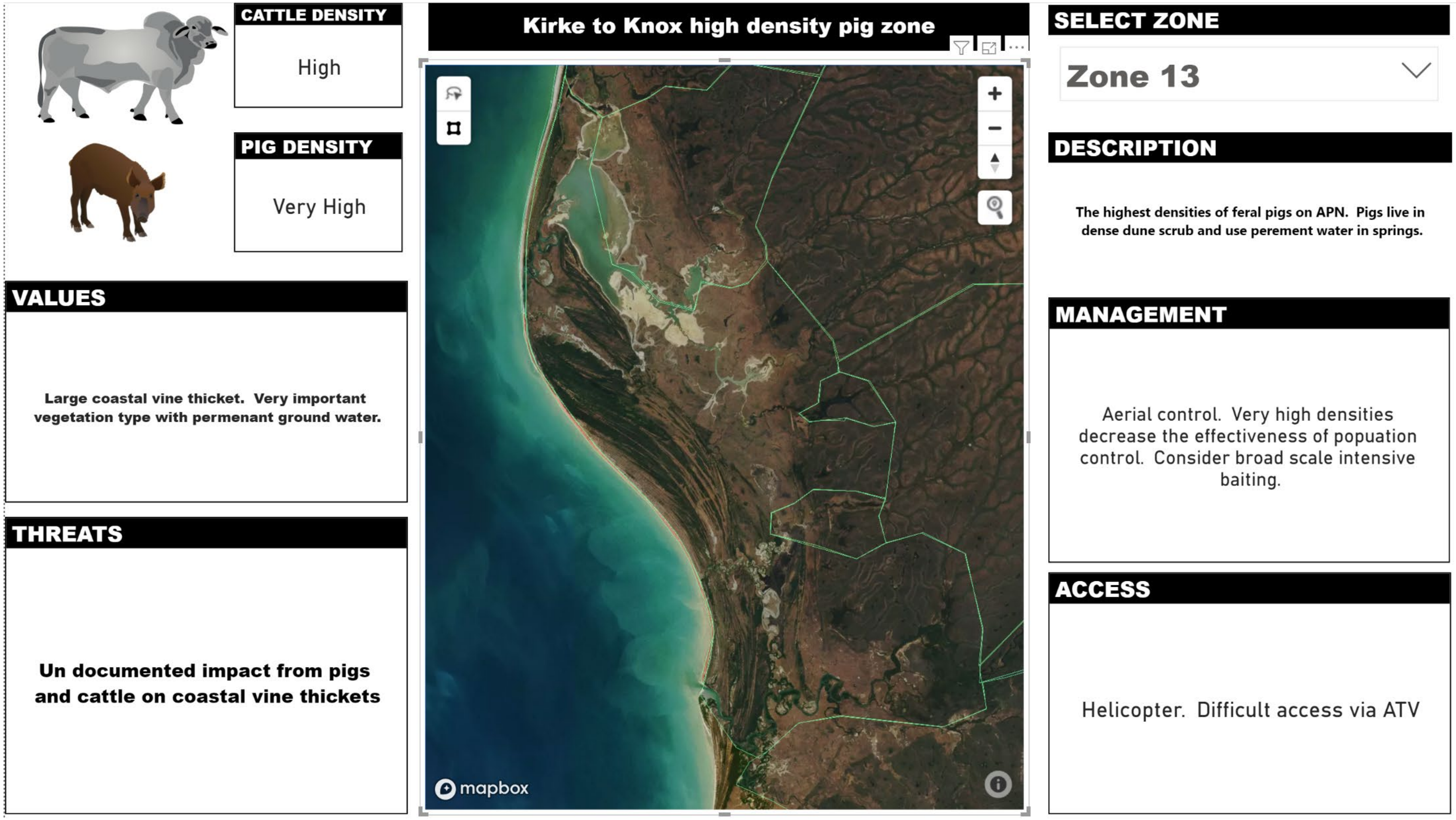


Figure 61. Zone 13 details.

5.5.8 Seasonal management for zone 14

(Figure 62)

Zone 14 is accessible via the main access road leading down to the coast and should be prioritised for strategic, targeted management of late dry-season waterholes through trapping and baiting activities in the late dry season. Waterholes can be accessed via ATV and planned access tracks to major waterholes could provide dry season access via 4WD vehicle.

This zone has very good tracking data from the Feral IoT project indicating that pigs do not move very far throughout the year and are reliant on a handful of late dry-season waterholes.

5.5.8.1 Onchan min. Early dry season. May to July.

The exclusion fence should be checked and repaired as soon as access is possible. If pigs move inside the fence during this period damage can be significant before repairs are made.

5.5.8.2 Kayanman Pung Nganth Ling-Ling and Thurpak. Late dry season. October to December.

Maintain pig exclusion fence at the Blue Lagoon waterhole to demonstrate feral pig impacts to funders and Traditional Owners. Use the feral pig tracking data from the Feral IoT project to identify key late dry-season resource use by pigs in this zone (Figure 63). In the late dry season, the collared feral pigs concentrated their activities around three main water sources (Figure 64.)

Movement in the wet season was much broader including one pig shifting onto the coastal zone (Figure 65). The pigs moved less in the late dry season and were found in the middle of drying waterholes for most of the time (Figure 66). This is most likely reflecting temperature control through wallowing, access to water for drinking, a reliance on the remaining vegetation associated with the waterholes that retain water into the late dry season and most likely hunting of aestivating fresh water turtles that bury themselves in these waterholes to avoid the late dry-season heat and dryness. These data indicate that through identifying key late dry-season waterholes in this zone APN could have success conducting targeted trapping or baiting in this zone. The area is heavily treed making aerial control and pig detection from the air very difficult.

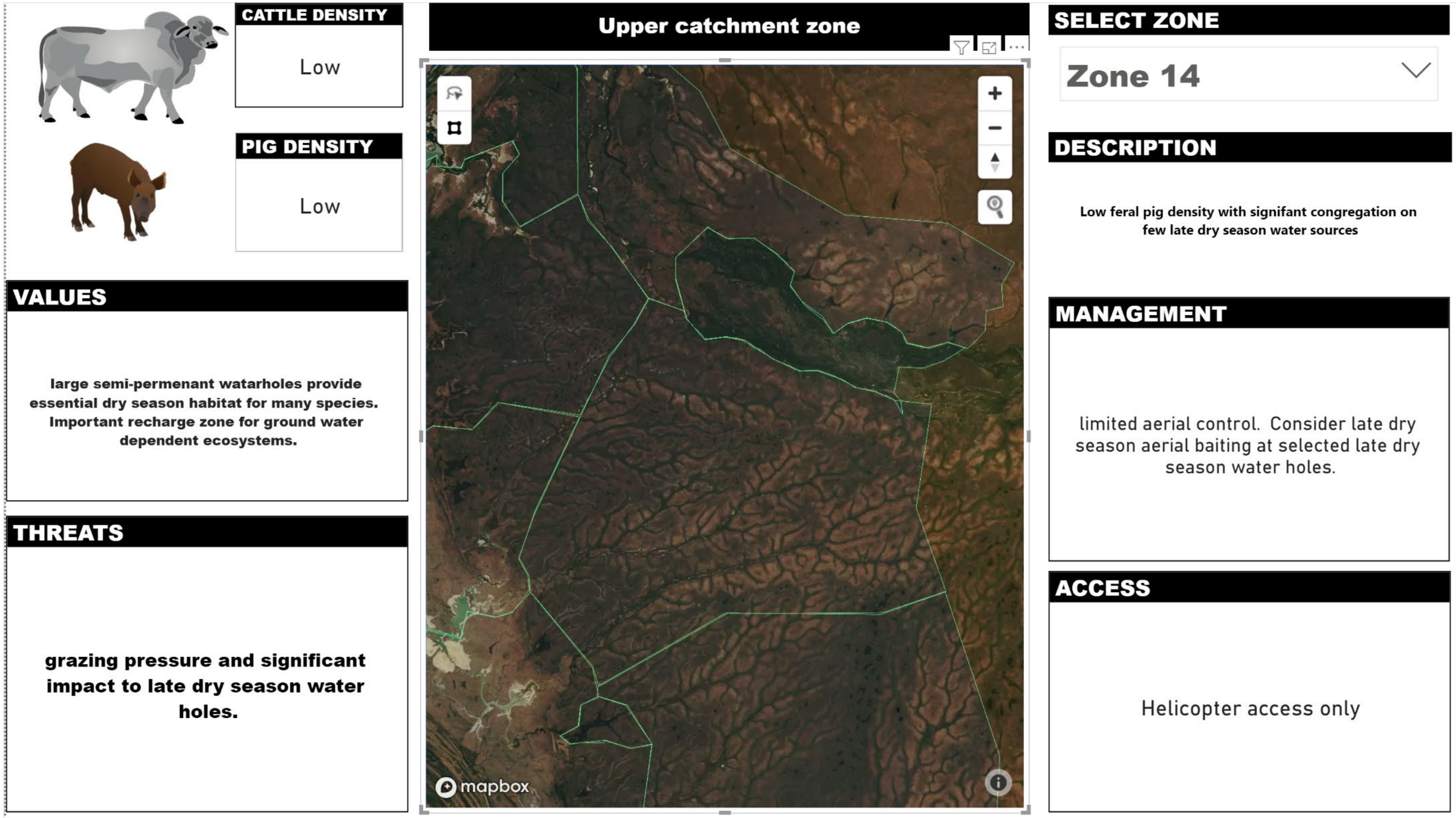


Figure 62. Zone 14 details.

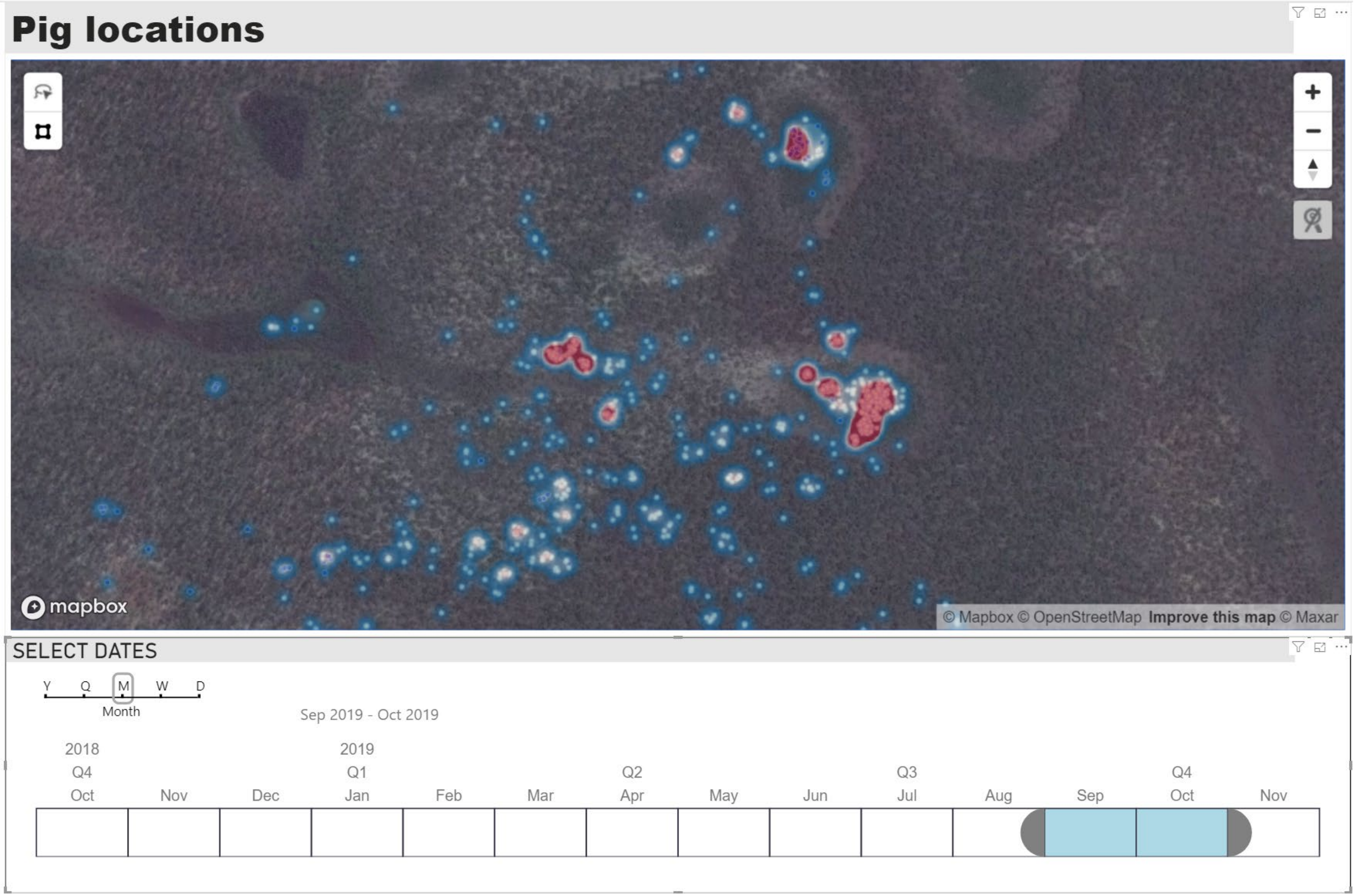


Figure 63. Close-up of pig movement in the late dry season indicating significant reliance on three waterholes with two driving most of the late dry-season activity.

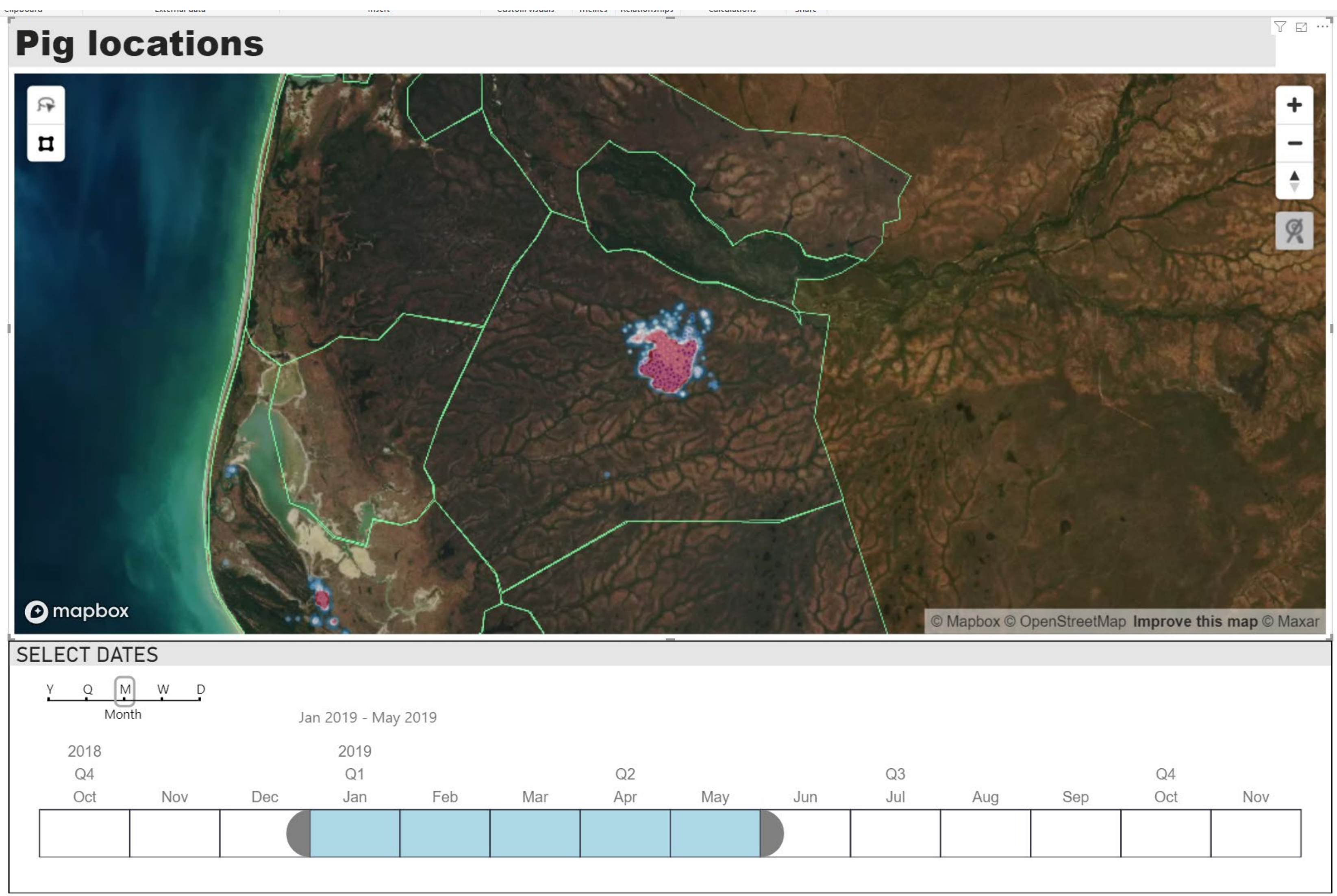


Figure 64. Widespread wet-season movement in zone 14. Note one pig moved into the coastal zones (bottom left) during this period indicating high connectivity in the landscape.

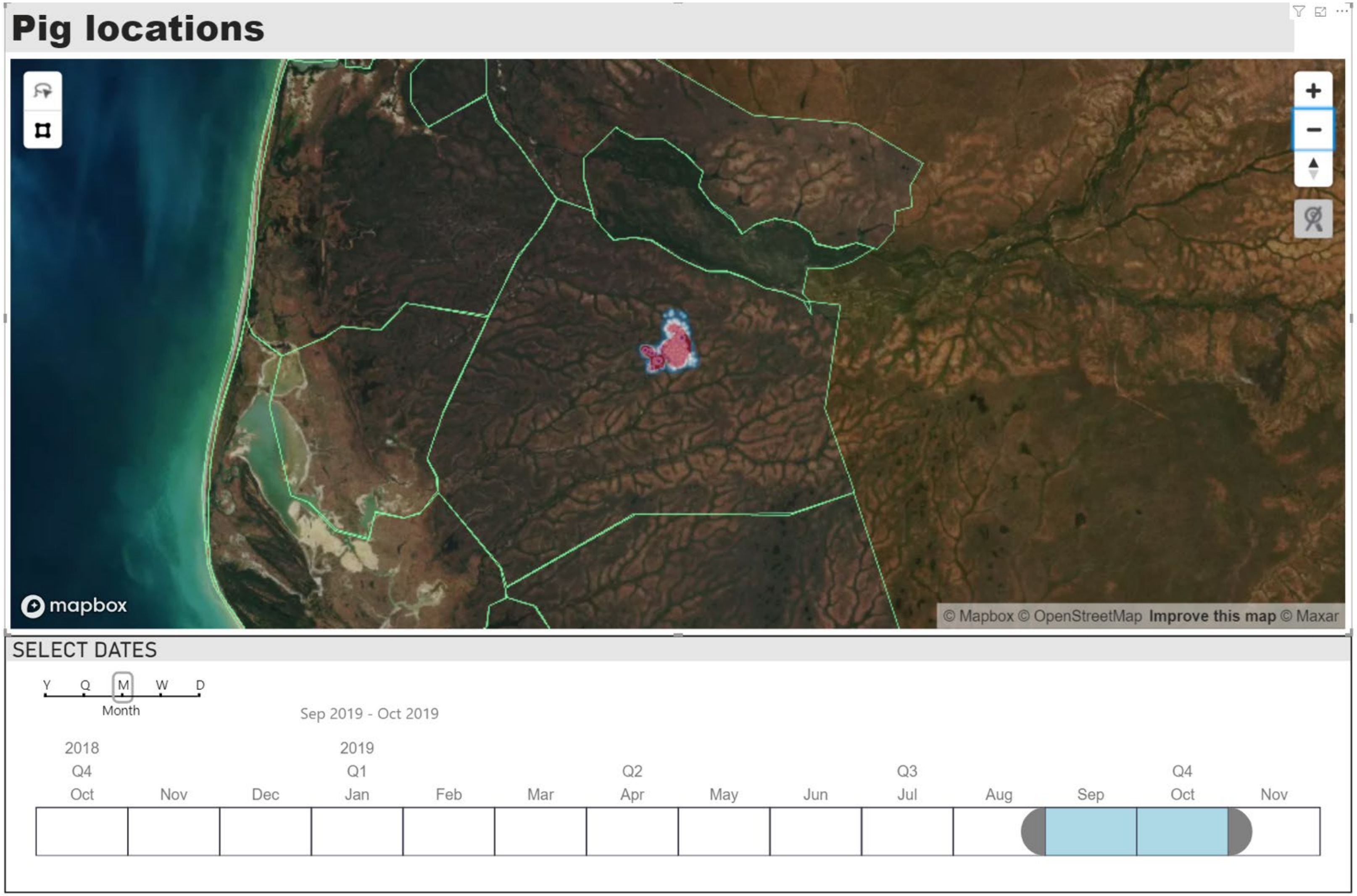


Figure 65. Restricted movement recorded in the late dry season in zone 14.

5.5.9 Seasonal management for zone 11

(Figure 66)

The Sinclair Creek groundwater-dependent ecosystem is one of the most important aquatic refugial habitats in northern Australia. This remote area has virtually no information recorded. Feral pigs are largely excluded from the major spring-feed section due to extensive permanent water with dense floating vegetation. Where the spring-feed section flows into more open flood plain areas feral pig damage is very significant. Due to access constraints and limited resources, there are no ongoing management controls for this area. Future environmental funding should prioritise significant investment in protecting and rehabilitating this area through extensive aerial control and baiting activities to dramatically reduce feral pig impacts.

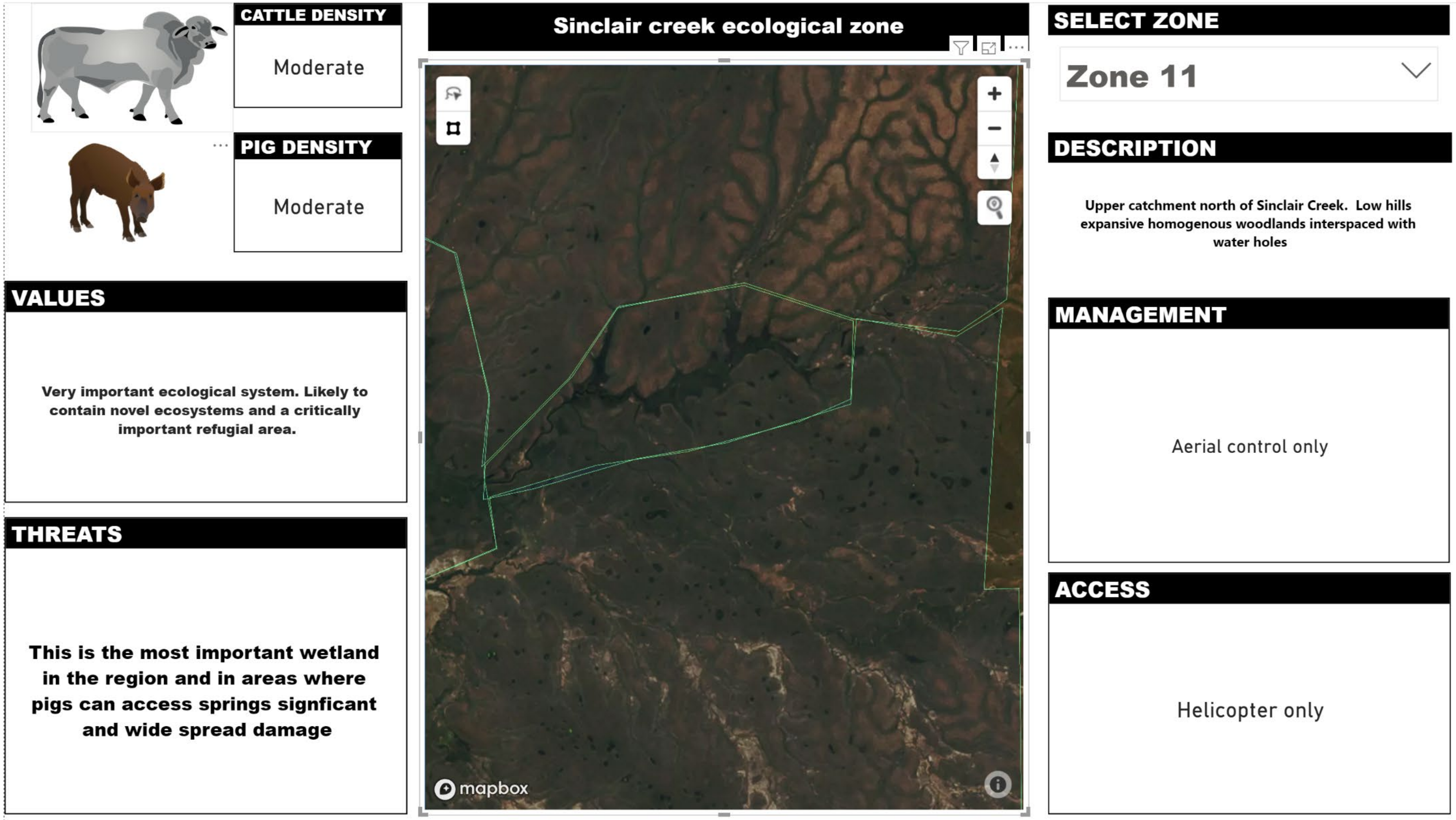


Figure 66. Zone 11 details.

5.5.10 Quantifying changes in pig population following control by zone

5.5.10.1 Methods

Quantifying spatio-temporal effort by zone

GPS tracks were collected for each shooting event between 2014 and 2020. This activity was undertaken by different feral animal control contractors and GPS tracks were not collected in a similar way each time. Tracks were collected with the wrong date/time stamp and others were provided only as images within a report without the data files or metadata.

Due to the variability and uncertainty of data quality we chose to normalise effort by calculating the total distance travelled in each zone during the shooting period. This is linked back to the GPS point files which documented pigs shot and were collected in a standardised way each time. In some months and years data were not collected by the shooting contractors or were collected using methods that were not directly comparable to the methods we devised for the project. We exclude these records from this analysis. After removing the unreliable data, we were left with nine events representing 48 days of shooting (Table 13).

Table 13. Shooting data highlighting in green events with verified data.

Event no.	Month	Year	Days	Cost heli	Cost shooter (avg)	Ranger costs ($40/hr)	Total cost	Total pigs	Length (km)	Notes
1	**September**	**2014**	**6**	**15750**	**9325**	**700**	**25775**	**1023**	295	exclude – cannot verify – missing data
2	**November**	**2014**	**5**	**13770**	**9325**	**612**	**23707**	**856**	1266	exclude – cannot verify - missing data
3	**May**	**2015**	**4**	**11790**	**9325**	**524**	**21639**	**943**	535	exclude – cannot verify - missing data
4	September	2015	6	20700	9325	920	30945	1282	1378	include
5	November	2015	3	9810	9325	436	19571	547	779	include
6	May	2016	6	17550	9325	780	27655	1320	1354	include
7	September	2016	6	16830	9325	748	26903	1290	1103	include
8	May	2017	5	27000	9325	1200	37525	1200	1931	include - for summary but no spatial data available for pig locations
9	October	2017	8	32270	**9325**	**1300**	**42895**	812	….	exclude - no gps tracks available
10	August	2017	5	23100	**9325**	**1320**	**33745**	866	….	exclude - no gps tracks available
11	March	2018	4	14840	9325	848	25013	580	410	include
12	June	2018	6	32550	9325	1432	43307	1291	1451	include
13	August	2018	7	21560	**9325**	**1148**	**32033**	800	….	exclude - no gps tracks available
14	October	2019	6	13400	**9325**	**1492**	**24217**	1171	**3203**	include
15	September	2020	6	15835	9325	1452	26612	1390	2213	include

Effort by hours

An attempt was made to compile a detailed hourly figure for each shoot. We collected all the helicopter invoices that outlined number of hours for the helicopter for each day. There was not sufficient detail in the invoices to accurately reflect the number of hours spent dedicated to shooting. During shooting activities helicopters are often used for other purposes and invoices rarely reflect the daily hours split between activities. This exposed a critical data gap for accurately monitoring shooting activities. For future investments in feral animal control, ranger groups should demand itemised activities from contractors to enable better accounting of effort and expense.

Providing minimum invoice requirements for contracting helicopter companies and aerial shooting contractors as part of grant rules should be a high priority for future government investments in feral animal control activities.

GIS methods

We aggregated the total length of GPS paths for each of the defined management zones by survey event. Each event is defined by month, year and the number of days over which the shoot occurred (Figure 67 and Figure 68). ArcGIS desktop 10 (esri.com) was used to split the lines according to the zone they intersect with and output a new shape file using the split polylines function (xtools.pro). The Identity tool (xtools pro) was used to intersect the split polylines for the survey period with the management zones to append the zone number to each split line. The calculate geometry tool (xtools pro) was used to calculate the total length (km) of each of the split lines in each zone. The dissolve features tool (ArcGIS 10) was used to aggregate the data by zone using the sum on the length field as the output statistic. The calculate geometry tool was used again to append the size of each zone into the table. All values were exported into a table and an index of effort was derived for each zone by dividing total length for each shooting event by the total area of the zone.

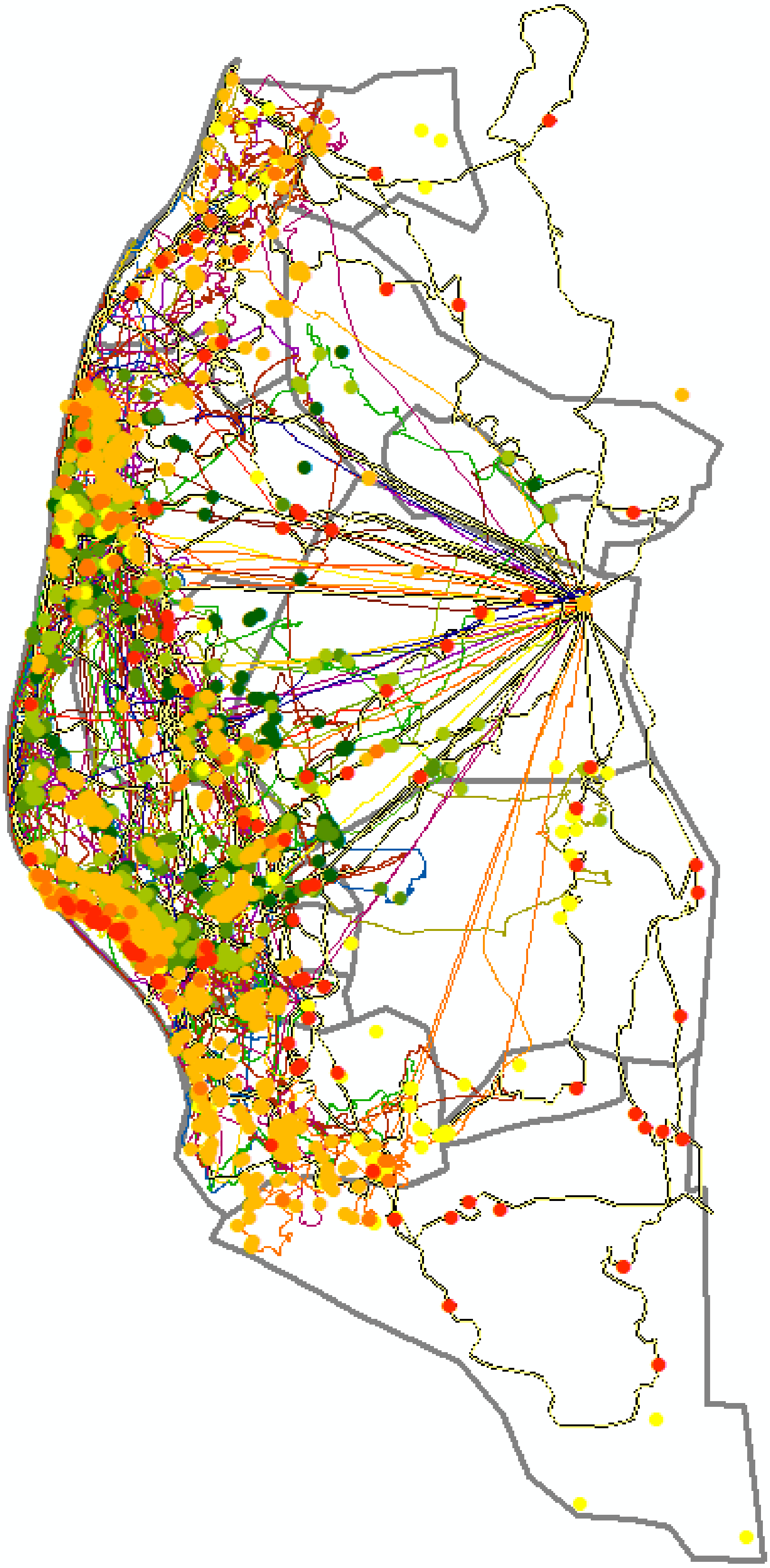


Figure 67. All available shoot paths and culling data 2014 to 2020 for the APN study area.

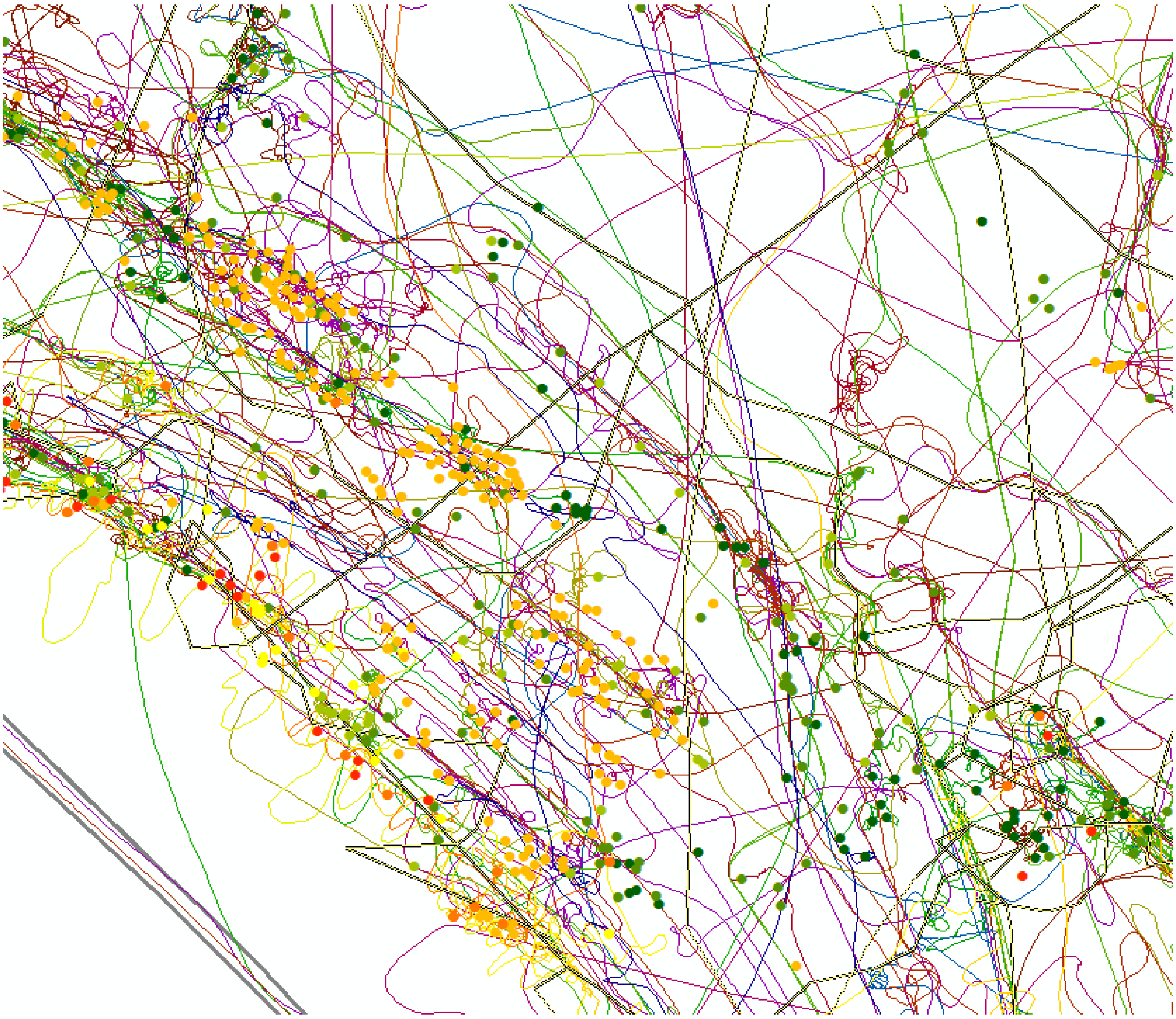


Figure 68. Close-up of flight paths in one of the high-density pig control areas demonstrating the concentration of effort in some areas.

Results

Total costs

A total of $565,959 was spent on aerial culling in the APN management area over six years including 14 shooting events, 78 days and 354 hours of helicopter time. The greatest expense was for helicopters ($360,555) and shooting contractors ($127,764). The total involvement for APN rangers and Traditional Owners was 354 hours equalling only $14,160 of the total being spent on local employment (Table 14).

Table 14. Total costs for aerial culling at APN.

Expense	Description	Total	Total local value to Wik people
Helicopter hours	354 hours of helicopter time dry price @~$700 per hour	259755	0
Helicopter fuel	354 hours at average $120 per hour	42480	0
Ferry costs	14 shooting events with average of 6 hours per event. $1200 per hour	100800	0
Shooter contracts	78 days, average $1638 per day (ammunition inclusive)	127764	0
Travel costs (contractors)	14 shoots at an average of $1500 per shoot	21000	0
Ranger costs	1 ranger observing per shoot at $40 per hour, 354 hours	14160	14160
	TOTALS	**$565,959**	**$14,160**

Pig shooting results

When considering the data that could be verified (8 shooting events), there is a relationship between effort and total pigs culled (Figure 69). These data suggest that once the effort exceeds 1,000 km for a shooting event, at the APN study area, there is limited return on investment with around 100 extra pigs shot for more than double the effort. In the absence of targeted control operations (i.e. when shooting is aiming to remove as many animals as possible rather than reduce impact on certain values), there is little to be gained beyond the first three days of culling. This is important in this case as most shooting events were carried out over more than five days indicating that significant savings (up to half) could be made with little impact on the results. However, as APN is using the aerial control to protect marine turtles from pigs, the analysis needs to account for changes in pig population across time in management zones adjacent to nesting beaches.

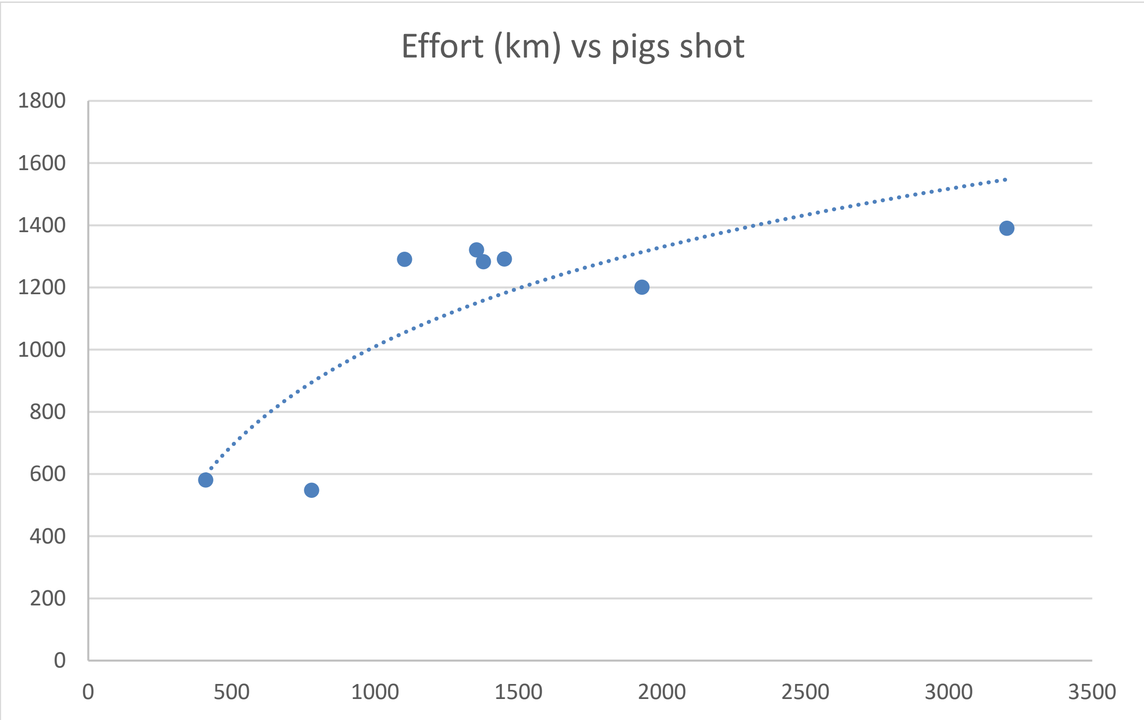


Figure 69. Total kilometres flown (effort) verses number of pigs shot for eight culling events at APN.

If appropriate data sets had been collected by feral animal contractors and helicopter pilots including:

i. latitude, longitude, date, time, number of pigs shot for each cluster
ii. time-embedded GPS track accurately marking the start and finish of each shooting event
iii. number of pigs missed in each cluster engaged

then it would be possible to accurately measure the effectiveness of shooting activities across time in areas of interest. Here we have had to make coarse approximations as the contractors did not collect these simple metrics.

Effort in each management zone

Here we illustrate effort versus return for key management zones in the APN study area.

Zone 7 is the management zone that is directly adjacent to the intensive turtle management beach (Figure 70). This zone received consistent attention over time, with an increase in 2019 in response to planning sessions indicating more effort was required to protect nesting beaches. In the absence of planning due to the COVID-19 pandemic the culling was undertaken by a shooting contractor and, as demonstrated here, the effort dramatically reduced in this zone. This zone has few pigs so many hours can be expended to kill fewer pigs which has led to less effort in this zone when shooters have not been given specific direction. Figure 70 illustrates that populations have remained relative steady over time with fluctuations in total pigs shot reflecting changing effort over time.

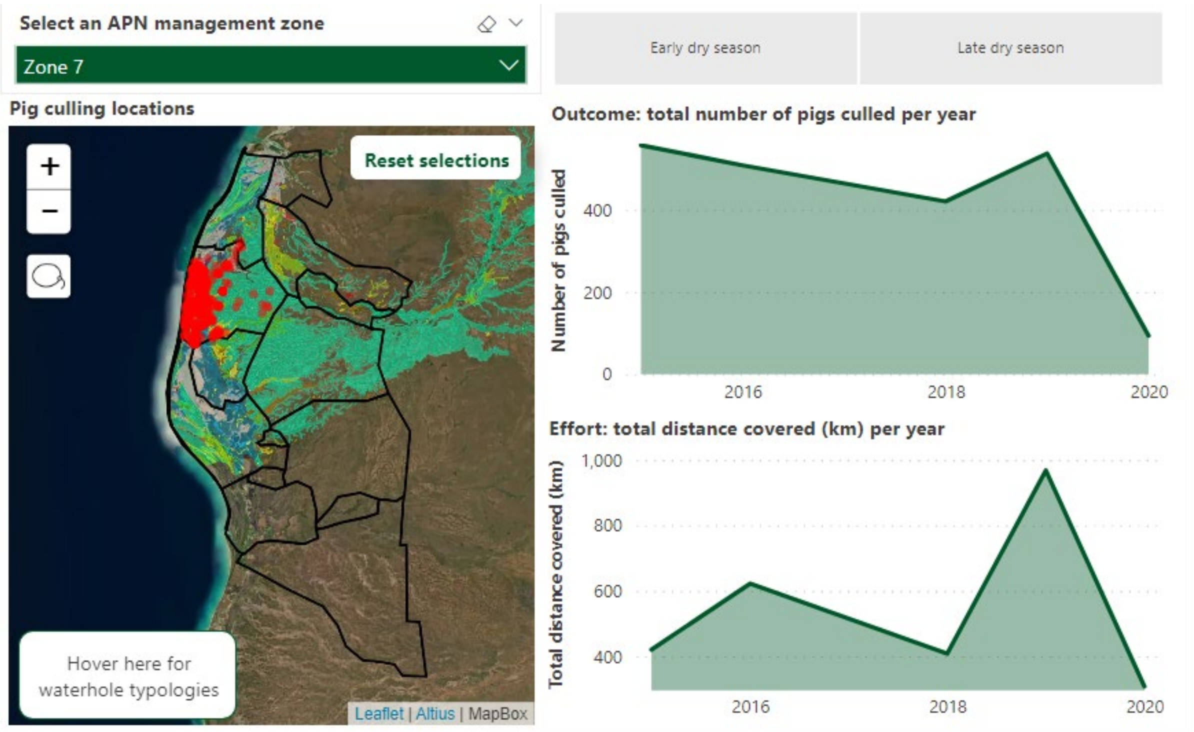


Figure 70. Zone 7 culling data.

Zone 8 has not been the focus of intensive control over the study period as this is a hunting area for Traditional Owners and little was known about nesting on the adjacent beach. Aerial nest surveys of turtle nests in 2017 indicated that this beach has high turtle nesting density and very high depredation of nests by pigs. More effort has been applied in this zone since 2018 (Figure 71).

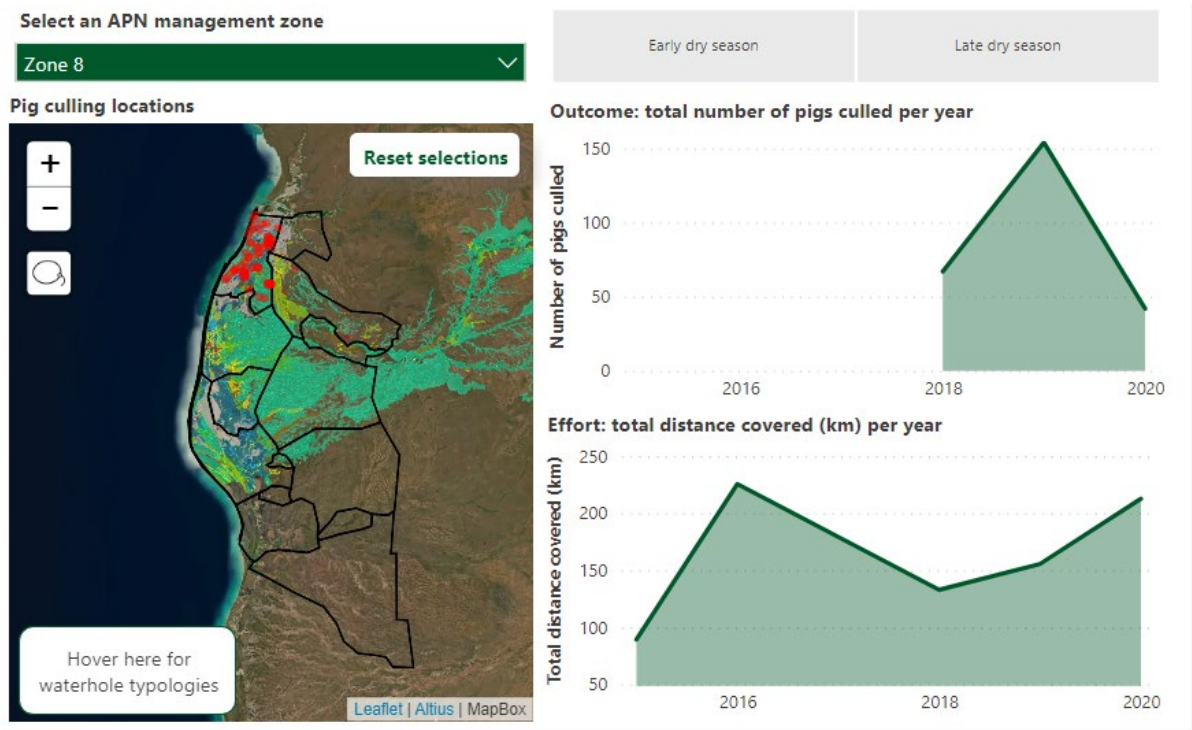


Figure 71. Zone 8 culling data.

Zone 16 has had more regular effort since 2018 (Figure 72). This site is not a key management zone and the effort recorded since 2018 reflects a propensity for contract shooters to seek out new areas to increase the total number of pigs killed. Figure 72 shows that in 2018 around 300 extra pigs were culled, which would greatly increase the event total. However, killing these animals offered no tangible benefit for the APN management objectives, and as this zone is the furthest away from the refuelling station the ferry costs are significant.

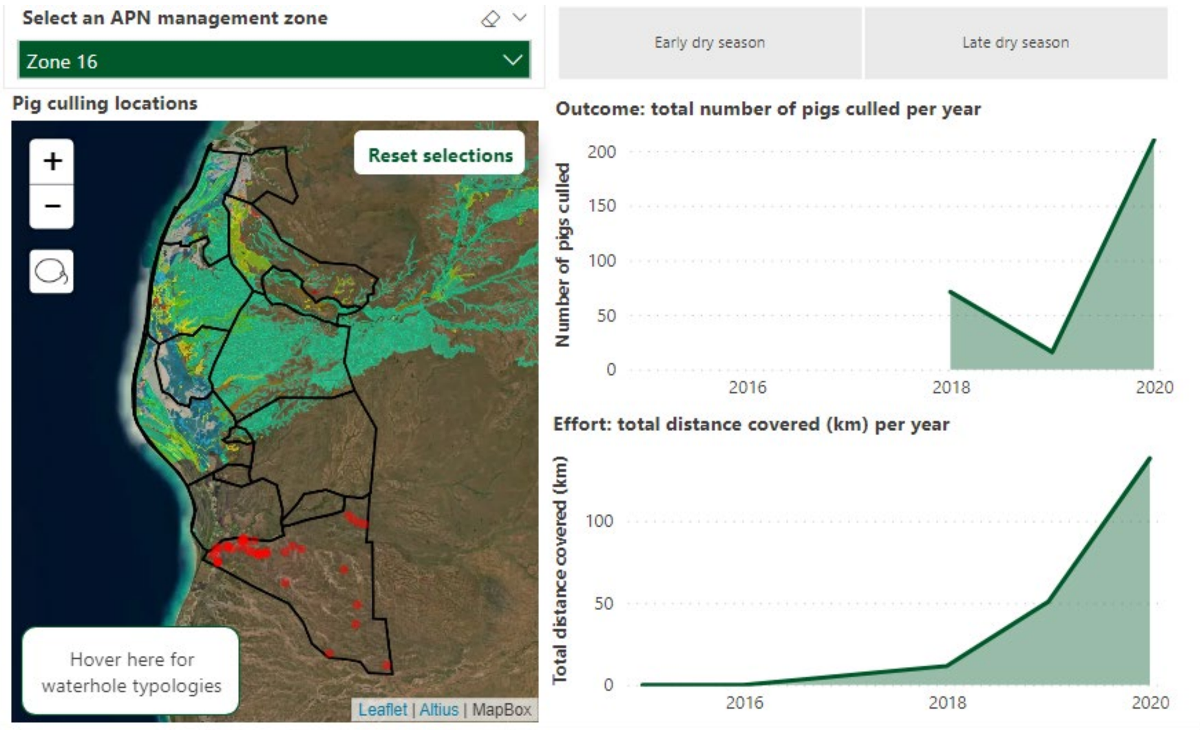


Figure 72. Zone 16 culling data.

Zone 13 supports the highest density of feral pigs in the region (Figure 73). The great majority of pigs killed for all shooting events are from this zone. The data shows that, despite consistent effort, pig numbers remain high and lower pig numbers are a result of less effort rather than a reduction in population. The culling efforts in this zone have not reduced pig populations over time, even with up to three culling events per year since 2014. This result is not surprising as this zone has complex vine thickets where pigs can hide during culling events. It is likely that each event is killing only 10–15% of the total population in this zone. The logistic growth model for pigs predicts that populations would recover annually with this level of culling (Figure 74).

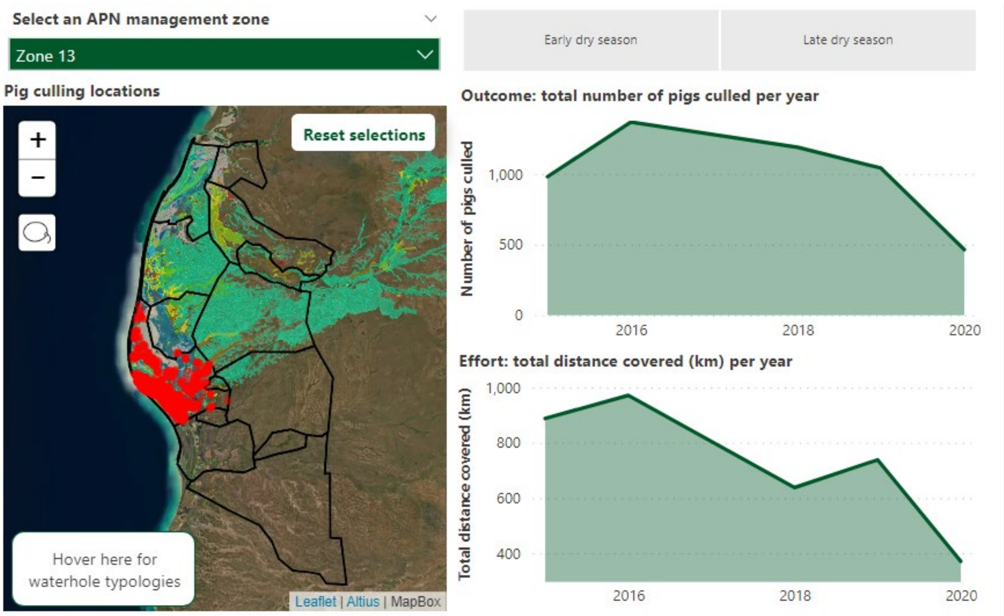


Figure 73. Zone 13 high-density feral pig zone.

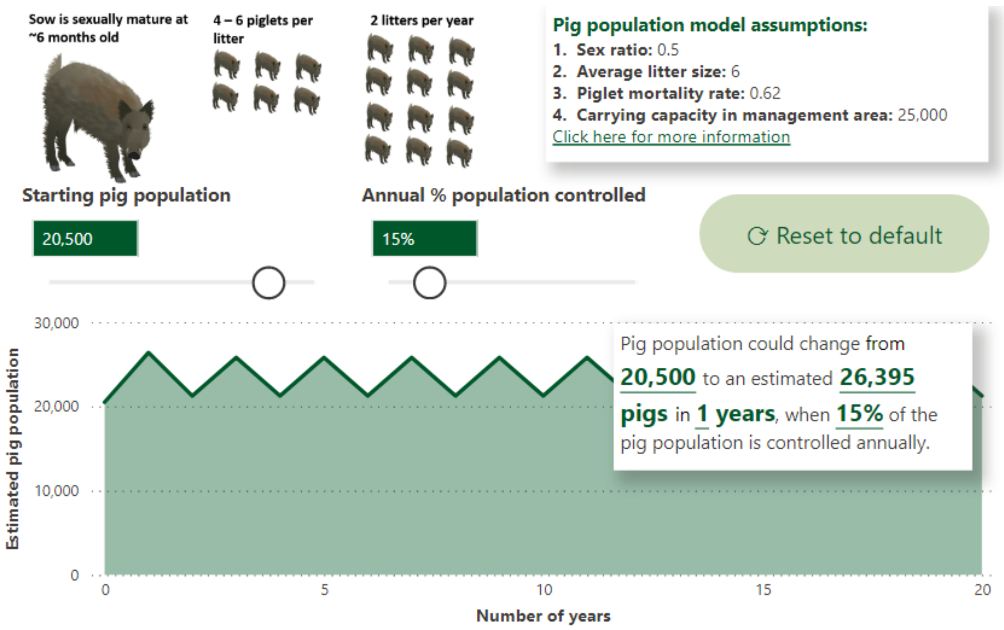


Figure 74. Population growth model for feral pigs predicts populations would recover annually, and could become denser, with 15% annual culling.

5.6 Recommendations for strategic management activities for APN to maximise benefits

5.6.1 Aerial control

Broad-scale aerial control should be maintained in the medium to low density pig areas where marine turtle nest depredation has been recorded. There is no evidence that aerial control in the high-density area (zone 13) has had any impact on biodiversity values or marine turtle nesting. A more intensive integrated pest control program is required in zone 13 and aerial control effort and resources should focus on zones 1, 2 (beaches) and 7, 8 and 9 (moderate to low density pig areas adjacent to primary turtle nesting habitat). The Distance Sampler application should be used to collect detailed data on where and how many pigs are shot in each shooting event. Contracts with professional shooters and helicopter companies should include a clause requiring timestamped GPS tracks to be collected that mark the start and finish of each shooting event, with clear itemisation of effort, so that costs and efforts can be accounted for (money, distance and time). Where possible an R44 or larger should be used for shooting so Traditional Owners and rangers can oversee the shooting operations and independently record animals shot. In the absence of this detailed data there is no evidence of control effectiveness and finding external financial support for ongoing control will be difficult.

5.6.2 Baiting

Poison baiting has proven to be one of the most effective means of targeted control of populations causing damage to marine turtles. Zones 1, 2 and 3 (beaches) could greatly benefit from intensive poison baiting every 4–5 years. Poison baits can kill other animals such as dingoes so a management partner should be engaged to assist with the planning and monitoring of large-scale baiting activities. Baiting is a controversial management technique so planning and implementation needs to be sensitive to public and community perceptions and values.

5.6.3 Exclusion fencing

Special waterholes and cultural sites can be fenced to exclude feral pigs and other large animals. This activity is expensive (~$5,000 per km of fencing) and requires substantial commitment to maintain the fence annually. Feral pigs are persistent and intelligent and will quickly find any weak points in the fence. Pickets should be placed 5 m apart and any uneven areas require substantial extra engineering to remove any gaps a pig can lever and dig under. Barbed wire should be attached to the bottom of the fence to discourage digging. Fencing costs are around $5,000 per km so smaller wetlands should be targeted. Fences require annual maintenance in the early dry season to fix any breaks and to clean up fallen timber. Ringlock fence has larger gaps on one side and usually the smaller gaps are placed at the bottom. These wetlands are significant refugial areas for freshwater turtles so, to avoid trapping turtles in fenced water holes or excluding turtles that travel across land to find the waterhole, the larger gaps should be installed to the bottom. Every 10–20 metres, a wire can be removed which widens some of the gaps allowing large turtles to escape if required.

5.6.4 Strategic hunting and trapping to protect key species or habitats

During management and research operations over the past six years we have observed that most of the depredation on marine turtles is done by individual boars during peak nesting periods. In this case aerial control is not likely to be effective as the control needs to target individuals rather than aiming for general population reduction. Our data also indicates that feral pig predation remains constant in the same geographic area in the absence of hunting pressure (i.e. pigs have limited home ranges and target known food sources consistently in an area in the absence of external pressure). To strategically control individual pigs to protect marine turtle nests we propose an adaptive management program of intensive and targeted ground control, informed by ongoing monitoring of predation events. We have developed a data management dashboard linked to monitoring methods that maps depredation events (Figure 75).

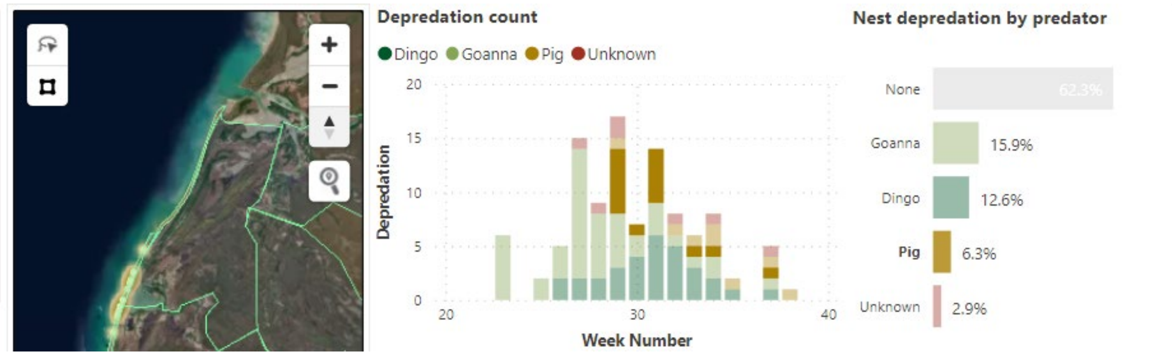


Figure 75. Example of the interactive dashboard displaying the location and timing of pig depredation of nests in the 2018 nesting season.

5.7 Recording effort and participation

One of the strategic goals of APN is to increase local participation across all land-management activities. When considering the costs and benefits of different control methods it is important to understand the value of each activity in the context of how much funding is distributed outside community employment.

Some feral animal monitoring and management activities require specialist skills (e.g. aerial platform shooting or monitoring activities). To better understand how resources are being spent across management zones we provide a reporting template with simple metrics that account for time, cost, and local participation in each activity (Table 15, Figure 76). The spreadsheet in Table 16 should be updated monthly for each zone and displayed in the interactive dashboard.

Table 15. Example of spreadsheet to be maintained for tracking effort, costs and local participation.

Zone	Year	Month	Date	Mgt activity	Traditional season	Cost	Days	Ranger staff	Traditional Owners	External input
02	2019	Dec	1/12/19	Nest survey	Kayaman Maal	5000	5	0	0	1
02	2019	Nov	1/11/29	Nest survey	Kayaman Maal	10000	12	0	0	1
02	2019	Oct	1/10/19	Nest survey	Kayaman Maal	10000	12	0	0	1
02	2019	Sep	1/09/19	Nest survey	Kayaman Maal	10000	12	0	0	1
07	2019	Oct	9/10/19	Aerial Control	Kayanman Pung Nganth Ling-Ling	5000	1	0	0	2
08	2019	Oct	9/10/29	Aerial Control	Kayanman Pung Nganth Ling-Ling	2000	1	0	0	2
09	2019	Oct	9/10/19	Aerial Control	Kayanman Pung Nganth Ling-Ling	2000	1	0	0	2
13	2019	Oct	9/10/19	Aerial Control	Kayanman Pung Nganth Ling-Ling	10000	2	0	0	2
14	2019	Oct	9/10/19	Aerial Control	Kayanman Pung Nganth Ling-Ling	1000	1	0	0	2
15	2019	Oct	9/10/19	Aerial Control	Kayanman Pung Nganth Ling-Ling	1000	1	0	0	2
16	2019	Oct	9/10/19	Aerial Control	Kayanman Pung Nganth Ling-Ling	1000	1	0	0	2

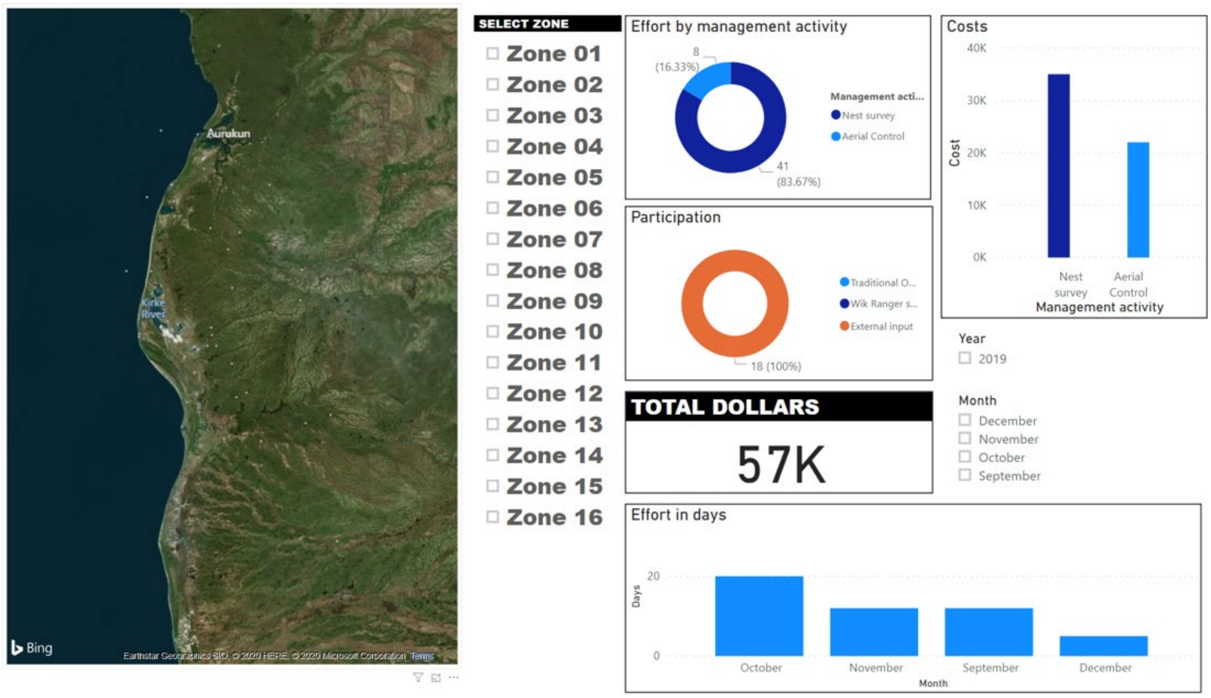


Figure 76. Screenshot of the interactive effort summary example that could be used by ranger groups to track their investment. A linked spreadsheet keeps track of monthly effort and displays totals and can be filtered by zone, year, month and activity.

6. Development of a reporting system for assessing the impact of feral pig management on aquatic systems

6.1 Introduction

Several reporting frameworks offer a useful guide about the current and changing environmental reporting requirements to assess and monitor pressures and measure the state of natural resources. These frameworks are increasingly incorporating social and economic data and consist of innovative valuation methods that could potentially guide reporting on ecosystem health and management outcomes at sub-regional and regional levels. Some of these reporting frameworks include those that focus on monitoring the state of wetlands and include:

- ABS Australian Environmental-Economic Accounts
- Federal government (Department of Agriculture, Water and the Environment) directory of determining nationally important wetlands
- Australia's Ramsar sites
- Queensland Government's WetlandInfo.

Others focus on monitoring, evaluating and reporting on management performance and impacts delivered through Landcare, Working on Country and other community-based NRM programs. At the national level this includes frameworks such as MERIT, regional frameworks such as the Eastern Cape York water quality improvement plan and local Traditional Owner efforts as part of the efforts and responsibility to look after Country.

The national environmental accounts is an inventory of environmental information that has been systematically organised to deliver readable information to the public on measures of change in the value of natural capital (land, air, marine, water, ecosystems and living organisms). It is based on an international framework, the System of Environmental-Economic Accounting (SEEA) framework, to track transactions between the environment and the economy (BoM 2013). The SEEA framework is based on a stocks-and-flows model to account for changes in value (stock) of natural assets using both monetary and non-monetary terms. Natural capital and associated flows of ecosystem services are key to establishing relationships between assets in environmental accounting. Ecosystem accounts are a new type of environmental accounts that treat ecosystems as an integrated whole. The ecosystem account is a comprehensive framework that considers the value of the ecosystem function, services and benefits to society, and is based on the use of the non-monetary values of environmental accounting. New methods being developed in the environmental accounts are extending environmental measurement and assessment to ecosystem assets and their related capacity to provide ecosystem services, and to expand reporting to include the social and economic realms of the human-environment system.

The ABS Australian Environmental-Economic Accounts estimate a monetary value of the Australian natural assets using an international statistical valuation model of the SEEA. Valuation is based on the use of integrated socioeconomic and environmental indicators such as gross value added for economic production, and energy and water consumption for indicators of environmental pressure. The ABS natural capital valuation calculates productive values for subsoil, land and timber assets, and has a separate experimental estimate of the value of the national water resource stocks that is based on tradeable water rights.

The Federal Department of the Environment and Energy also offers a directory of nationally important wetlands that have been agreed to under the ANZECC wetland network. These listed wetlands have been identified as nationally significant using six criteria that include historical and cultural significance of the wetland, the type of wetland in a particular biogeographic region, and the type of habitat the wetland provides. The department also provides a directory of its internationally important wetland sites (Ramsar sites). These sites represent unique or rare wetlands that are important to conserving biodiversity. The recent Ramsar policy paper (Kumar et al. 2017) affirms the necessity of recognising and integrating multiple values of wetlands into planning, management and policy. The policy is explicit about the importance of valuing ecosystem services including intrinsic wetland values and their material and non-material contributions, and their provisioning and regulating services to human society, ecological communities and landscapes.

The Queensland Government offers a comprehensive set of tools to aid assessment and monitoring of wetlands. Its wetland classification scheme uses attributes to describe and differentiate wetland types by function, status and values, and has been designed to improve knowledge for wetland management. The wetland classification attributes are classified by scale of data capture and reporting and are categorised by measurable biophysical and ecological characteristics (including vegetation structure and communities, morphological and hydrological data) as well as geography and landscape characteristics to develop wetland typologies. The Queensland Government's assessment and monitoring tools also assist practitioners and researchers to determine extent, condition, values, pressures and risks, and ultimately changes to the ecological character of wetlands. Water quality, biological features, wetland extent and type are the main indicator categories used to assess the pressure on and the state of wetlands. Assessment of wetland values is based on the provision of indirect benefits to human society through environmental processes, organisms, habitat, and the condition of the particular ecosystem. Identification and use of cultural resource categories in wetland values and management have not yet been developed in the state's WetlandInfo framework.

The Eastern Cape York water quality improvement plan that covers important wetlands and rivers in the Eastern Cape, was developed by Cape York Natural Resource Management, and was designed to feed into the Reef 2050 long-term sustainability plan. Development involved extensive consultation with scientists, Traditional Owners and local communities, and included collection of information on water assets, threats and pressures, potential management actions and environment values, and includes information on cultural and spiritual values of Traditional Owners and non-Indigenous residents. The operation of the plan involves Traditional Owners and community members in on-ground water quality improvement works and monitoring. Reporting is based on the seven themes of the Reef 2050 Plan Outcomes Framework: ecosystem health, biodiversity, heritage, water quality, community benefits, economic benefits and governance (Commonwealth of Australia, 2015).

This is supported by the National Landcare Program which provides funding for community-based on-ground land management activities that include feral animal monitoring and management. A range of activities are covered including community engagement, collaborative planning, fencing off key wetland areas and managing the impacts caused by feral animal populations in the region.

6.2 Creating a digital dashboard

The project team assessed the available reporting systems and decided to use an extensible digital solution that is becoming commonplace across businesses and government agencies called Microsoft PowerBI. We worked with PowerBI company DiscoverEI (discoverei.com) to aggregate the project data into an accessible interactive dashboard. This method enables ongoing development to occur to match changing requirements of end-users and to add in new data sets as they are collected.

We selected this method as we recognised that feral animal management and monitoring needs to take a values-based approach to assess impacts. Values change across sectors and land types and monitoring/reporting solutions need to adapt to the specific goals and contexts of different areas and social settings.

6.3 Results

The dashboard visualised data and results under five key headings:

1. Waterhole typology
2. Impact assessment
3. Freshwater ecology
4. Terrestrial fauna
5. Feral pig management
6. Cultural values.

Under each category the various methods used to measure impacts are summarised with narratives and methods described. The landing page has links to each of the categories and summaries the methods used for each site surveyed, which are displayed on an interactive map (Figure 77).

Click the pig icon to access the dashboard.

https://app.powerbi.com/view?r=eyJrIjoiOTQyYjAxZTAtNGIzMS00MDM2LWI1ODUtZmIxNTI3ZjJlOTBhIiwidCI6IjJiNzQ1YWMxLTZmNGEtNGUwZS1hOTczLWVkM2YyZjQ3NWUxNyJ9&pageName=ReportSectionb94273a8a90daa032188

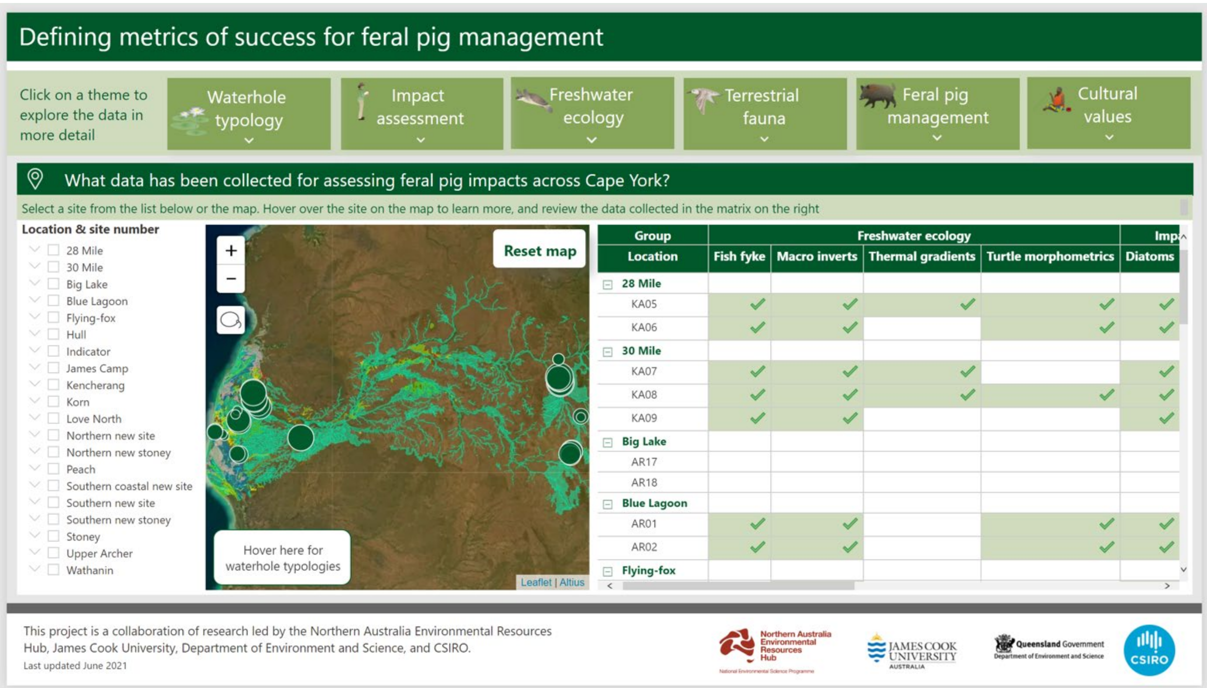


Figure 77. Landing page with links to data categories.

6.3.1 Waterhole typology

The first category is waterhole typology (Figure 78). Here we present a map of the waterhole categories with associated descriptions. These waterhole types reflect preferred habitat for feral pigs. We present the results from hundreds of aerial photographs taken in the APN study area in the late dry season of 2018 with summaries of a pig preference rating and pig damage score. Each waterhole type can be selected to view the distribution of pig damage across the waterholes surveyed and each waterhole photograph is displayed. The intent of this method is that waterholes can be surveyed via helicopter across time and changes to the distribution of pig damage can be reported following management intervention. This method also provides a baseline assessment of pig damage and variance within a waterhole type for future assessments. At the top of this page there are selectors for year, season and waterhole type so that annual assessments can be done.

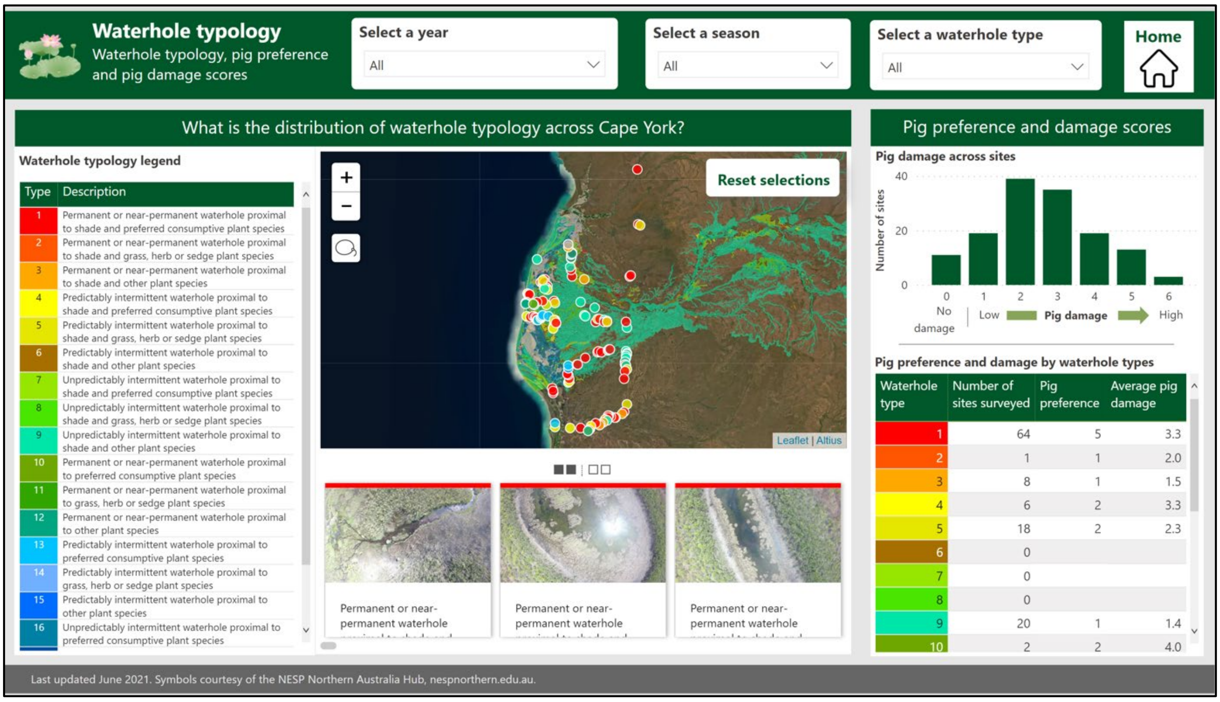


Figure 78. Waterhole typology page.

Data for each waterhole is presented when the user hovers over the location on the map. Points on the map are coloured based on waterhole type (Figure 79).

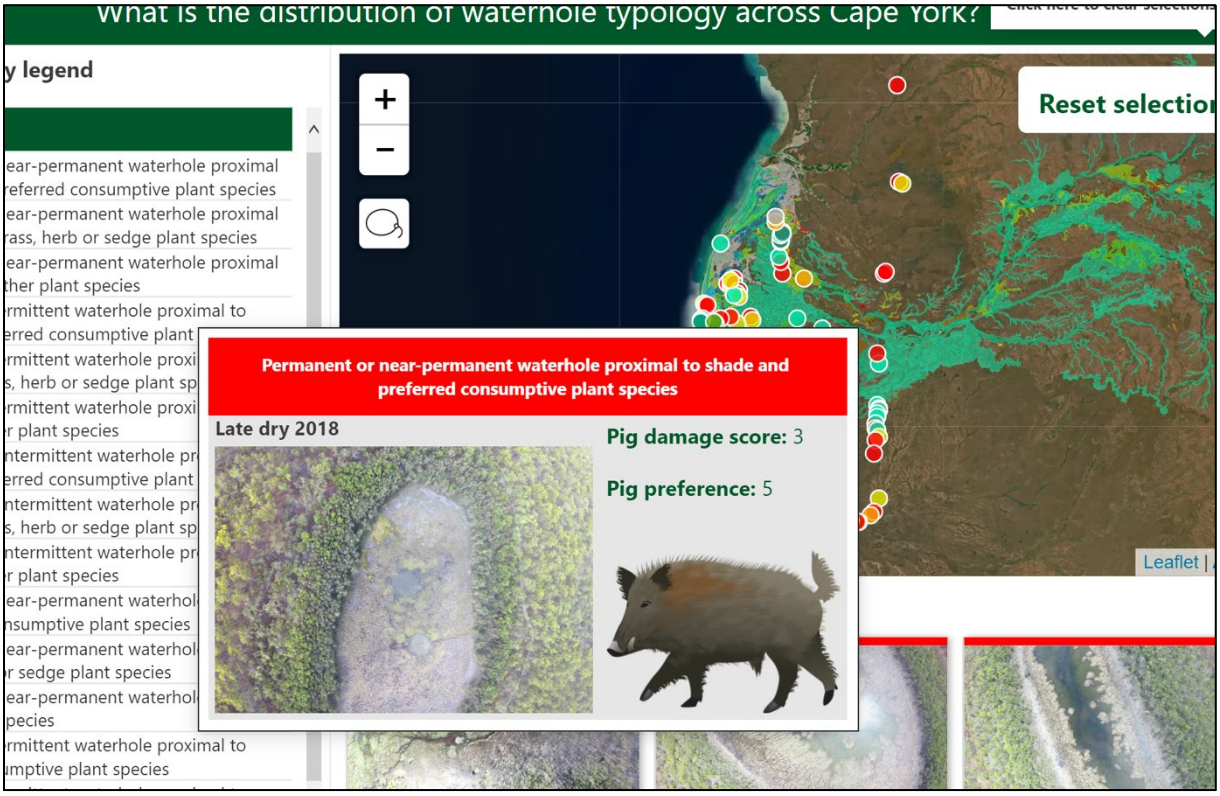


Figure 79. Demonstration of pop-up summary information about a waterhole that is displayed when the user hovers over a point on the map.

6.3.2 *Impact assessment*

The second category aggregated data on impact assessment metrics. This included:

1. Pig damage
2. Terrestrial invertebrates
3. Sediment coring
4. Diatoms
5. Field water quality
6. Lab water quality.

6.3.2.1 *Pig damage score*

This page summarises the data from each site in regard to how well pig exclusion fences protected waterholes. Data from each site is displayed when clicked and an aggregated summary graph shows the data for each treatment type (Figure 80). A button can be clicked to show conceptual diagrams of pig impact given different fencing states (Figure 81).

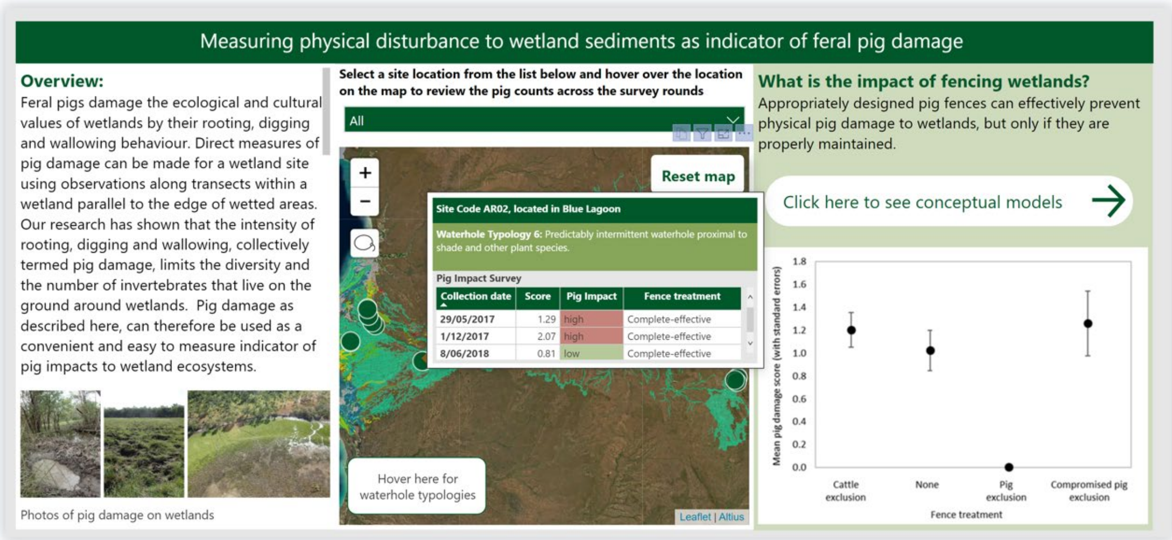


Figure 80. Pig damage score metrics for our study area.

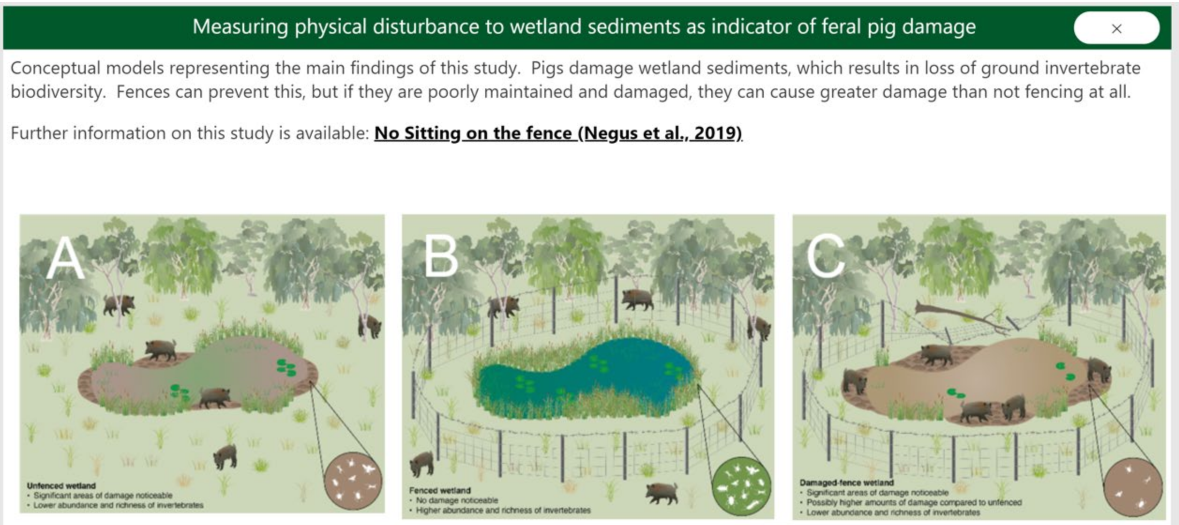


Figure 81. Conceptual models of pig fence impacts are displayed in a full screen.

6.3.2.2 Terrestrial invertebrates

Terrestrial invertebrates were surveyed in the same area where pig damage metrices were surveyed. This page provides a summary of richness and abundance of terrestrial invertebrates in relation to high or low pig-damage categories (Figure 82).

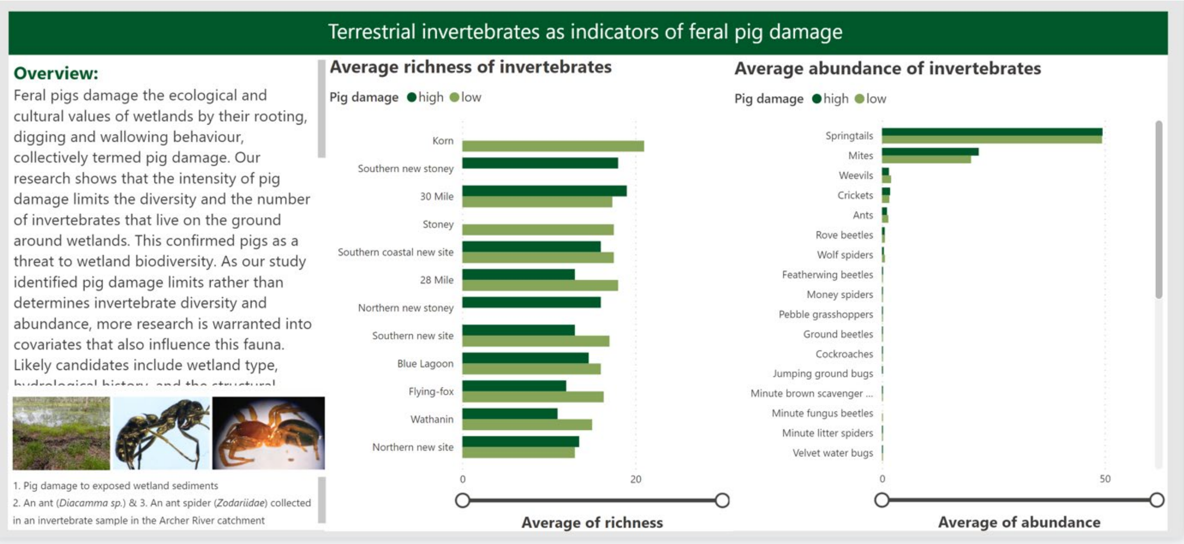


Figure 82. Terrestrial invertebrate metrics.

6.3.2.3 Sediment cores

Sediment core results demonstrated the utility of this method for determining when pigs arrived in an area and correlating changes to pollen cores and diatoms to establish ecological shifts associated with the arrival (Figure 83). This page is static, but data can be linked to sites and waterhole typologies once more coring is done in a region.

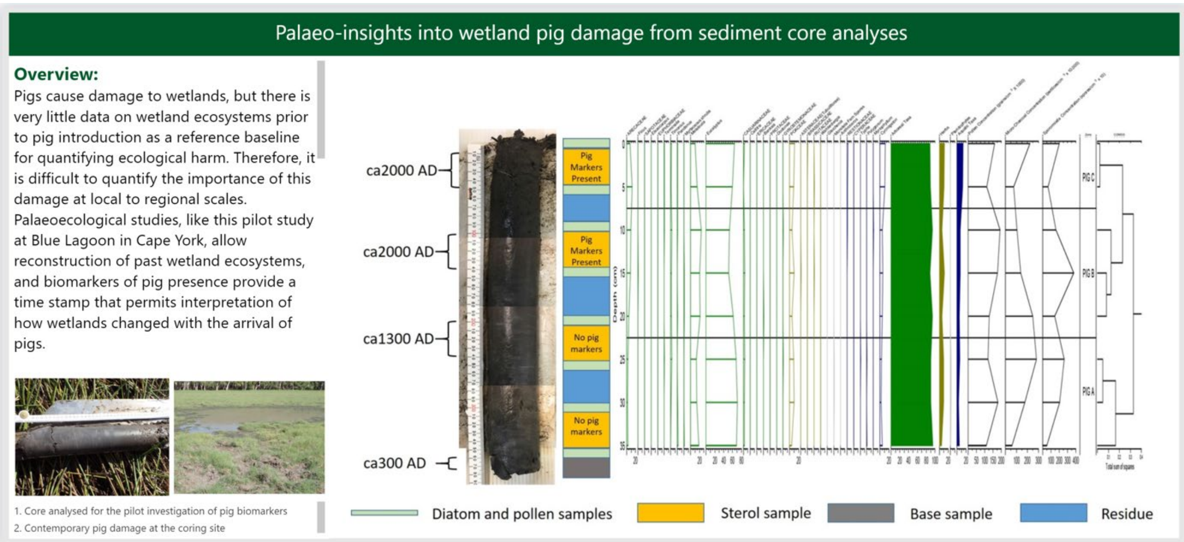


Figure 83. Sediment core summary page.

6.3.2.4 Diatoms

Diatoms are useful indicators of impact. In this page we present the abundance of different species of diatom collated at each site (Figure 84). This represents a baseline assessment of diatoms for selected sites, and changes in abundance and richness for each site can be reported across time following management intervention.

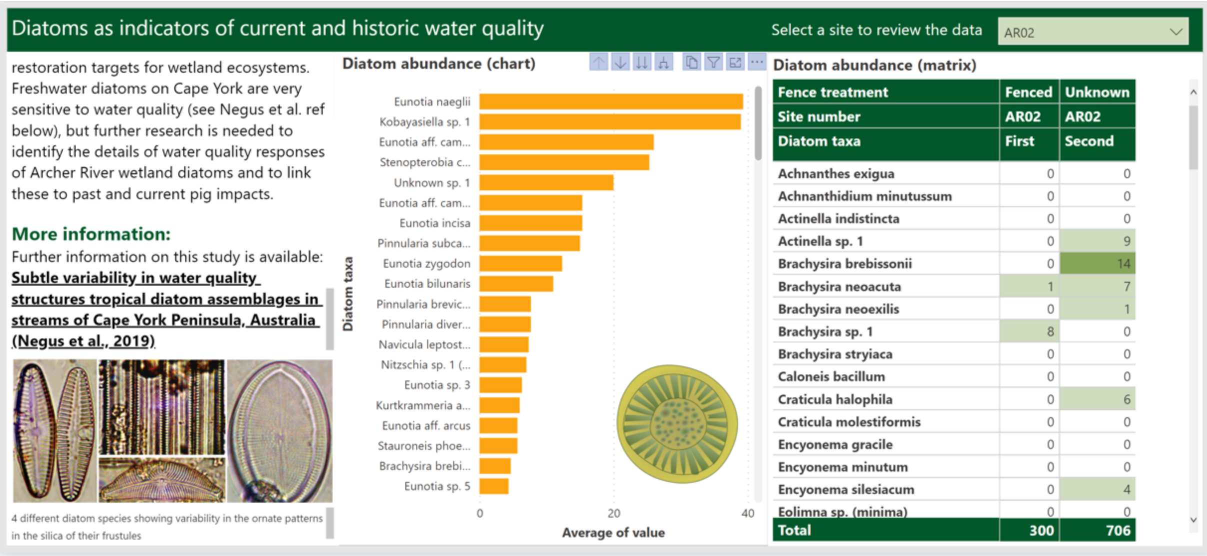


Figure 84. Diatom summary page.

6.3.2.5 Field water quality

On this page we summarise water quality metrics measured from survey equipment in the field across diurnal and nocturnal fluctuations (Figure 85). These data provide a useful variable from which to compare differences in aquatic fauna and site structure. We display four key metrics (DO, EC, pH and temperature) which show changes in these values in the late dry season and early dry season. These data are very useful for comparing changes across time following management interventions and can also be used to help describe natural differences between waterhole types.

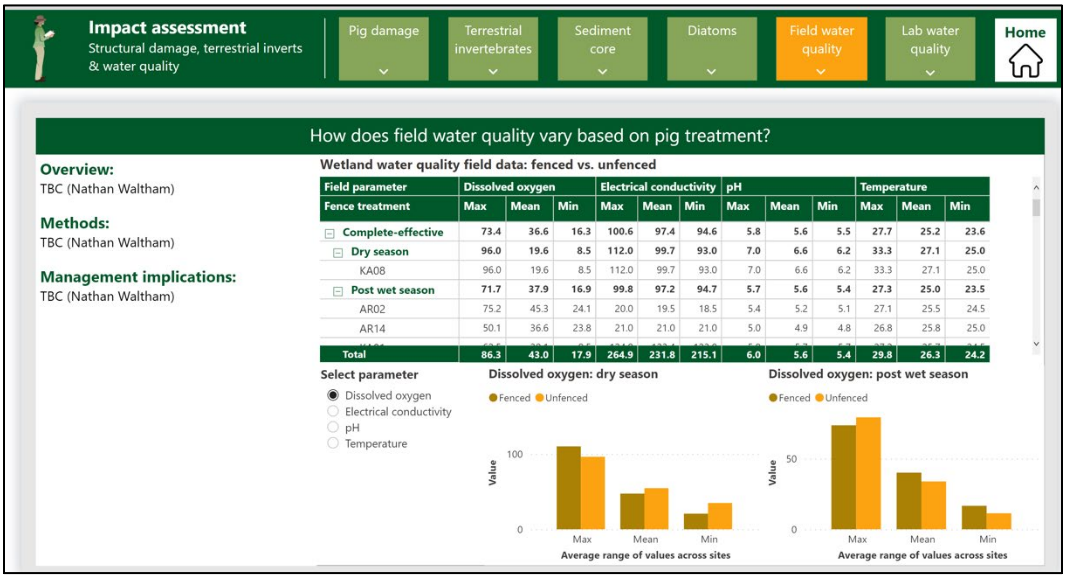


Figure 85. Field water quality metrics for each site.

6.3.2.6 Lab water quality

Detailed water quality data were collected for each site in different seasons (where possible) (Figure 86). This page enables users to choose the water quality metric and see how they differ between sites. These data are useful for long-term monitoring and can be used in analysis for comparing relationships with factors like typology or pig impact. Here we only have one year of detailed water quality data, but this page can be adapted to report changes in different water quality elements over time as more data is collected.

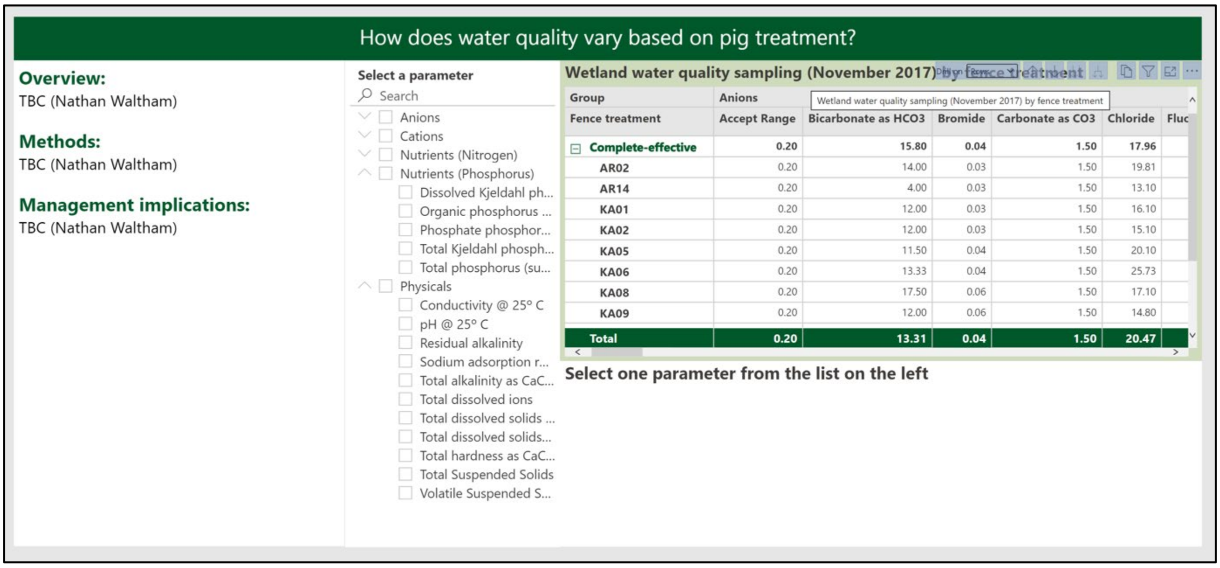


Figure 86. Lab-based water quality metrics for each site.

6.3.3 *Freshwater ecology*

The freshwater ecology category has three pages linked to it:

1. Fish impacts
2. Freshwater turtle impacts
3. Thermal gradients impacts.

6.3.3.1 Fish impacts

Freshwater fish communities were examined using a combination of methods to establish differences in fish assemblages and abundance associated with different waterhole types and under different pig impacts. This page summarises the fish data (richness and abundance) for fenced and unfenced sites in the Archer River basin region (Figure 87).

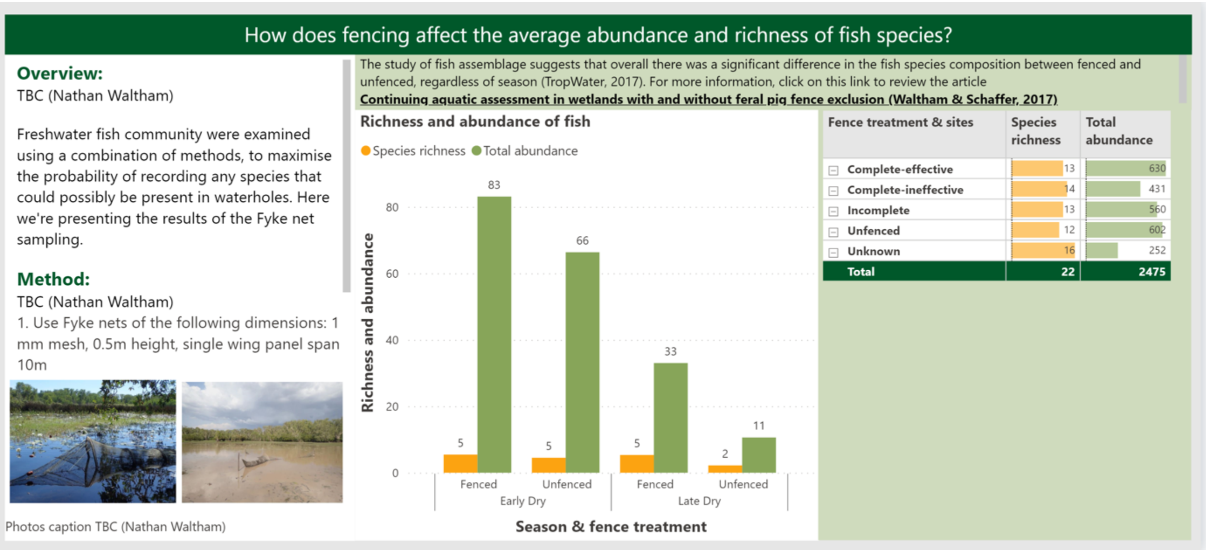


Figure 87. Fish richness and abundance compared with fencing treatment.

6.3.3.2 Freshwater turtles

In this study we completed an experiment that tested the number of turtles that are likely to be trapped by pig exclusion fences without modification and with modification (Figure 88). This page enables the user to change the dimensions of the fence modification to display how many turtles are likely to fit through the gaps. This page is important as a common method for wetland restoration is to use fencing. In our study we found some sites with fences stopped turtles from leaving drying waterholes or accessing waterholes during seasonal movement. However, simple modifications can allow turtles to move freely through fences.

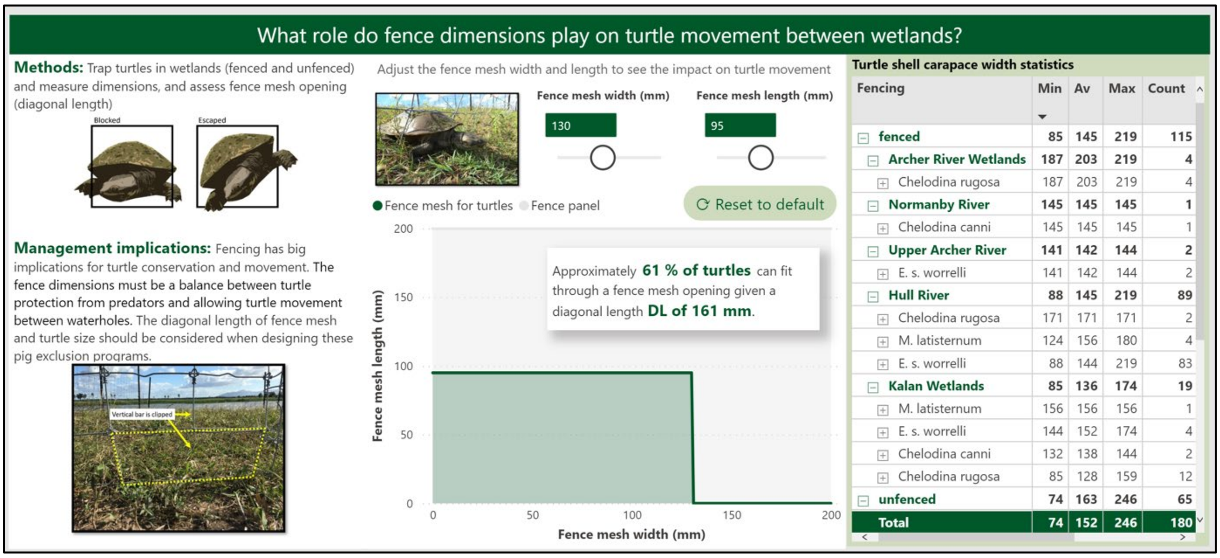


Figure 88. Freshwater turtle morphometrics compared with fence gaps on commonly used pig exclusion fencing.

6.3.3.3 Thermal gradients

This page summarises the results of temperature loggers in the context of experimental work that quantified critical thermal thresholds for four common fish present in waterholes at the end of the dry season (Figure 89). The page allows the user to slide the date and time to show thermal relationships at various levels within selected waterholes. When the user selects the fish species the red line shifts to indicate the critical thermal thresholds. The temporal thermal patterns are displayed showing the number of times when thresholds were exceeded at the sites. These data can be used to correlate changes in wetlands over time with potential impacts on fish so represent a potential method that can be applied as a proxy for wetlands health and fish impacts.

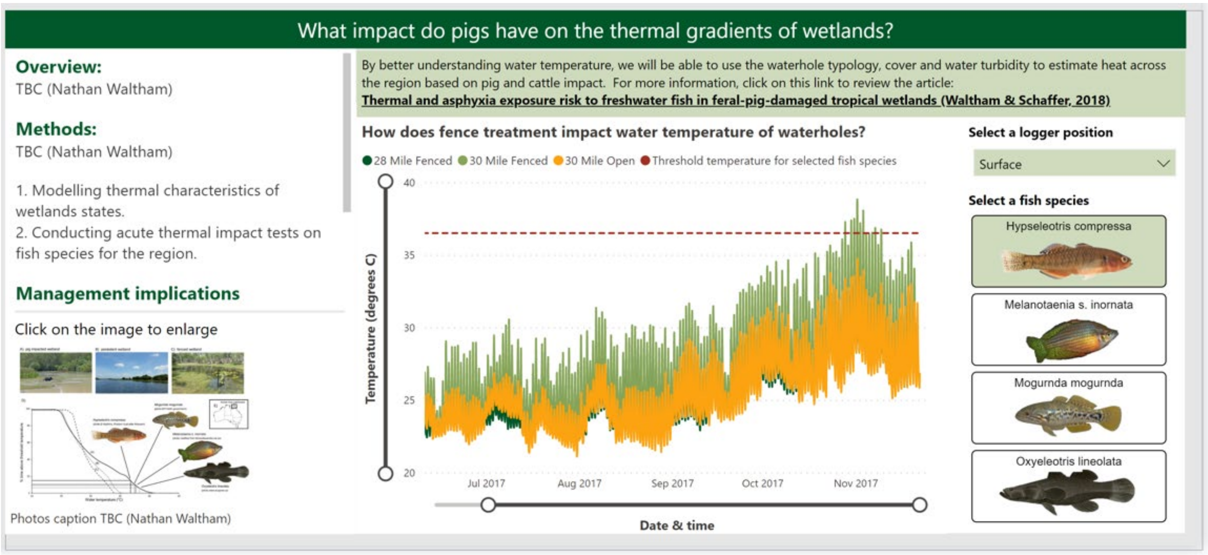


Figure 89. Thermal gradients and critical temperature thresholds for common fish in the study area.

6.3.4 *Terrestrial fauna*

The terrestrial fauna impacts section has one summary page (Figure 90). This page pictorially and numerically summarises the richness and abundance of species at each site, categorised by waterhole type and season. This allows users to see the inherent differences in fauna composition between sites. The broad taxa can be selected to display the summary information individually (e.g. just frogs) or combined (e.g. all taxa).

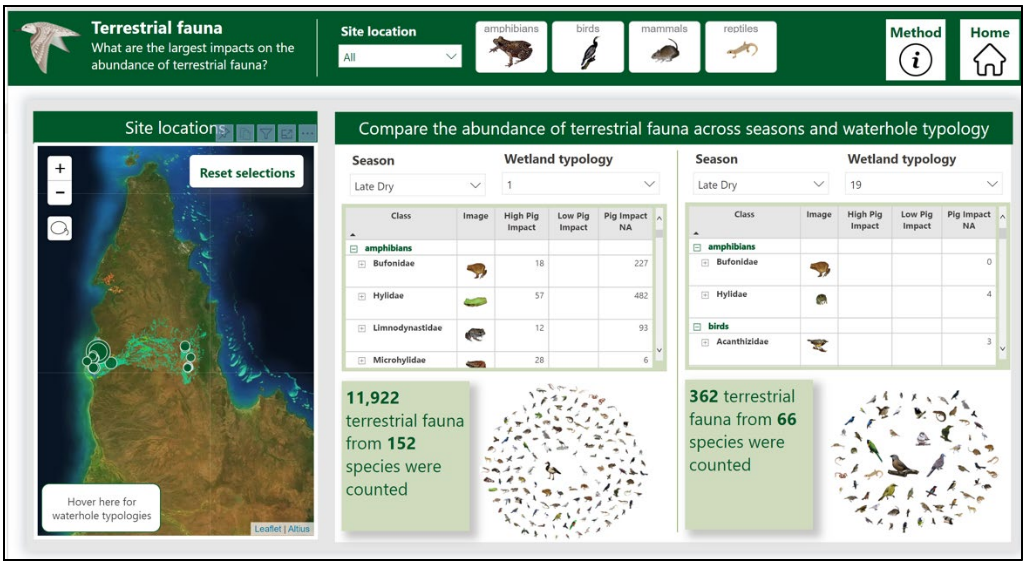


Figure 90. Terrestrial fauna summary by wetland type and season. Here we display the difference between type 1 and type 19 in the late dry season demonstrating the significant difference between a permanent waterhole compared with an ephemeral waterhole.

When just reptiles are selected the dashboard only displays information about the reptile species (Figure 91).

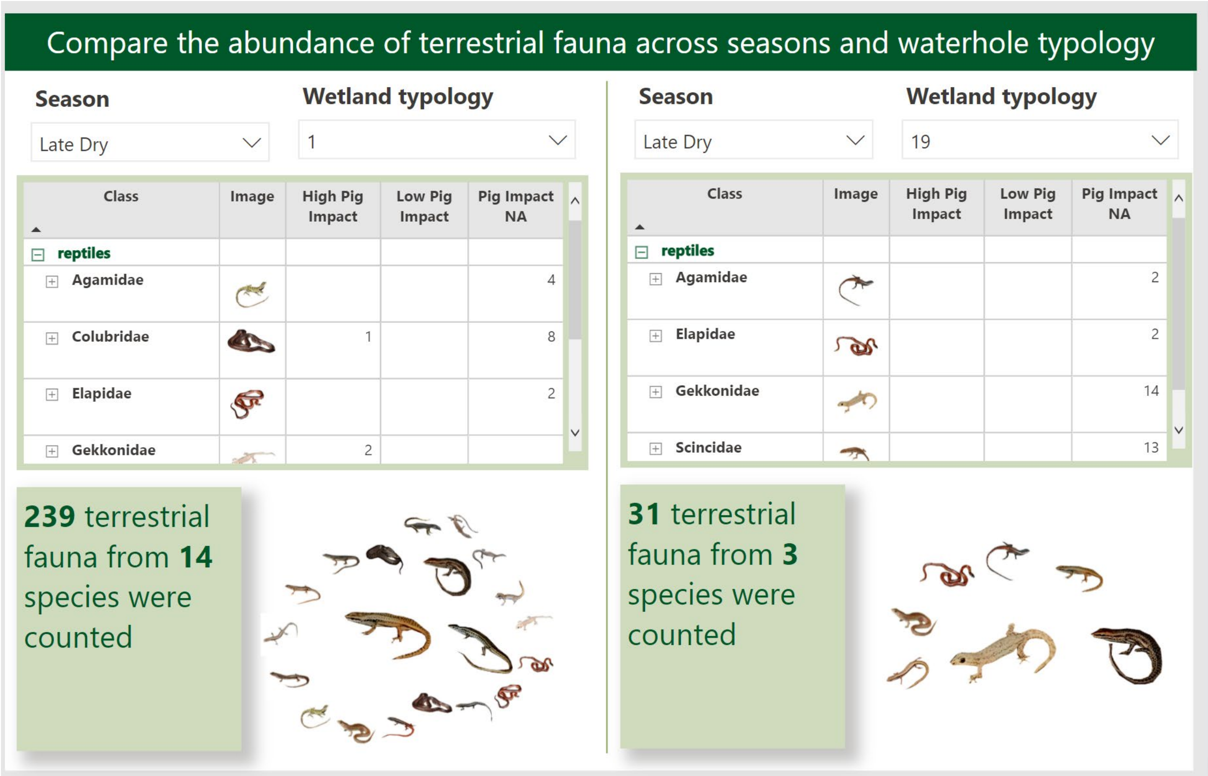


Figure 91. Just reptile data displayed.

6.3.5 Feral pig management

The feral pig management category has three pages linked:

1. Pig population dynamics calculator
2. Pig shooting data from our study
3. Turtle depredation data from our study.

6.3.5.1 Pig population calculator

We developed this page to demonstrate to users the challenge of controlling feral pigs (Figure 92). The user can select the starting population and the percentage population they can control each year. The calculator applied a logistic growth formula to estimate population recovery over 20 years. For most common examples of control (e.g. limited control budgets), where a large effort and expense is expended in the first year and this is followed up by smaller consistent culls, populations recover very quickly (within three years). Here we demonstrate the average annual removal at APN (1,500 animals) from the base population (25,000) to demonstrate the likely population dynamics for APN's investment in control. To refine this approach we could create base population estimates for each zone and use this to identify areas where population control could be more effective.

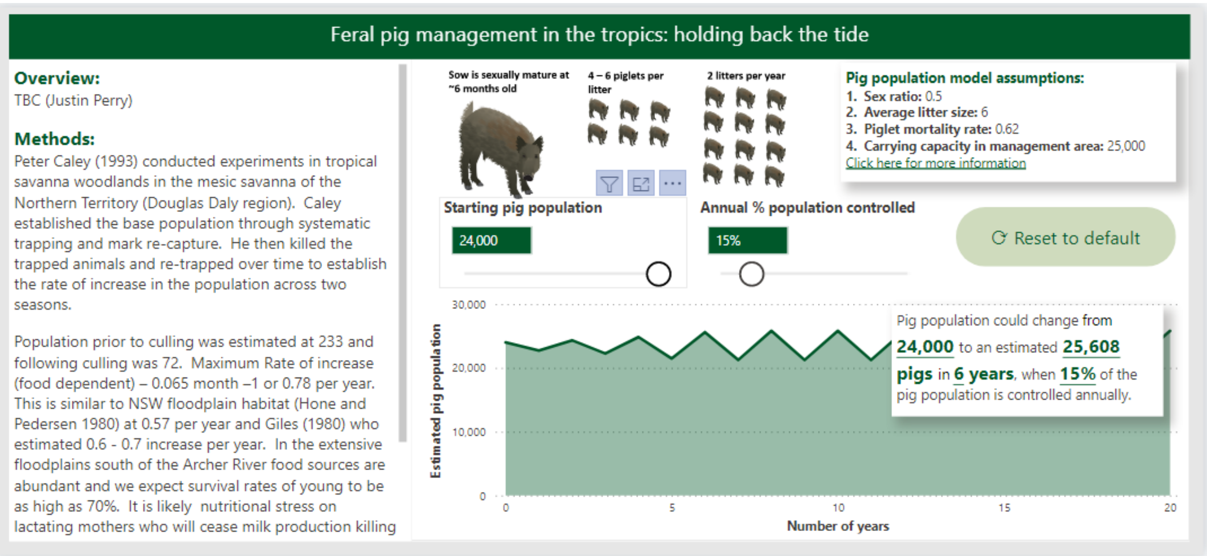


Figure 92. Feral pig control calculator.

6.3.5.2 Feral pig shooting data

One of the greatest expenses for any feral pig management program in large remote estates in northern Australia is aerial control by helicopter. In our study we quantified the number of pigs shot by effort (total km travelled per shoot) for each year in the study area. We summarised the data by management zones selected by APN (Figure 93). Figure 94 illustrates how effort from contract shooters has increased in a remote management zone removed from any values or management goals identified by Wik families for APN management. This data has been used to prioritise limited resources to protect critical values and to increase the amount of local participation in activities.

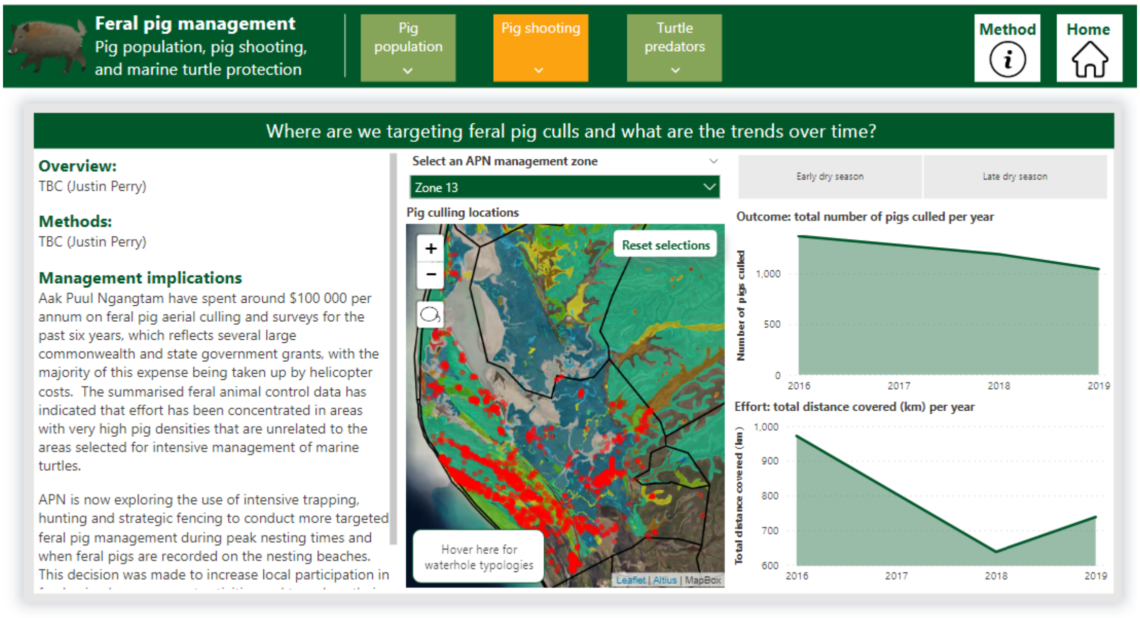


Figure 93. Feral pig shooting data 2016–2019, Aak Puul Ngantam. Management zone 13 has been selected illustrating that pig numbers have remained relatively constant – these results are likely driven by changes in effort rather than declining populations.

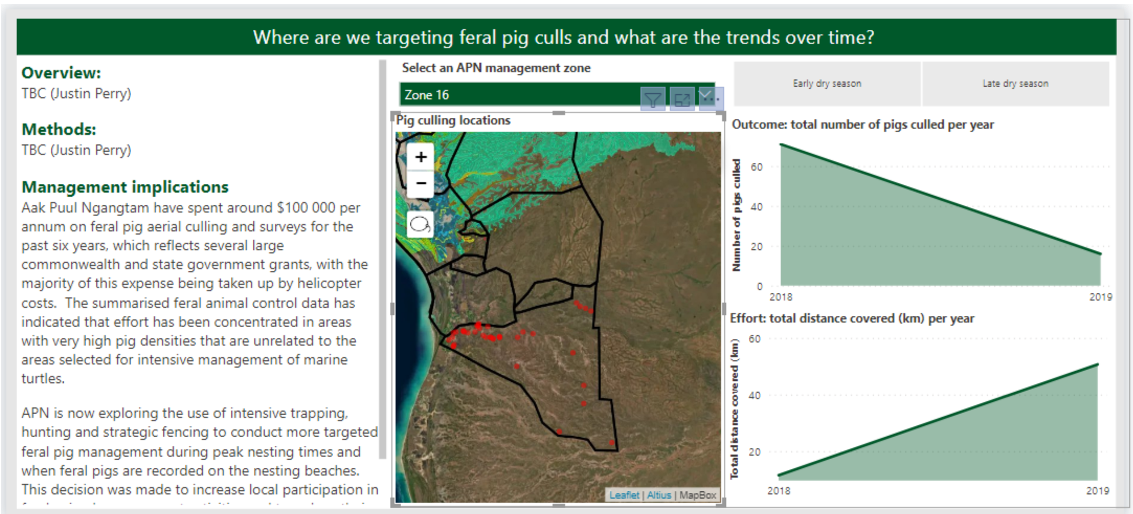


Figure 94. Feral pig culling data with a remote management zone selected (zone 16) demonstrating an increase in effort over time for very limited returns and no prescribed value.

6.3.5.3 Marine turtle depredation

One of the primary aims of APN's feral pig control program is to protect olive ridley, flatback and hawksbill turtle nests from pigs. In this page we summarise the results from an intensive monitoring program completed in partnership with APN (Figure 95). APN turtle monitoring staff collected weekly information on the depredation of turtle nests along ~50km of nesting beach in the study area. We summarised these data to demonstrate when and where predation events occurred. This summary was used to develop a comprehensive turtle protection plan that accounted for the variability in predation and nesting density across the year. Users can see the method used (Nestor) and a summary of the effectiveness of physical nest protection for each predator type by clicking on images in the bottom left of the page (Figure 96).

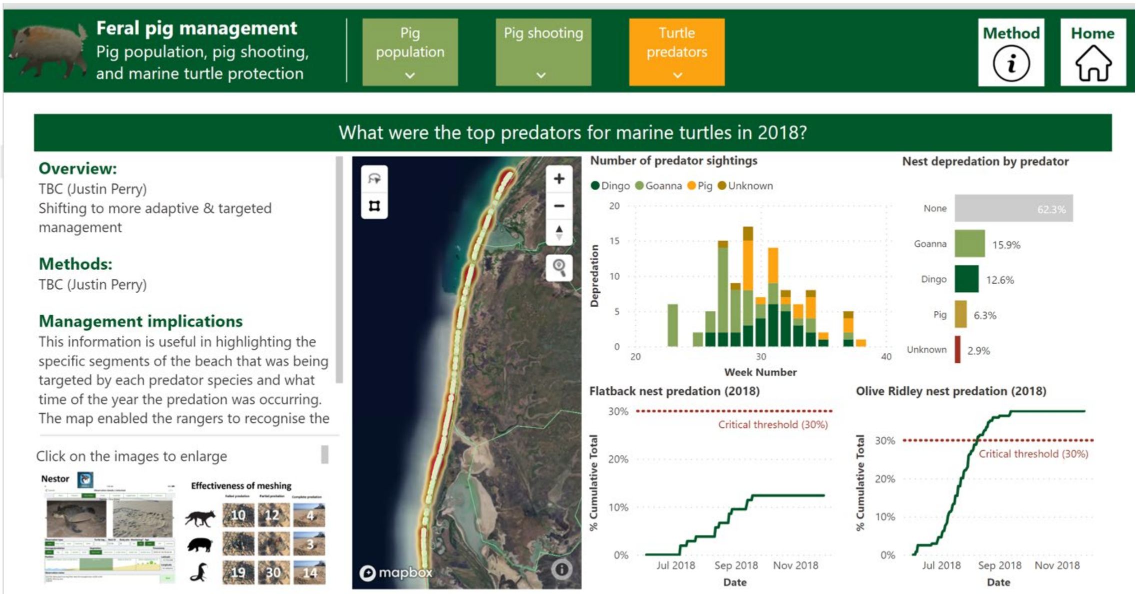


Figure 95. Marine turtle depredation by week at APN.

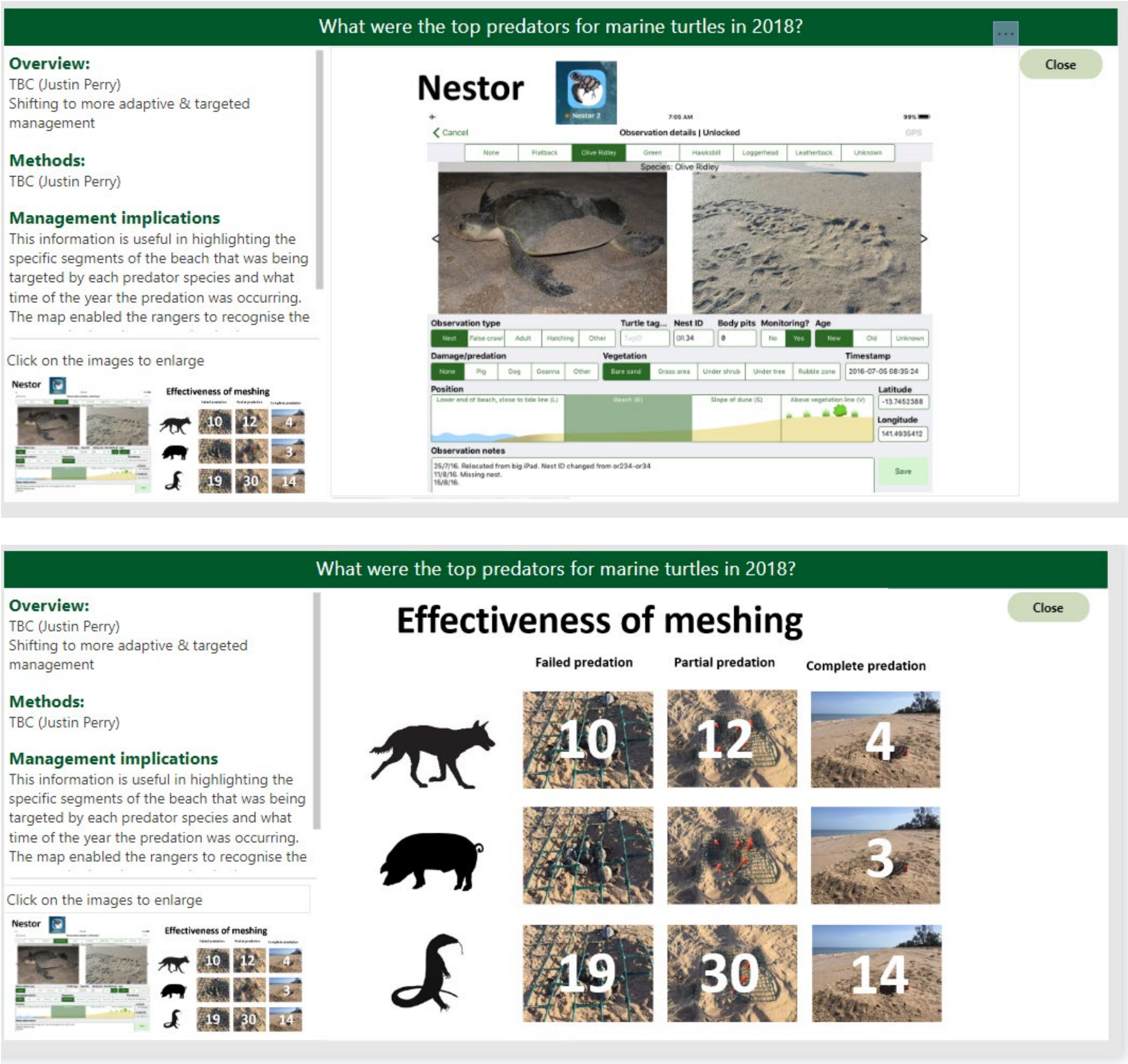


Figure 96. The mobile application used to collect the data and a summary of key results are displayed when users click on images in the bottom left of the page.

7. General discussion

In northern Australia, there is growing recognition of the importance of wetlands to biodiversity and ecosystem health, along with their cultural value to Indigenous communities. Feral pigs (*Sus scrofa*) and cattle (*Bos taurus*) pose significant threats to wetland system ecology and biodiversity through negative impacts on wetland vegetation assemblages, biological communities and water quality. Feral pigs are among the world's top invasive species. Population estimates are difficult to ascertain in Australia due to the broad distribution of feral pigs and the lack of systematic population surveys; however, previous studies have suggested as many as 13–23 million. Feral pigs have a direct physical impact in both natural landscapes as ecosystem engineers as well as in the cultural landscape as pests. They eat or destroy crops, muddy waterholes used by cattle, prey on lambs and wildlife, compete with native species for resources, cause erosion and alter wetland systems. However, not all sectors of society are united in a view to remove feral pigs from the landscape and reduce their impact. On the flip side, pigs are a source of recreation (to hunters), money (from meat and skin export, pet food, and to some small extent, the local food market), and importantly, as a food source for remote communities. This dichotomy in the agenda of Australians with respect to feral pig management requires a nuanced approach to establish socially acceptable control measures.

While the impact of feral pigs and cattle on wetland structure and function is well documented, their effect on biodiversity, ecosystem services, and the consequent impact of changing wetland function on Indigenous values and wellbeing is not well understood. In this research we quantified the impact of feral species on wetland condition, and the effectiveness of control measures on mitigating the threats to aquatic systems. To do this, we defined, evaluated, and calibrated metrics used to describe the impacts.

Project 2.5 sought to better define impact of feral animals on wetland health and their subsequent impact on cultural wetland values through the development of an integrated monitoring and reporting system. To capture the complexity of metrics that describe both biophysical and cultural impacts of feral pig management, a collaborative team of ecologists, human geographers, Traditional Owners, and land managers developed a framework which integrated quantitative indicators to monitor and report on wetland biophysical values with cultural ecosystem services research. The framework, which places strong emphasis on embedding cultural values and supporting Indigenous-led management and planning, enables the comparison of investment in control, with consequent impacts on environmental values. The project comprised five general components.

- aggregation of an extensive baseline data set for the Archer River basin to assess change under future investment strategies
- generation of new wetland/waterhole typologies for the Archer River basin to support modelling of the spatial and temporal distribution of feral pigs
- development of a cultural ecosystem service wetland typology to support wetland management on Wik Peoples' traditional lands
- cost–benefit analysis of selected control methods for feral pigs
- development of a reporting system for assessing the impact of feral pig management on aquatic systems.

The establishment of a baseline data set and monitoring methodologies to assess feral species impact on wetlands allows land managers to identify priority wetlands for targeted management, while providing a means to evaluate the impact of current feral species management on feral animal abundance. The 10 monitoring methodologies developed and described in project 2.5 are replicable and allow land managers to review change over time. The establishment of new wetland typologies supersedes old typologies that did not support the modelling of feral pig data and omitted cultural values. Cost–benefit analysis of select control methods for feral pigs enables the comparison of investment against impacts, supporting better future decision-making for land managers.

Project highlights

Project 2.5 has delivered research outcomes that have led to direct changes to the way feral pigs and cattle are being managed across millions of hectares on Cape York Peninsula. Research partners have increased the baseline knowledge of feral pig impacts and management through the production of technical mapping products, software, monitoring tools and peer reviewed journal articles.

The team has communicated these impacts through a variety of media and has delivered presentations and advice to a broad cross-section of stakeholders including government policy departments, land management organisations and conservation entities. Project outcomes are supporting national initiatives for feral animal control.

Impacts from this project include:

- 51 Indigenous participants involved in research and monitoring through deep collaboration with APN Cape York and Kalan Enterprises
- 5 journal articles published
- 8 journal articles in preparation or in review
- 1 Queensland Government mapping product
- 1 software product (HealthCountryV2 – Turtle Trackers)
- 1 digital dashboard
- 2 iPad applications
- substantial media interest
- 2 award nominations – finalist in both (NT NRM Awards, i-Awards – merit award)
- 1 award winner (Mumbrella, Best use of owned media)
- 3 national committees using project data (African Swine Fever taskforce, national feral pig management strategy – development, national feral pig management implementation).

7.1 Conclusions and recommendations

Project 2.5 identified that in the absence of purposeful, impact-driven management and monitoring, it was impossible to assess positive or negative change from landscape-scale feral pig control, and limited benefits accrued for Traditional Owners and funders. However, when control was targeted and associated with clear metrics of success (e.g. protection of marine turtles), management interventions were successful and sustained.

We recommend that control programs are targeted to enhance and protect defined values and, for this to be effective, control needs to be paired with monitoring and assessment that tracks values with defined critical thresholds that reflect positive or negative change to values.

In this project, we developed wetlands monitoring and assessment tools which enable land managers to analyse and interpret baseline metrics on system health and identify priority wetlands for targeted management. The use of digital assessment and decision-support tools can provide vital information to land managers to enable them to undertake effective and robust control programs. The interactive dashboard presented in this report provides an extensible system that can be modified by end-users to ingest and visualise data they are collecting. This allows land managers to test the value of the data they are collecting for assessing impact on different values.

This research found that effective feral pig management requires the following elements.

1) Continuous and purposeful collaboration with land managers and/or Traditional Owners to clearly define the values that are being impacted and the desired outcomes that the management activities aim to enhance.
2) Metrics of success must be tied to the values and outcomes that the program aims to enhance – i.e. monitoring of control impact should focus on measures of change in ecosystem, social and cultural values.
3) Control actions need to be tailored to the differences in feral animal densities, alongside the values the program aims to enhance.

Through involvement of all key management groups this project has fostered a shared understanding of the most effective and efficient ways to manage feral animals to deliver joint social, environmental and cultural benefits. This project has developed real-world solutions that can be practically implemented by land managers to support continued management of feral species.

7.2 Using what we have learned

This research has demonstrated feral animals negatively impact terrestrial invertebrates, freshwater turtles, marine turtles, and freshwater fish in the late dry season. This is linked to direct predation of nests and individuals of freshwater and marine turtles, and habitat modification that impacts the ecological function of waterholes. At the same time, we demonstrated new methods for monitoring the changes in impacts at different scales using readily available technology (mobile devices, off-the-shelf drones and cameras attached to helicopters). Several of these methods can be applied systematically by land managers working in similar ecological systems to support robust monitoring and reporting. Here we suggest a way to bring together various elements presented in this report into an operational monitoring program (Figure 97).

Figure 97. Infographic showing suggested use of the methods discussed in this report. We suggest an adaptive management approach where baseline information is derived and then sites are monitored annually to report changes. Step 1: Desktop waterhole typology and management units mapping. Use waterhole typology mapping framework to map all waterholes in the management area. Select practical management units based on assessment of access, values, vegetation and impacts. Step 2: Waterhole typology mapping. Fly helicopter with GPS-enabled camera across the management areas to quantify and categorise waterhole types and impacts. Step 3: Select monitoring sites. Choose sites that reflect impacts, values and waterhole types. Select three (ideally five) sites in each type to account for variance within types. Step 4: Survey the selected sites. Using a drone, collect detailed aerial photos of each waterhole – fly at 50 m altitude, use photogrammetry software to stitch images into a geo-rectified image. Step 5: Feral animal management operations. Undertake various management operations and collect detailed monitoring data (e.g. location, date, time, costs, effort and human resources). Step 6: Reporting and adaptation. Use HealthyCountryAI framework to create spatio-temporal reports visualised using interactive digital dashboards. Following management events, observe the trend in the values that are being monitored and alter management actions. Return to step 2 and start the adaptive cycle again.

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Appendix 1: Papers in preparation

Please contact Justin Perry (justin.perry@nailsma.org.au) for information on the status of the papers in preparation.

1. Applying a versatile, comprehensive, attribute-based waterhole classification to ecosystem-based management challenges

Author list: K Glanville, J. Perry, T. Ryan, M. Ronan, P. Zivec

2. Categorising Wetlands to Accommodate Indigenous biocultural approaches and Values)

Author list: Peci Lyons, Justin Perry, Cathy Robinson, Melissa Sinclair, APN Traditional Owners (TBD).

3. The soil propagule banks of ephemeral wetlands of northern Australia and potential impacts of wild pigs on vegetation recruitment.

Author list: Cassandra S. James, Justin Perry, Jason Schaffer, Eric Vanderduys and Nathan Waltham

4. Porcine palaeoinsights: the use of faecal biomarkers in sediment chronologies to characterise wetland ecosystems before and after their invasion by feral pigs

Author list: Jonathan C. Marshall, Andrew C. G. Henderson, Helen Mackay, Patrick Moss, Peter Negus, Fred Oudin, Justin Perry, John Tibby