Wild Deserts

A project to reintroduce locally extinct mammals

Draft Ecological Health Monitoring Framework

Version 1 May 1 2017

DISCLAIMER

Cover photo – Red siliceous sand dunes within the Sturt National Park (Rebecca West/Reece Pedler; UNSW Wild Deserts)

1. Introduction and Objectives

Wild Deserts is a new project partnership between University of New South Wales and Ecological Horizons, working in collaboration with the NSW Office of Environment and Heritage. The vision of the Wild Deserts project is *"To understand, restore and promote desert ecosystems through ecosystem manipulations, reintroductions and collaborative partnerships".* Wild Deserts aims to reintroduce seven locally extinct mammals to the 'Sturt Service Site', a 350 km^2 area of the Strzelecki Dunefields system in the west of Sturt National Park (Figure 1). This will be achieved by constructing two 20 km^2 predator exclosures and eradicating introduced predators and rabbits from within those exclosures to establish functioning healthy ecosystems. The project will also aim to establish locally extinct mammals beyond the fences into the 'buffer zone' (Figure 1). The Wild Deserts project proposes to undertake a two staged-approach to achieve this, firstly reintroducing animals into the Wild Training Zone (a 104km^2 bounded area, Figure 1) where predator numbers will be tightly controlled and individuals will have the opportunity to learn anti-predator skills, before species are reintroduced into the remainder of the buffer zone.

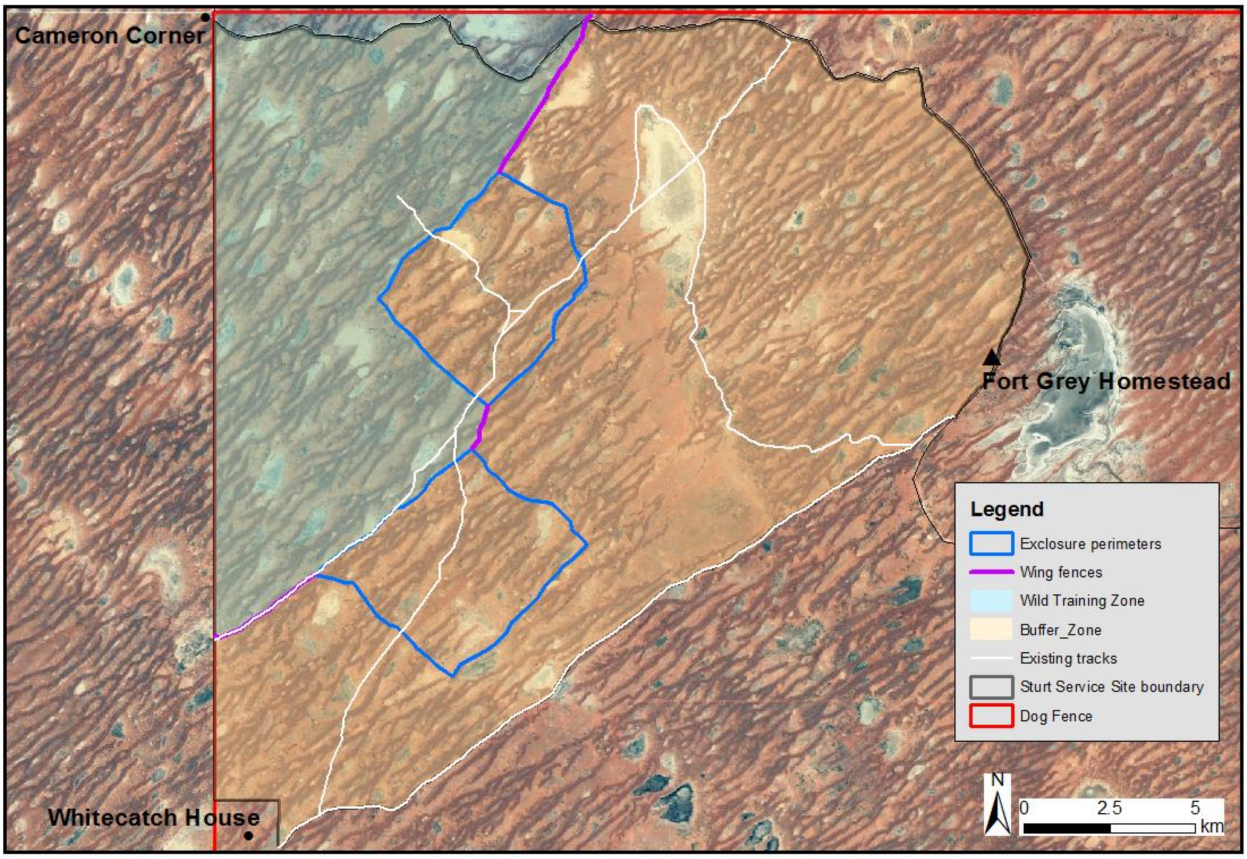


Figure 1. Map of the Sturt Service site, in which the mammal reintroductions are to take place. The proposed layout is shown, including indicative exclosure placement.

As per the contract agreement with OEH, Wild Deserts is to develop an Ecological Health and Monitoring Framework (EHMF) designed to measure performance against improving ecosystem health. This needs to entail sufficient scientific rigour to assess and report any ecological impacts/benefits associated with the reintroduction project, both inside the exclosures and within the buffer zone. Ecological Health will be considered improved when:

- Threats (stressors) are reduced below level where they impact biodiversity
- There is an improvement in the status of at least some species, including agreed threatened species, and status for other species is considered acceptable
- Ecological processes are considered resilient to disturbances

The EHMF forms part of the Strategic Adaptive Management (SAM) framework, which is in development for the Wild Deserts project. As part of this adaptive approach, the EHMF will be updated annually.

2. Threats to arid zone ecosystem health

Australia's arid zone ecosystems have undergone significant change since European arrival. The inception of pastoralism and introduction of placental predators resulted in significant impacts on the biodiversity in arid zone ecosystems.

<u>Landuse history of Sturt National Park</u>

The area now designated as Sturt National Park was first taken up by pastoralists in the 1870s, with initial high stocking densities. Stock numbers in the western Division of NSW reached 15.5 million sheep equivalents in 1887 following a period of high rainfall, but by 1902 numbers had plummeted to five million as a result of overstocking, drought and high rabbit numbers (Gerritsen 1981). The 1890s also saw the expansion of rabbits in the arid zone, with huge plagues decimating vegetation and denuding the landscape. In combination with high stocking densities, the erosional power of wind and water made substantial and irreversible changes to soil and vegetation.

The Sturt Service Site was formerly part of Fort Grey Pastoral Lease, which from 1898 formed part of Yandama Station; comprising 3,000 square miles and the leases: Fort Grey, Boulka, Tilcha, Warratta and Mokely. In 1899, Yandama Station shore 52,568 sheep and sent 5,383 sheep and 1500 head of cattle to market (Gerritsen 1981). During the 1950s, new pastoral bores were established on Fort Grey Station to areas previously remote from grazing by sheep and cattle. These included several bores within the Sturt Service Site: Devis Bore (sunk 1952; failed 1968), Collins Bore (sunk 1955) and Watties Bore (sunk 1960) (Klöcker 2009).

<u>Current threats with the Sturt Service Site:</u>

Total grazing pressure (feral and native herbivores): The combination of historical grazing by domestic stock, introduced herbivores (rabbits, goats) and high densities of kangaroos have resulted in extensive vegetation changes to the Sturt Service Site. These include limited recruitment of long-lived trees, shrub encroachment (Gordon *et al.* 2017) and replacement of long-lived perennial species with annual or invasive species. Ultimately, this has reduced palatable species for herbivores, decreased cover and degraded habitat structure.

Feral and introduced predators: The introduction of feral cats and red foxes to Australia introduced novel predators which resulted in a cascade of extinctions, particularly for mid-sized mammals in the 'critical weight range' (CWR) (Burbidge and McKenzie 1989). In addition, ground nesting birds and some groups of reptiles have suffered declines or contractions in range (Gordon *et al.* 2017, Sadlier and Pressey 1994, Smith *et al.* 1994).

Loss of native mammals: In the Simpson-Strzelecki Dunefields Bioregion, the introduction of feral and introduced predators and introduced herbivores resulted in the extinction of all medium-sized native mammals (body mass 1000-5000 g) (Letnic and Dickman 2006, Woinarski *et al.* 2015) and the current listing of 47 threatened species (OEH 2017). Many of the changes in vegetation are also linked to the loss of the ecosystem functions performed by these once abundant native mammals. Often referred to as ecological engineers, species such as bilbies, bandicoots and bettongs create foraging pits in the soil which serve as collection points for nutrients and seeds, creating niches for plant establishment, cycling nutrients and enhancing water infiltration(James and Eldridge 2007). Bettongs also create large warren systems which provide shelter sites for reptiles. The loss of these mammal species has undoubtedly changed landscape and ecological processes in Sturt National Park (Noble *et al.* 2007).

Provision of artificial water sources: The provision of artificial sources of water in the arid rangelands has dramatically changed ecosystems through providing a focus for grazing by domestic stock and native and feral mammalian herbivores (James *et al.* 1999). Within the disturbance gradient, termed the 'piosphere', around these waterpoints (Lange 1969), the soil crust is typically broken, erosion is high and unpalatable plants dominate, with a decrease in abundance of palatable native perennial grasses due to selective grazing (James *et al.* 1999). Within the Sturt Service Site, a previous study comparing sites close and distant to artificial watering points closed 35 years prior was unable to detect changes in vegetation and faunal assemblages, suggesting that these waterpoint areas have sufficiently recovered (Klöcker 2009). However, this study did not compare the effects of artificial waterpoints which remained open at the time, supporting high densities of macropods.

Climate change: Under climate change, droughts and floods are predicted to become more frequent in Australia, making the world's most variable rainfall environments even more unpredictable (Trenberth *et al.* 2015). The long-term warming trend in the tropical Indian and western Pacific Oceans, attributed to human-induced climate change (Knutson *et al.* 2013), is already resulting in exceptional rainfall events in inland Australia (Lim *et al.* 2016, Ummenhofer *et al.* 2015). Further, average summertime temperatures have shown an increasing trend of 0.5 °C per decade since 1970 in western NSW [http://www.bom.gov.au/climate/change]. In coming decades, these trends are predicted to intensify, with increased frequency of intense and prolonged heatwaves (Meehl and

Tebaldi 2004). Species particularly vulnerable to heatwaves include small birds, (McKechnie and Wolf 2010), but the vulnerability of other species and ecosystems to changes in temperature and rainfall is complex and difficult to predict (Huey *et al.* 2012).

3. Improving the status of native species

The Wild Deserts project is part of the NSW Saving our Species program, a state-wide program to address the growing number of plants and animals facing extinction. Since European settlement, 25 mammal species have become extinct in NSW. Of the surviving mammal species, 59 % are threatened with extinction. Reintroduction of mammals is a significant component of the *Saving our Species* program, which aims to maximise the number of threatened species that can be secured in the wild in NSW over the next 100 years. As per the contract with OEH, seven locally extinct mammals, termed 'the Sturt Species', have been identified for reintroduction to the Sturt Service Site. The Sturt Species, their ecological roles and likely benefits and impacts to the ecosystem are summarised in Table 1.

Intensive management to remove the threats to the Sturt Species to enable successful establishment will also benefit other threatened species within the area. There are 47 threatened species known or predicted to occur in the Western CMA, Strzelecki Dunefields system (OEH, 2017) which are detailed in Appendix A and include 16 birds, 9 mammals, 12 plants and 10 reptiles. Appendix A indicates the threats identified for each species. As the majority of species are at threat from grazing and introduced predator pressure, the activities of the Wild Deserts project should significantly reduce the threats for these species. In addition to these threatened species, benefits are expected for other non-threatened species and the ecosystem generally.

Table 1. The seven species listed for reintroduction to the Sturt Service Site, their ecosystem role and potential benefits and impacts to the local ecosystem

Species	Key threats	Ecosystem role	Diet	Benefits to local ecosystem and resident species	Potential impacts on local ecosystem and resident species
Greater bilby	Introduced predators	Engineer - burrowing, omnivorous	Seeds, bulbs, invertebrates	Increase soil health - turnover & mixing, nutrients - diggings trap organic matter, soil moisture - increase water infiltration, mycorrhizal fungi, plant nutrients - increases seedling germination and establishment, creation of refuge burrows for other species	Predation of some reptiles and amphibians Soil disturbance from foraging pits/burrows Depletion of seed bank
Western barred bandicoot	Introduced predators, grazing, cropping	Engineer - digging, omnivorous	Insects, seeds, roots, herbs, small animals	Increase soil health - turnover & mixing, nutrients - diggings trap organic matter, soil moisture - increase water infiltration, mycorrhizal fungi, plant nutrients - increases seedling germination and establishment	Predation of invertebrates or small reptiles and mammals Removal or depletion of seed bank of certain plant species
Golden bandicoot	Introduced predators	Engineer - digging, omnivorous	Insects, seeds, roots, herbs, eggs	Increase soil health - turnover & mixing, nutrients - diggings trap organic matter, soil moisture - increase water infiltration, mycorrhizal fungi, plant nutrients - increases seedling germination and establishment	Predation of invertebrates
Burrowing bettong	Introduced predators, rabbits	Engineer - burrowing, omnivorous	Seeds, roots, leaves, fungi, termites	Increase soil health - turnover & mixing, nutrients - diggings trap organic matter, soil moisture - increase water infiltration, mycorrhizal fungi, plant nutrients - increases seedling germination and establishment, creation of refuge burrows for other species, warrens provide thermal protection for range of species	Grazing of chenopod species and perennial seedlings. Depletion of seed bank
Stick-nest rat	Introduced predators, grazing, rabbits	Engineer - stick nest builder, herbivore	Leaves and fruits of succulent plants	Nests provide habitat for invertebrates and small mammals/reptiles	Grazing of chenopod species
Crest-tailed mulgara	Introduced predators	Meso predator	Invertebrates, lizards, small mammals	↑ ecosystem function - meso predator currently absent from system, control rodents or plague locusts	Predation of small mammals/reptiles
Western quoll	Introduced predators	Apex predator	Invertebrates, lizards, small mammals, birds	Native top-order predator - ↑ ecosystem function Control overpopulation of other reintroduced species	Predation on small mammals/reptiles Predation of other reintroduced mammal species

4. Creating a resilient ecosystem

The vision of the Wild Deserts project is "*To understand, restore and promote desert ecosystems through ecosystem manipulations, reintroductions and collaborative partnerships*". Using knowledge of the current ecosystem state and the likely effects of the management proposed (feral eradication and mammal reintroductions), we suggest that an improved future ecosystem should have the following characteristics:

<u>Reintroduced species</u>

- Successful reintroduction of locally extinct species results in native ecosystem engineers, herbivores, omnivores and predators

<u>Feral animals</u>

- Introduced predators replaced with native ones

<u>Resident species</u>

- Complete and 'balanced' trophic structure that includes representative assemblages of reptiles, birds, inverts, bats, mammals, plants, fungi etc.
- Complete and well-structured plant communities (tussock grasses, succulent perennials present, long-lived perennials)
- Invertebrates become the dominant grazers

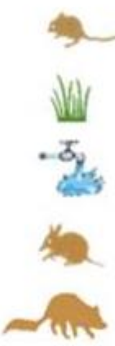
<u>Ecological processes</u>

- Artificial water points are removed
- Soil nitrogen, phosphorous and carbon source and sink dynamics reinstated
- Altered soil structure with increased potential for water and nutrient infiltration
- Reduced erosion and less frequent duration of inundation
- Refugia established (burrows, ground cover, three-dimensional structures/cavities)
- Restored variability of fire regimes (promoting heterogeneity and inequilibrium)
- Restored magnitude and duration of balanced productivity pulses
- Resilient to climate change

In order to achieve this desired state, we can view the current ecosystem within the Sturt Service Site as passing through five stages of improvement in ecosystem health as outlined in Figure 2. The conceptual model demonstrates the management actions that will be implemented to transition between each state and the expected ecosystem changes (Figure 2) as a result of management. The conceptual model can then be tested through the collection of ecological data within each of the treatment areas (exclosures, wild training zone and buffer zone).

Figure 2. A conceptual model illustrating the Strategic Adaptive Management stages in improving ecosystem health for the Wild Deserts Project.

Key:



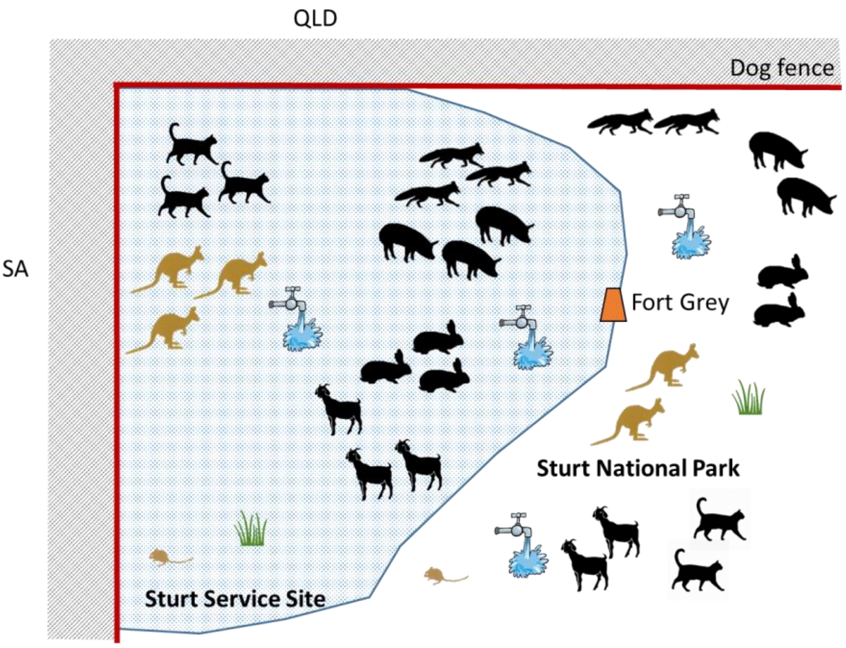
Native resident species affected by threatening processes (e.g. small mammals, reptiles, ground-nesting birds)

Vegetation structure and ground cover

Artificial water points

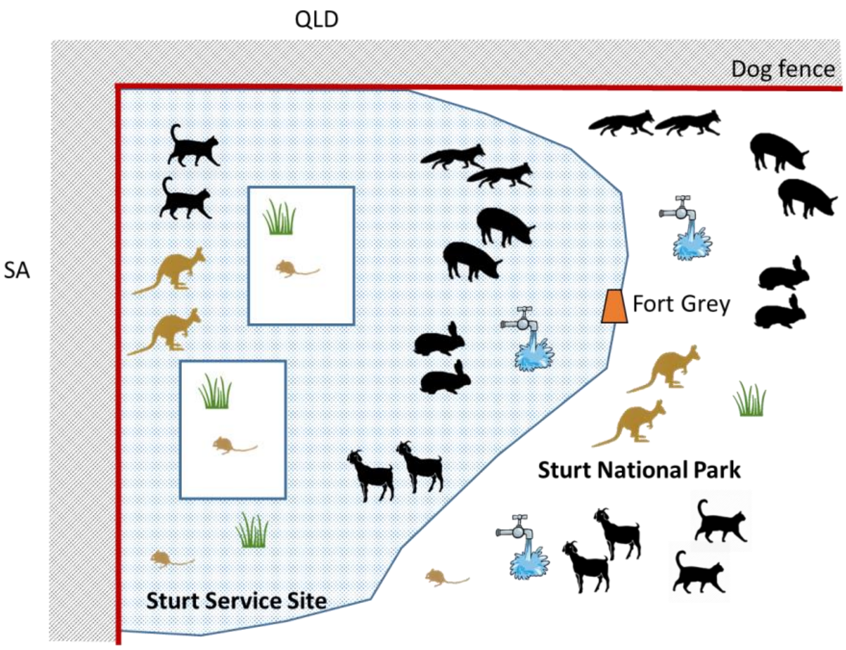
Reintroduced native herbivores and omnivores – bilby, bettong, stick-nest rat, bandicoots

Reintroduced native predators – mulgara, quoll



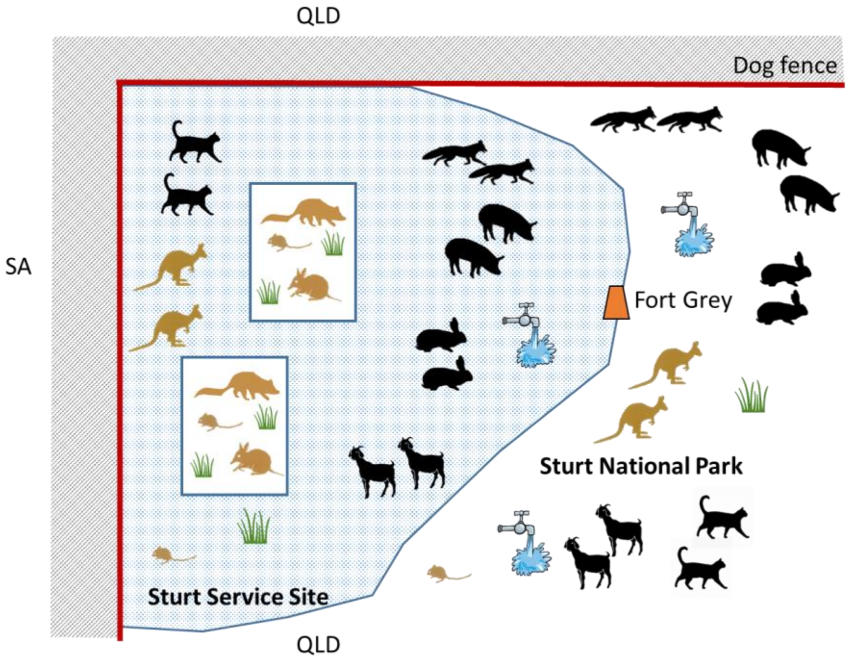
Stage 1. Current State

Ecosystem is dominated by feral predators, herbivores, omnivores and overabundant kangaroos. Artificial waterpoints are maintained. Vegetation heavily browsed, ground cover minimal. Resident native species assemblages affected by threatening processes.



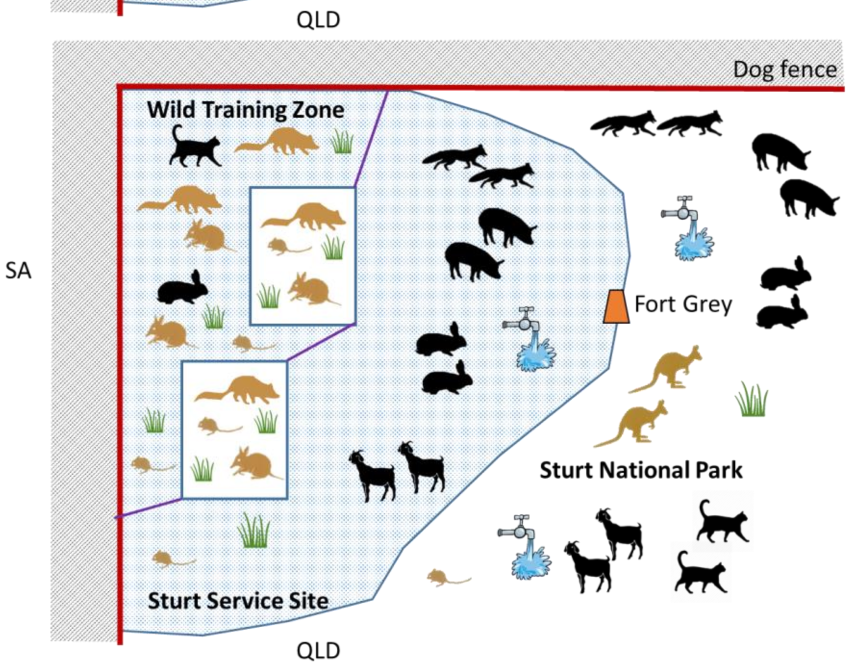
Stage 2. Exclosures constructed

Within exclosures: feral predators, herbivores, omnivores and kangaroos are removed and artificial waterpoints removed; vegetation structure starts to recover and ground cover starts to increase; threatening processes for resident native species are removed.



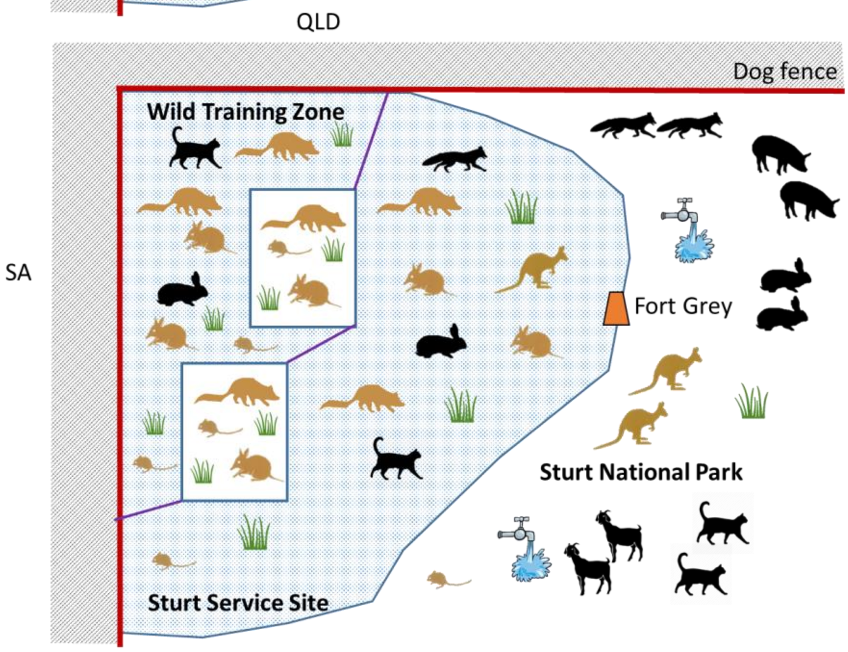
Stage 3. Reintroductions to exclosures

Within exclosures: native predators, herbivores and omnivores are reintroduced; vegetation structure continues to recover; ground cover continues to increase; native resident species previously affected by threatening processes begin to increase in abundance.



Stage 4. Reintroductions to Wild Training Zone

In wild training zone; feral predators, herbivores and omnivores reduced, artificial water points closed, kangaroos removed. Native predators, herbivores and omnivores reintroduced to wild training zone. Vegetation structure recovers, ground cover and resident species begin to increase in wild training zone.



Stage 5. Reintroductions to Buffer Zone

Feral predators, herbivores and omnivores reduced and artificial water points closed in buffer zone. Native predators, herbivores and omnivores reintroduced to buffer zone. Vegetation structure and ground cover is restored in buffer zone. Resident native species assemblages are no longer affected by threatening processes.

5. Ecological Health Indicators

As per the contract, the EHMF must provide for the collection of baseline data on ecological health indicators within the exclosures and buffer zone with indicators drawn from:

- Taxa that have experienced declines/extinctions since Europeans including threatened species
- Taxa directly/indirectly affected by mammalian extinctions
- Threatening processes such as feral animals and altered fire regimes
- Ecological processes including disturbance processes, water and nutrient cycles, trophic structuring

To measure the progression of the Wild Deserts project through the stages outlined in the conceptual model (Figure 2), we have identified ecological health indicators related to four key categories;

1. **Reintroduced species** – the 7 Sturt Species
2. **Introduced mammals** – introduced/feral predators, herbivores and omnivores
3. **Resident species** – flora and fauna susceptible to threatening processes
4. **Ecological processes** – disturbance processes, water and nutrient cycles, trophic structuring

We have also prioritised indicators within each category into two monitoring streams:

1. **Core** – monitoring of these indicators will be conducted by on-ground staff at the frequency stated and used to feed back into strategic adaptive management on a regular and ongoing basis
2. **Partnership** – we expect that monitoring of these indicators will be conducted in collaboration with external partners where additional funding and resources will be sought. These indicators will likely form discrete studies or snapshots in time rather than ongoing monitoring.

Below we outline the indicators within each indicator category and the monitoring methods that will be used.

5.1 Reintroduced species

The successful establishment of the seven reintroduced species will play a critical role in restoration of the ecosystem. In order for successful establishment of each species to be determined, the thresholds listed in Table 2 need to be met for releases into the exclosures, the wild training zone and the buffer zone.

Table 2. Short, medium and long-term thresholds for successful establishment of the Sturt Species following reintroduction.

Short-term **0 – 12 months**	**Medium term** **12 months – 2 years**	**Long term** **2 – 10 years**
• >50% of release animals have survived	• >40% of released animals have survived • Evidence of successful breeding • F1 individuals recruited to the population	• Steady population increase during first 5 years • Increase in population distribution to include >50% of suitable habitat • Population recovery after drought to pre-drought levels

To determine whether these thresholds have been met, we will use a range of monitoring techniques (Table 3). While many of these monitoring methods will be part of our core monitoring stream we expect that a number of student research projects will supplement these data with the use of experimental manipulations to examine specific aspects for each species such as release protocols, influence of source population, prior training on survival and diet. These aspects will be further outlined in the *Wild Deserts Research Strategy.*

Table 3. Monitoring methods and frequency of data collection for reintroduced species

Indicator	**Aim**	**Monitoring method**	**Frequency and duration**	**Monitoring stream**
All reintroduced species	Determine survival post-release	Radio-tracking	weekly for first 6 months after release	Core
All reintroduced species	Determine population trends and distribution	Spoor transects	Quarterly Ongoing	Core
All reintroduced species	Determine reproductive status, condition and recruitment	Cage trapping/spotlight netting	Annual Ongoing	Core
All reintroduced species	Determine genetic viability of the reintroduced populations	Genetic screening	Once, 8 years post release	Partnership

Radiotracking

A proportion of the release group for each species will be fitted with radio-transmitters and monitored intensively for 6 months post-release to determine survival, habitat use and dispersal from the release site. This information will be fed directly into the Strategic Adaptive Management Plan to determine any actions which may need to be taken if a particular population is at risk of not meeting the short-term criteria for establishment.

Spoor transects

The abundance of each reintroduced species will be indexed quarterly using spoor counts along repeat transects within each exclosure (see Figure 4). The sand surface along the transect is cleared of animal tracks the night before the count by dragging an 80 cm wide iron bar behind an all-terrain vehicle. The following morning all animal tracks that enter the 80 cm wide drag are counted, with a separate track counted each time an animal's track enters and exits the transect. The average tracks per kilometre are then calculated for each species. These spoor counts can also be used to monitor for incursions of introduced/feral mammal species to the exclosures which will initiate the incursion management plan (see Section 5.2).

Cage trapping/spotlight netting

The body condition, reproductive health and recruitment of each of the reintroduced species will be assessed through an annual cage trapping session within each exclosure. A four-night trapping session will enable a population estimate through mark-recapture and for new individuals to be marked. Bilbies can be challenging to catch in cage traps so spotlight-aided capture with dab nets will also be conducted to determine body condition, reproductive health and recruitment. Some reintroduced species (bandicoots, stick-nest rats, mulgaras) may also be caught in pitfall trapping surveys, using deep, wide pits (see Section 5.3).

Genetic screening

Selection of individuals from diverse source populations will be used to maximise the genetic diversity of the release population for each species. To monitor genetic diversity over time, genetic samples will be taken from each founder animal prior to release. During annual cage trapping at 8 years post release, genetic samples will be taken from a proportion of each species to assess genetic diversity to determine if genetic supplementation is necessary. This will ensure the long-term genetic viability of each species. Any genetic issues detected will be submitted in a report to OEH with proposed strategies to address them.

5.2 Introduced mammals

The successful exclusion of introduced mammal species will be critical to the restoration of the ecosystem within the Sturt Service Site. Transition through each of the stages of the conceptual model will require a slightly different focus for monitoring and management of introduced mammals. At stage 1, our monitoring will focus on quantifying abundance of introduced mammals within the existing environment. During stage 2, monitoring and management efforts will increase to ensure eradication of introduced mammals from within the exclosures. During stage 3 monitoring for introduced mammals will then shift focus to incursion detection within the exclosures and reducing pressure from introduced mammals around the boundary. At stages 4 and 5 management and monitoring practices will focus on reducing introduced mammal densities in the wild training zone and buffer zone to facilitate establishment of reintroduced species.

A number of monitoring techniques will be implemented to assess the abundance and distribution of introduced mammals within the exclosures, the wild training zone and the buffer zone (Table 4). This information will then be used to target management techniques for eradication. Continued monitoring will track progress towards eradication within the exclosures and determine the effectiveness of management techniques in the wild training zone and subsequently the broader buffer zone.

Table 4. Monitoring methods for introduced mammal species

Indicator	Aim	Monitoring method	Frequency and duration	Monitoring stream
Introduced mammals	Determine density and distribution	Spotlighting	Quarterly Ongoing	Core
Introduced mammals	Determine abundance and distribution	Spoor counts	Quarterly Ongoing	Core
Fence	Determine fence integrity and incursions	Fence patrol	Weekly Ongoing	Core
Introduced mammals	Determine presence/absence	Remote cameras	As required	Core
Guts and scats of predators	Determine diet of predators	Scat and gut contents analysis	As available	Partnership

Spotlighting

Quarterly spotlight counts will be used to assess the density and distribution of introduced mammals within the exclosures, the wild training zone and the buffer zone. During eradication programs within the exclosures, spotlight counts will likely be conducted more regularly. Transects will be conducted within all treatments (Figure 3). A driver and spotter will travel one way on each track counting all animals seen on the left hand side of the vehicle. Counts will then be used to calculate density estimates for each species. Spotlight counts will also be used to assess the density of kangaroos within the Sturt Service Site.

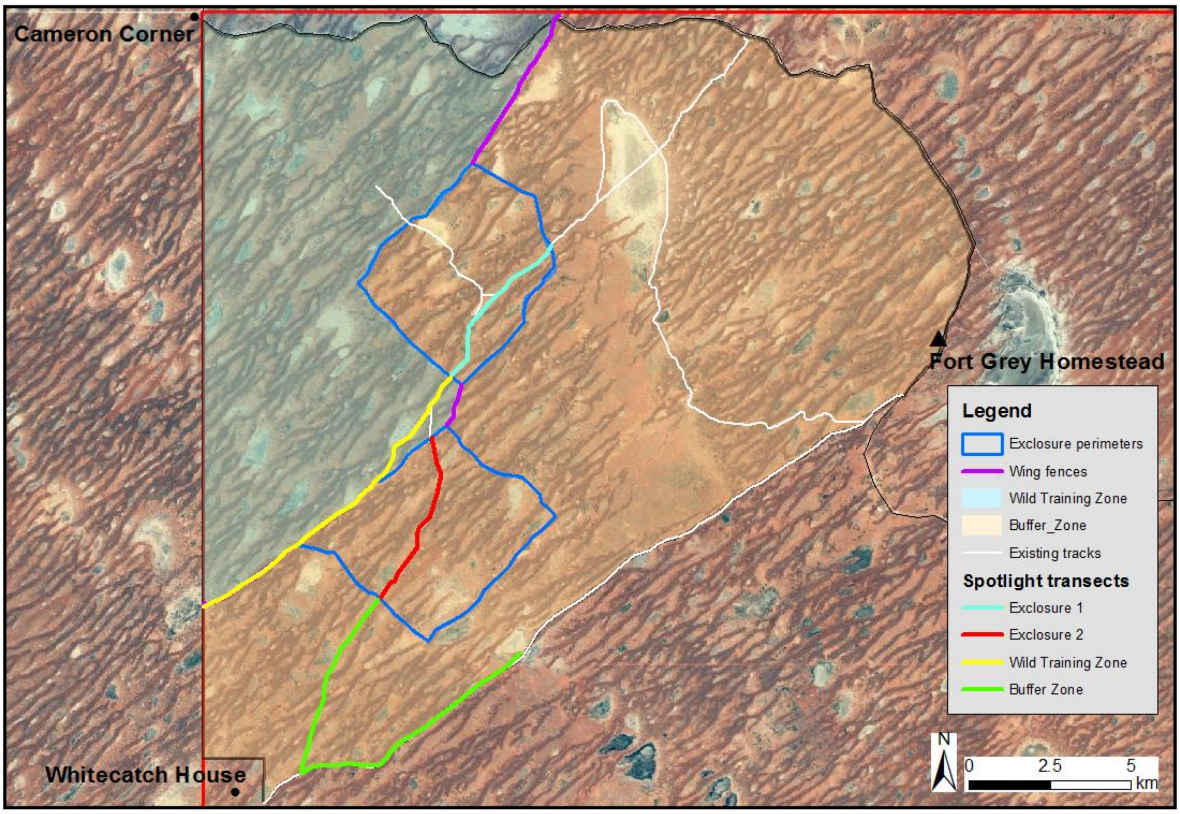


Figure 3. Spotlight transects to be conducted quarterly within the exclosure boundaries and the buffer zone

Track/Spoor transects

Track transects will be conducted quarterly to examine activity indexes of introduced mammals within each treatment and to monitor for incursions within the exclosures (Figure 4). The transect is cleared of tracks the night before the count by dragging an 80 cm wide iron bar behind an all-terrain vehicle. The following morning all tracks that enter the 80 cm wide drag are counted, with a separate track counted each time an animal's track makes a discreet crossing of the transect. The average number of tracks per kilometre are then calculated for each species. During the eradication stage, more frequent track transects, including intensive monitoring of the road networks within each exclosure, will be used to track progress and to target trapping efforts to remove introduced mammals. Once the Sturt Species have been reintroduced, the weekly fence patrol will also involve checking the road networks within each exclosure for tracks of introduced mammals. Again, spoor transects can also be used to monitor the activity index of kangaroos within each treatment.

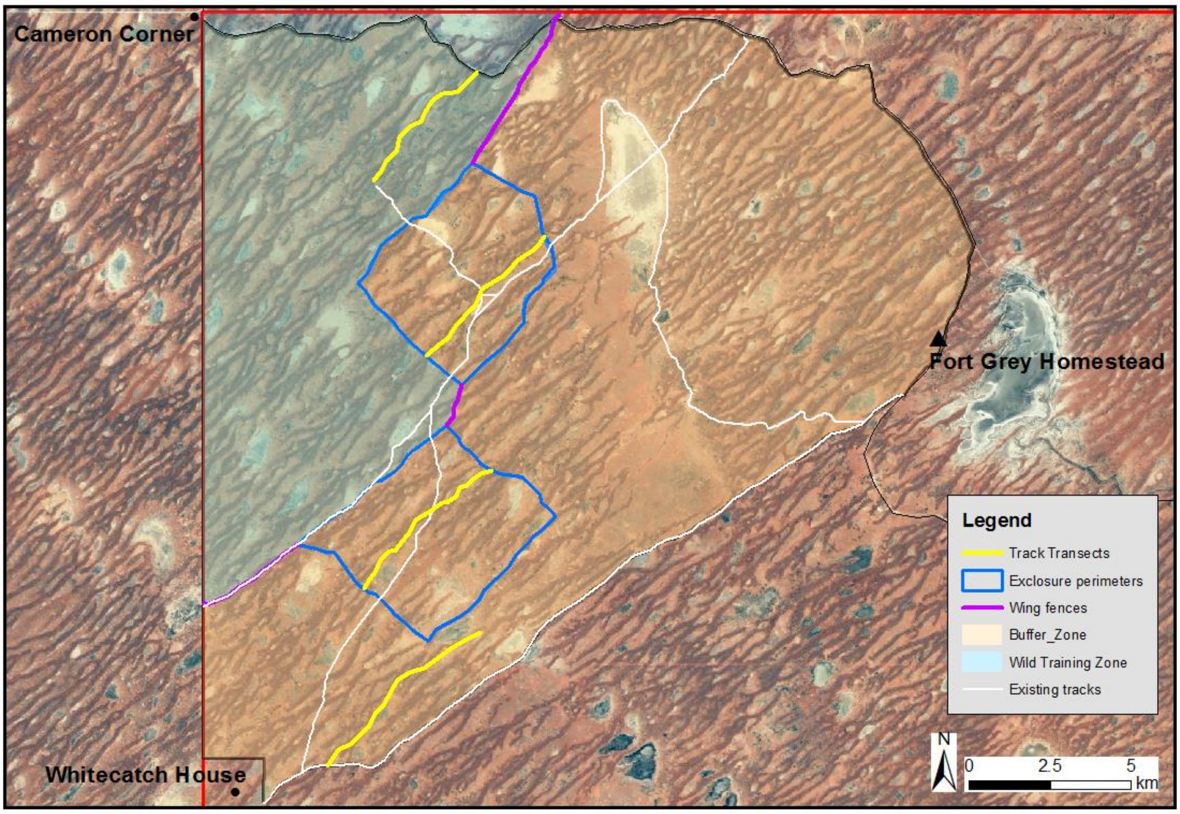


Figure 4. Quarterly track transects to be conducted within each of the exclosures and the buffer zone

Fence patrols

Following feral species eradication from within the exclosures, weekly fence patrols will be conducted from a vehicle to check for fence integrity and to monitor for signs of feral species incursion.

Remote cameras

During the eradication phase, remote cameras will be deployed to provide additional information on the status of introduced species within the exclosures.

Diet analysis from scats and gut contents

Dietary analysis of introduced/feral predator scats and gut contents can provide useful information on prey that predators are targeting. All predators trapped/shot as part of the monitoring program will be dissected and their gut contents identified to species or genus level, where possible. Predator scats will be collected opportunistically from within the site, for analysis of hair and bone fragments which may identify prey species. This data will be particularly useful when reintroduced species are released into the wild training zone and buffer zone.

Incursion management plan

An incursion management plan will be developed and appended to this EHMF following the next annual revision of this document. The management plan will detail strategies for monitoring and managing the incursion of introduced predators or rabbits, based on the species of incursion and the species which have been reintroduced to the exclosure at the time (e.g. baiting more effective for foxes than cats, leg-hold traps are challenging once species such as bettongs and bilbies are established, poison oats work well for rabbits in dry times). This management plan will then be implemented as part of the strategic adaptive management plan, should an incursion be detected through any of the methods described.

5.3 Resident species

A number of resident fauna species will be useful indicators of changes in ecological health. These include taxa that have experienced declines since European settlement or have been affected by mammalian extinctions. Groups include small native mammals (e.g. hopping-mice, dunnarts), ground nesting birds (e.g. Quail-thrushes, Wedgebills, Buttonquail), resident granivorous birds (e.g. Parrots, Pigeons), small insectivorous reptiles (e.g. geckos, skinks). To monitor changes in these species groups and the broader ecosystem we will establish 28 long-term monitoring sites (7 within each exclosure, 7 in the wild training zone and 7 within the buffer zone, Figure 5).

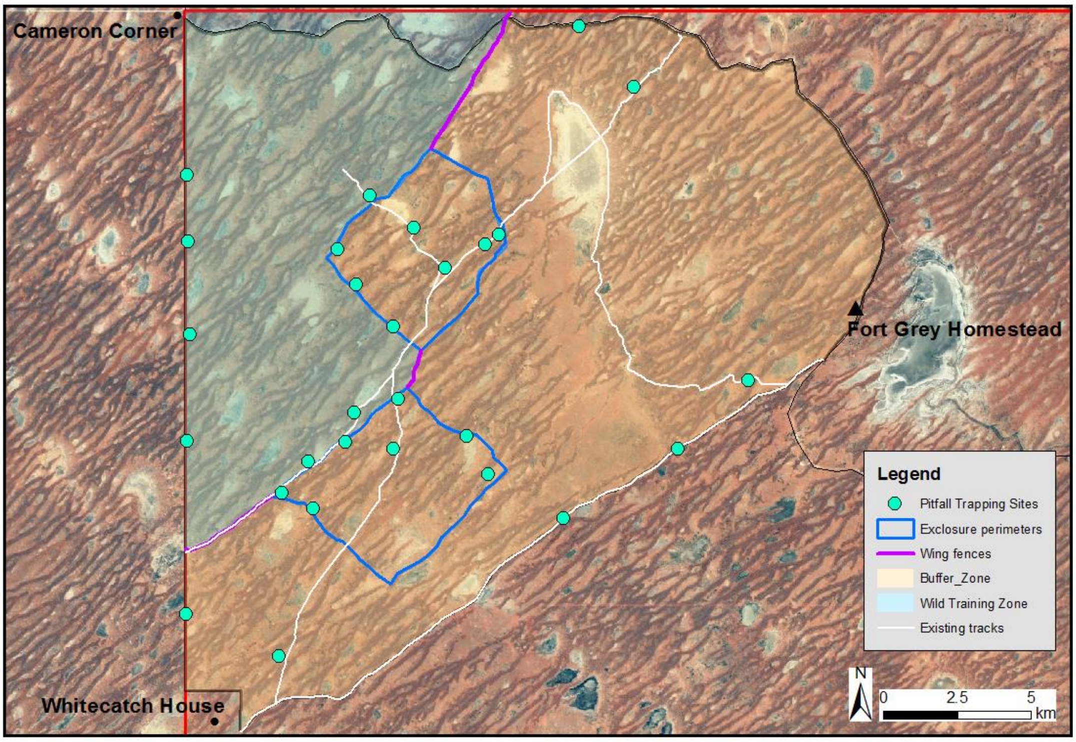


Figure 5. Location of long-term monitoring sites within each treatment area. Each monitoring site consists of a 2 ha (200 m x 100 m) area straddling areas of sand dune and productive swale. These monitoring sites incorporate the two main landscape features (dune and swale) and have been selected at areas of the landscape in which we expect to see greatest ecological change as a result of the management activities proposed (removal of macropod browsing and medium size mammal reintroduction). These sites consist of sandplain areas supporting *Marieana spp*., adjacent to dunes with *Acacia aneura/Acacia ramulosa/Acacia ligulata/Dodonaea viscosa* (Figure 6).

Figure 6. Example of a proposed monitoring site; a 200 m x 100 m (2 ha) area straddling the dune slope and adjacent areas of sand plain supporting chenopod shrubs and grasses. The redline above denotes the approximate path of the pitfall trap line (R West / R Peddler; UNSW Wild Deserts).

At each monitoring site, a range of monitoring activities will be conducted (Table 5). Some data will specifically assist in monitoring listed threatened species within the area (resident threatened species, as distinct from the reintroduced mammals) (Appendix A). Data on threatened species collected by the Wild Deserts project will be provided to OEH in annual reports and submitted to the Bionet database. A meeting held with Graeme Armstrong (Saving our Species Senior Project Officer - West Region) on 16 March 2017 identified that there are no current SOS monitoring projects within the Sturt Service Site but that there are opportunities to discuss potential collaborations and standardise monitoring with the Wild Deserts EHMF framework in future projects.

Table 5. Summary of resident species indicators that will be monitored, their frequency and monitoring stream

Indicator	Method	Aim	Frequency and duration	Monitoring stream
Small mammals, reptiles, invertebrates	Pitfall trapping	Determine abundance and diversity	Annual Ongoing	Core
Birds	Transects and listening posts	Determine the abundance and diversity	Annual Ongoing	Core
Flora - all	Jessup transects Ground cover quadrats	Determine the floral diversity Determine recruitment of perennial species Determine ground cover	Biennial Ongoing	Core
Ground cover Woody cover	Drone aerial photography	Determine the percentage ground cover	Annual Ongoing	Partnership
Bats	Anabat surveys	Determine the response of bats	To be determined	Partnership

Pitfall trapping

At each of the 28 sites, pitfall lines will be established. Sites will be trapped annually for four nights and incorporate 10 pitfall traps across the dune, sandplain interface. To maximise the diversity of species which can be caught, deep wide (225 mm diameter x 60 cm deep) and deep narrow (150 mm diameter x 60 cm deep) pits will be installed. Deep wide pitfall traps will also likely capture some of the reintroduced mammals (bandicoots, stick-nest rats and mulgara) and will likely prove useful in monitoring individual survivorship, recruitment and population trends for these species.

Bird transects

Bird species diversity and abundance will be conducted at each of the monitoring sites using walking transects, in which the observer traverses 1.5 km on foot along a permanent transect, recording the number of individual birds of each species seen/heard within 50 m either side of line (100 m), separating those birds that fly over.

Through external collaborations, it is hoped that use of sound meters or listening posts can be trailed for analysis of bird calls.

Vegetation surveys

We will conduct Jessup transect and quadrat surveys to estimate floral diversity, ground cover and examine browsing pressure. Jessup transects give an indication of long term change in perennial vegetation. Permanent pegs are used to mark the beginning and end of a 100 m Jessup transect. The transect is divided into 20 quadrats, each of 2 m width and 10 m length. The number of adult and juvenile plants of each perennial species is counted in each quadrat. At each monitoring site, separate permanently marked quadrats will be established and the cover for the standing vegetation (dead or alive), litter, bare ground, individual species measured at different height categories (0-30 cm, 30 cm-1 m, >1 m). As vegetation changes are slower to respond we will conduct this monitoring every 2-3 years following collection of a baseline survey in year 1.

Drone aerial photography and remote sensing

At each site we will fly a drone over a 200 x 200 m area annually to examine long-term changes in vegetation structure and ground cover. Post-processing will be used to determine percentage cover of woody plants and ground cover. We will use Landsat/MODIS imagery available through Google Earth Engine to quantify differences in ground cover, NDVI and annual vs. perennial cover between the broader areas of the exclosures and the buffer zone over time.

Anabat surveys

We hope to work with external collaborators to conduct bat surveys. It is most likely that bat monitoring will be conducted at two or three discreet intervals over the ten-year project and compared to measured responses in prey items and habitat structure.

5.4 Ecological processes

Broad landscape function and ecological processes are also likely to change as the area transitions between the current and desired state. Some areas will be tracked through core monitoring, while others will be achieved through student projects and collaborations (Table 6).

Table 6. Summary of ecological process indicators that will be monitored, aims and frequency

Indicator	Method	Aim	Frequency	Monitoring stream
Soil Chemistry	Soil Sampling	Examine changes in chemical composition of soil	To be determined	Partnership
Diggings	1 ha plot surveys	Determine changes in soil structure and water infiltration	Annual	Core
Refuges	1 ha plot surveys	Determine the abundance of refuges	Annual	Core
Mycorrhizal fungi	Scat analysis and fungal spore surveys	Examine role of reintroduced species in fungal life cycles	To be determined	Partnership
Soundscape	Sound meters	Determine changes in the soundscape of the environments	To be determined	Partnership

Soil sampling

Changes in soil nitrogen, phosphorus and carbon over time are expected as soil turnover increases through the introduction of fossorial mammals. By sampling soil from the dune and swale prior to management activities and at following time intervals, these changes may be determined.

1 ha plot surveys

Reintroduction of digging mammals to the ecosystem is expected to significantly transform soil turnover, water infiltration rates and the presence of refuges. Using 1 ha survey plots at each of the 28 monitoring sites diggings and burrows will be quantified on an annual basis to determine changes over time. It is likely that student projects will further investigate specific aspects of diggings and refuges, including measuring water infiltration rates.

Mycorrhizal fungi

Digging mammals spread mycorrhizal fungi, which are important in helping plants to increase their absorption of nutrients and fix nutrients. Bettongs, bilbies and bandicoots are known to eat fungal fruiting bodies. The reintroduction of these species will therefore likely return the symbiotic tree-fungus-marsupial relationships to the ecosystem. These changes can be monitored through the use of scat analysis and fungal spore surveys from the 28 monitoring sites inside the exclosures and the buffer zone. The exact methods for this project will be further developed with external collaborators.

Refugia surveys

The abundance and characteristics of refugia for small mammals is likely to change over time. These refugia are species specific (e.g. thick areas under *Rhagodia* or *Maireana* bushes suitable for stick-nest rat nest sites, or dense accumulations of leaf litter under *Acacia* or *Grevillia* trees, suitable for bandicoot day-nests). Through student projects, these differences in refugia between exclosures and the buffer zone will be examined.

Acoustic sampling

New technology is currently emerging to quantify the soundscape of environments. As the ecosystem is restored it is expected that changes in the soundscape of the environment will occur e.g. more insects as invertebrates become the dominant grazers. Wild Deserts will be an important test site for this developing technology.

6. Measuring performance

The success of the Wild Deserts project in achieving the objective of improving ecosystem health will be demonstrated by significant progress towards the desired state for a resilient ecosystem within the exclosures and the wild training zone in comparison to the buffer zone. As the project progress towards stage 5 and reintroduced species are added to the buffer zone, we will then expect to see progress towards the desired state within the buffer zone. Comparisons of monitoring data collected within each treatment will be provided in quarterly and annual reports. We also expect that a number of scientific publications will result from the monitoring proposed within this framework. Table 7 reviews the characteristics of the desired state and how the proposed array of monitoring methods will enable the Wild Deserts project to report on progress towards each one.

Table 7. Desired states for a healthy ecosystem and which monitoring methods will measure progress

Indicator	Desired State	Monitoring methods																		
		Radiotracking	Track transects	Cage trapping	Genetic screening	Spotlighting	Fence patrol	Remote cameras	Scat and gut content analysis	Pitfall trapping	Bird transects	Jessup transects	Palatable sp. quadrats	Drone surveys	Remote sensing	Anabat surveys	Soil sampling	1 ha plots	Sound meters	Fungal spore surveys
Reintroduced species	Successful reintroduction of locally extinct species	X	X	X	X	X		X		X										
	Native ecosystem engineers, herbivores, omnivores and predators	X	X	X		X		X		X										
Feral animals	Introduced predators replaced with native ones					X	X	X	X											
Resident species	Complete and balanced trophic structure that includes representative assemblages of reptiles, birds, inverts, bats, mammals, plants, fungi									X	X			X					X	X
	Complete and well-structured plant communities											X	X	X						
	Invertebrates become the dominant grazers									X									X	
Ecological processes	Soil nitrogen, phosphorus and carbon dynamics reinstated																X			
	Soil structure increased potential for water/nutrient infiltration																	X		
	Reduced erosion														X					
	Refugia established													X				X		
	Restored variability of fire regimes														X					
	Restored magnitude and duration of productivity pulses														X					
	Resilient to climate change														X					

Appendix A.

Threatened fauna species in Western CMA which occur within Strzelecki Dunefields system and may be monitored by the Wild Deserts Project (P – pitfall trapping, B- bird transect/listening post, T- track counts, J- Jessup transects).

Common name	Scientific name	Type	NSW status	Occurrence in SNP	Key Threats							Monitoring methods
					Introduced Predators	Grazing/Stock	Habitat degradation/ loss	Rabbits	Goats	Hunting/Poaching	Poison	
Australian Bustard	*Ardeotis australis*	Bird	Endangered	Known	x	x				x		B
Spotted Harrier	*Circus assimilis*	Bird	Vulnerable	Known			x				x	B
Grey Falcon	*Falco hypoleucos*	Bird	Endangered	Known			x			x		B
Black-breasted Buzzard	*Hamirostra melanosternon*	Bird	Vulnerable	Known		x	x			x		B
Little Eagle	*Hieraaetus morphnoides*	Bird	Vulnerable	Known			x				x	B
Brolga	*Grus rubicunda*	Bird	Vulnerable	Known			x			x		B
Blue-billed Duck	*Oxyura australis*	Bird	Vulnerable	Known			x					B
Freckled Duck	*Stictonetta naevosa*	Bird	Vulnerable	Known			x					B
Flock Bronzewing	*Phaps histrionica*	Bird	Endangered	Known	x	x						B
Black-tailed Godwit	*Limosa limosa*	Bird	Vulnerable	Known								B
Plains-wanderer	*Pedionomus torquatus*	Bird	Endangered	Predicted	x		x	x				B
Hall's Babbler	*Pomatostomus halli*	Bird	Vulnerable	Predicted	x	x	x					B
Redthroat	*Pyrrholaemus brunneus*	Bird	Vulnerable	Known	x	x	x					B
Pied Honeyeater	*Certhionyx variegatus*	Bird	Vulnerable	Known		x	x					B
White-fronted Chat	*Epthianura albifrons*	Bird	Vulnerable	Known	x		x					B
Painted Honeyeater	*Grantiella picta*	Bird	Vulnerable	Predicted			x			x	x	B
Forrest's Mouse	*Leggadina forresti*	Mammal	Vulnerable	Known	x	x		x				P

Dusky Hopping-mouse	*Notomys fuscus*	Mammal	Endangered	Known	x		x	x	x			P, T
Desert Mouse	*Pseudomys desertor*	Mammal	C Endangered	Known	x	x						P
Sandy Inland Mouse	*Pseudomys hermannsburgensis*	Mammal	Vulnerable	Known	x	x		x	x			P
Long-haired Rat	*Rattus villosissimus*	Mammal	Vulnerable	Known	x	x		x				P
Kultarr	*Antechinomys laniger*	Mammal	Endangered	Known	x	x						P, T
Stripe-faced Dunnart	*Sminthopsis macroura*	Mammal	Vulnerable	Known	x	x	x					P
Little Pied Bat	*Chalinolobus picatus*	Mammal	Vulnerable	Predicted	x		x					A
Yellow-bellied Sheathtail-bat	*Saccolaimus flaviventris*	Mammal	Vulnerable	Known			x					A
Wedgesnout Ctenotus	*Ctenotus brooksi*	Reptile	Vulnerable	Known	x		x					P
Leopard Ctenotus	*Ctenotus pantherinus ocellifer*	Reptile	Endangered	Predicted		x						P
Centralian Blue-tongued Lizard	*Tiliqua multifasciata*	Reptile	Vulnerable	Known	x	x						P
Yellow-tailed Plain Slider	*Lerista xanthura*	Reptile	Vulnerable	Known	x		x					P
Eastern Fat-tailed Gecko	*Diplodactylus platyurus*	Reptile	Endangered	Predicted	x		x					P
Crowned Gecko	*Lucasium stenodactylum*	Reptile	Vulnerable	Known	x	x	x					P
Barrier Range Dragon	*Ctenophorus mirrityana*	Reptile	Endangered	Predicted	x		x	x	x			P
Interior Blind Snake	*Anilios endoterus*	Reptile	Endangered	Known			x		x			P
Woma Python	*Aspidites ramsayi*	Reptile	Vulnerable	Predicted	x		x					P
Narrow-banded Snake	*Simoselaps fasciolatus*	Reptile	Vulnerable	Known	x	x						P

Threatened flora species in Western CMA which occur within Strzelecki Dunefields system and may be monitored by the Wild Deserts Project (J- Jessup transects).

Common name	Scientific name	Type	NSW status	Occurrence in SNP	Key Threats							Monitoring methods
					Introduced Predators	Grazing/Stock	Habitat degradation/ loss	Rabbits	Goats	Hunting/Poaching	Poison	
Purple-wood Wattle	*Acacia carneorum*	Plant	Vulnerable	Known		x		x	x			J
	Atriplex infrequens	Plant	Vulnerable	Predicted		x	x	x				J
Green Bird Flower	*Crotalaria cunninghamii*	Plant	Endangered	Known			x	x	x			J
Perennial forb	*Dipteracanthus australasicus subsp. corynothecus*	Plant	Endangered	Known		x			x			J
prostrate forb	*Dysphania platycarpa*	Plant	Endangered	Predicted		x						J
Flame Spider Flower	*Grevillea kennedyana*	Plant	Vulnerable	Known		x						J
Silky Cow-Vine	*Ipomoea polymorpha*	Plant	Endangered	Known		x		x				J
Fleshy Minuria	*Kippistia suaedifolia*	Plant	Endangered	Known			x					J
	Polycarpaea spirostylis subsp. glabra	Plant	Endangered	Predicted		x						J
Fan Flower	*Scaevola collaris*	Plant	Endangered	Predicted		x	x					J
	Stackhousia clementii	Plant	Endangered	Known		x						J

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