

National Recovery Plan for the Central Rock-rat *Zyzomys pedunculatus*



Northern Territory Government



Australian Government

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Director, Species Conservation
Flora and Fauna Division
Dept. of Environment and Natural Resources

Northern Territory Government
PO Box 1120
ALICE SPRINGS NT 0871.

This recovery plan sets out the actions necessary to stop the decline of, and support the recovery of, the listed threatened species. The Australian Government is committed to acting in accordance with the plan and to implementing the plan as it applies to Commonwealth areas.

The plan has been developed with the involvement and cooperation of a broad range of stakeholders, but individual stakeholders have not necessarily committed to undertaking specific actions. The attainment of objectives and the provision of funds may be subject to budgetary and other constraints affecting the parties involved. Proposed actions may be subject to modification over the life of the plan due to changes in knowledge.

This plan should be cited as follows:

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Copies of the plan are available at:

<http://www.environment.gov.au/biodiversity/threatened/recovery-list-common.html>

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ABBREVIATIONS

ASDP	Alice Springs Desert Park (a Division of PWCNT)
CLC	Central Land Council, a statutory authority representing Aboriginal people in the southern Northern Territory under the <i>Aboriginal Land Rights (Northern Territory) Act 1976</i> . It also has functions under the <i>Native Title Act 1993</i> and the <i>Pastoral Land Act 1992</i>
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i> , Commonwealth Government Legislation
DENR	Northern Territory Department of Environment and Natural Resources
IBRA	Interim Biogeographic Regionalisation for Australia
NESP	National Environmental Science Programme
NP	National Park
NT	Northern Territory
PWCNT	Parks and Wildlife Commission of the NT
WA DPAW	Western Australian Department of Parks and Wildlife (previously the Department of Environment and Conservation)

SUMMARY

The central rock-rat *Zyzomys pedunculatus* (Waite 1896) is classified as Critically Endangered under the *Environment Protection and Biodiversity Conservation Act, 1999* (EPBC Act). It is the only member of its genus confined to the arid zone; the other four *Zyzomys* species are restricted to the wet/dry tropics of northern Australia. Historically, the central rock-rat occurred across a wide area of central Australia and in pre-European times occupied much of arid Western Australia. Currently, the species is endemic to the southern Northern Territory and most recent records (post-1996) are from an area of 1200 km², between 80 and 200 km west of Alice Springs, within the MacDonnell Ranges IBRA region. This represents a >95% reduction in extent of occurrence since European colonisation. Within the current extent of occurrence, central rock-rats are restricted to mountainous quartzite habitat which provides refuge from threatening processes. The species occurs patchily within this limited habitat and in 2016 the species' global area of occupancy was <500 ha.

Predation by feral cats is a key threatening process for this species. Despite their highly restricted occupancy, central rock-rats comprise a substantial component of feral cat diet in the west MacDonnell Ranges. This suggests that cats preferentially target them over more abundant and widespread prey types. Large-scale wildfires are the other key threatening process, though the impacts of fire are complex and interactive. For example, fire removes the protective cover of spinifex, potentially improving the foraging efficiency of feral cats and other predators. Conversely, the central rock-rat preferentially occupies sites with a recent fire history (<10 years post-fire), as these areas provide the most species-rich communities of seed-producing forbs and sub-shrubs.

Recovery actions for managing the wild population *in-situ* are focused on better understanding and mitigating the impacts of predation and wildfire, as well as using fire as a tool to maximise central rock-rat occupancy. Another key action is to develop a strategy for translocation to assess the benefits and risks and recommend the best approach for establishing an insurance population of this species in a predator-free area(s).

This Recovery Plan will operate within a 10-year time-frame, though it will remain in force unless reviewed and updated or replaced. The Northern Territory Government will review the plan five years after the date of implementation and will report to the Australian Government on progress against the plan's criteria for success. Through an adaptive management approach, new information and the evaluation of previous actions will be used to inform and improve the recovery program.

GENERAL INFORMATION

1.1 Conservation status

The central rock-rat (*Zyomys pedunculatus*) is listed as critically endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) with a conservation advice that provides information on the basis of the conservation assessment, the causes of decline and a brief summary of what could be done to stop the decline of, or support the recovery of the species (TSSC 2018). The central rock-rat is listed as endangered in the Northern Territory under the *Territory Parks and Wildlife Conservation Act* (TPWC Act), critically endangered in Western Australia under the *Wildlife Conservation Act 1950*, and critically endangered on the IUCN Red List.

The central rock-rat is one of 20 mammals that the Australian Government has identified as a 'priority species' under its Threatened Species Strategy (<https://www.environment.gov.au/biodiversity/threatened/publications/strategy-home>). As such, the Australian Government has prioritised resource allocation to support the species' recovery effort. The Australian Government Threatened Species Strategy also identifies the central rock-rat as one of two mammal species requiring emergency intervention given that expert ecologists have raised concerns that, following significant recent declines, the species could become extinct without early and immediate intervention.

1.2 Purpose of the plan

This document constitutes the national recovery plan for the central rock-rat *Zyomys pedunculatus*. The plan identifies the management actions and research necessary to

stop the decline of, and support the recovery of, the species so that its chances of long-term survival in the wild are maximised.

1.3 Consideration of previous Recovery Plan

This recovery plan builds upon the work undertaken in the previous national recovery plan for the species (Cole 1999) and replaces it. A review of the previous recovery plan concluded that it failed to ensure the successful recovery of the species. However, it is noted that the previous plan was only an interim plan, intended to cover a two year period. A full plan should have been prepared during the second year of the interim plan (Action 7) but was not completed. An assessment of the achievements and limitations for each of the specific objectives, recovery criteria, and recovery actions is given in Appendix 1. Concern with the recovery process covers two distinctive aspects. First, some components of the interim recovery plan seem not to have been clearly directed. Assumptions were made about the ecology of the species without first studying these and one action that was irrelevant to its recovery was included. The lack of understanding of the boom-and-bust population cycles exhibited by the species also resulted in misdirection of many activities. The other concern is that implementation of the plan was haphazard and not strategic and significant actions were not completed. Examples of these include the lack of implementation of surveys (action 1) and of an effective monitoring strategy (action 2). Further, animals were taken from the wild and bred in captivity without there being a carefully formulated plan for reintroduction to the wild or a captive management plan.

In light of these deficiencies, we have developed a new plan which takes into account the significant advances made in our understanding of the distribution and ecology of the central rock-rat and its threats. This plan includes realistic targeted objectives and explicit criteria for measuring the effectiveness of their implementation. The NT Government is already undertaking recovery actions listed in this plan and the central rock-rat is a top-10 priority species for management for the NT Department of Environment and Natural Resources (DENR), increasing the likelihood of achieving success.

1.4 International obligations

This recovery plan is consistent with Australia's international obligations. The central rock-rat is listed under the Convention on International Trade in Endangered Species

of Wild Flora and Fauna (CITES) Appendix I. The plan is consistent with the aims and recommendations of the Convention on Biological Diversity, ratified by Australia in June 1993, as the plan will assist in implementing Australia's responsibilities under that convention.

1.5 Affected interests

The central rock-rat is currently restricted to Tjoritja (West MacDonnell) National Park (managed jointly by the Northern Territory Government and Traditional Owners) and Haast's Bluff Aboriginal Land Trust. Based on historical records, it may be present on other areas of Aboriginal land and on pastoral leases. All affected interests will be involved in the implementation of this plan. Northern Territory Government agencies will oversee the recovery actions. Actions on Aboriginal land will be carried out in consultation and partnership with the Central Land Council, Indigenous ranger groups and Traditional Owners. Employment of traditional owners in recovery actions will be undertaken where possible. Recovery actions on pastoral leases will be undertaken in consultation with property managers. Collaboration with universities and research hubs (e.g. National Environmental Science Program; University of Sydney) will also be sought to achieve the research components of the recovery actions.

List of Stakeholders

NT Government	<ul style="list-style-type: none">- Flora & Fauna Division, Department of Environment and Natural Resources- Parks & Wildlife Commission of the NT (Department of Tourism and Culture)
Indigenous groups	<ul style="list-style-type: none">- Central Land Council- Anangu Luritjiku Rangers- Tjuwanpa Rangers
Community	<ul style="list-style-type: none">- Arid Lands Environment Centre- Territory NRM- Central Land Management Association
Research	<ul style="list-style-type: none">- National Environmental Science Program- University of Sydney- Charles Darwin University

	- Commonwealth Scientific and Industrial Research Organisation
Potential translocation	- Newhaven Station / Australian Wildlife Conservancy
	- Western Australian Government, Department of Parks and Wildlife
	- Alice Springs Desert Park, Parks & Wildlife Commission of the NT
	- Perth Zoo, Western Australian Zoological Parks Authority

1.6 Social and economic impacts

The implementation of the recovery plan is unlikely to result in any significant adverse social and economic impacts. Implementation of the actions developed in this plan will be on a small scale that will not significantly alter existing land uses. Some positive social and economic impacts are likely to arise from implementation of the plan including incorporation of Indigenous knowledge into the recovery process, employment opportunities for Aboriginal people, and training for Indigenous ranger groups.

1.7 Biodiversity benefits

Recovery actions for the central rock-rat will also benefit a diversity of animal and plant species that do not necessarily interact with this species, but occupy the same habitat. In particular, greater knowledge and improved management of threats acting within the rocky ranges of central Australia will benefit a wide range of native species. Fire and predator management are likely to benefit other threatened species which inhabit the rugged mountains, including black-footed rock-wallaby *Petrogale lateralis*, long-tailed dunnart *Sminthopsis longicaudata* and the central Australian population of the common brushtail possum *Trichosurus vulpecula*.

2. BIOLOGICAL INFORMATION

2.1 Description

The central rock-rat is a nocturnal, terrestrial rodent with large ears, prominent eyes and a stout build (weight = 70-150g). They have long, yellow-brown fur on the

upperside of the body and have cream to white fur on the underside (Watts & Aslin 1981). The tail is slightly longer than head and body, is densely furred and fattened at its base (Watts & Aslin 1981).

2.2 Reproduction

Little is known of reproductive seasonality or success. Captive females have given birth to litters of 1 - 4 young (Cole 1999). In the wild, juvenile individuals have been reported in March, April, July and November, indicating that, in suitable conditions, breeding may occur throughout the year (Edwards 2013a). Generation length is assumed to be 1 - 2 years, based on age at sexual maturity (5 - 6 months; Begg 1981) and longevity (probably 2 - 3 years) for congeneric species.

2.3 Diet

Information on diet of the central rock-rat during the contracted phase of the population cycle comes from a small sample of faecal pellets, collected from four individuals caught on Mt Sonder in June 2010 (Jefferys 2011). The diet at this time was granivorous, with seeds contributing 56-66% of scat composition. Leaf material was the only other major food category, contributing 25-37% of the diet. Seeds and/or leaf material from 12 species were identified – all were native species and 11 were dicotyledonous. The most commonly consumed plant species was the quartzite endemic *Leucopogon sonderensis*, with its seeds contributing 9%-40% and leaf material 8-28%. The other plants recorded in the diet were a mix of heath-like species characteristic of the upper southern slopes of the range (e.g. *Hibbertia glaberrima*) and the spinifex-community vegetation (e.g. *Exocarpos sparteus*, *Petalostylis cassioides*) typical of this landform.

Other information on central rock-rat diet is from lower elevation areas during one extended irruptive period (Nano *et al.* 2003; Edwards 2013b). These studies highlight the importance of seeds (72%, Nano *et al.* 2003; 57%, Edwards 2013b), the secondary importance of leaf material (21%, Nano *et al.* 2003), an increasing prevalence of stem material as environmental conditions become drier (up to 52% in one sample, Edwards 2013b), and a scarcity of invertebrate material (though see results from captive animals in Gaikhorst & Lambert 2009). Many of the plant species recorded in these

studies are fire-tolerant species that are ubiquitous throughout the region and occur in and outside of core refuge areas (e.g. *Sida*, *Solanum*, and *Ptilotus* spp.).

2.4 Distribution

2.4.1 Historic

Previously, the range of the central rock-rat extended throughout much of the southern NT and across a large portion of arid Western Australia. Holocene sub-fossil cave deposit records exist for Uluru Kata-Tjuta National Park (Baynes and Baird 1992) and the West MacDonnell Ranges (Johnson and Baynes 1982) in the NT, and the Carnarvon (Cape Range), Great Sandy Desert, Little Sandy Desert, Gascoyne, Murchison, Tanami and Yalgoo IBRA regions of Western Australia (Baynes and Jones 1993; McKenzie et al. 2000a,b).

Historical records (post-European settlement up until mid-1960s) of the central rock-rat are confined to the southern NT where it occurred across a relatively large geographic area, although confirmed records and reliable anecdotal accounts are restricted to seven locations: Mt Liebig, The Granites, Napperby Station homestead area, Mt Barkly, Devils Marbles (Karlukarlu), Alice Springs, and Illamurta Springs (Finlayson 1961; Watts and Aslin 1981). A relatively small number of specimens are lodged in world museums (33 in total and only four this century).

In 1976 (a period of high rainfall in central Australia) and 1990, NT Government staff searched for the species by trapping at known previous locations and at sites with potentially suitable habitat. Combined, these surveys comprised 15 000 trap nights but failed to detect the species (Wurst 1990). General fauna surveys undertaken during mid-1970's to mid-1990's in rocky range habitats of the southern NT, including 40 000 trap-nights in the West MacDonnell Ranges (Gibson and Cole 1993), and 30 000 trap-nights in range country outside of the West MacDonnell Ranges, did not locate the species. Based on these results, the central rock-rat was presumed extinct (Wurst 1990).

2.4.2 Current distribution

The central rock-rat was rediscovered in September 1996 from the Heavitree Range near Ormiston Gorge in Tjoritja (West MacDonnell) NP. During the period 1996 to

2002 it was located at 20 sites between 80 and 140 kilometres west of Alice Springs. The full extent of occurrence based on these records was approximately 1000 km², with a latitudinal and longitudinal extent of 20 km and 57 km, respectively. At this time the northern known limit of the species was on the boundary between Tjoritja (West MacDonnell) NP and Milton Park Station, and its southern limit to the south of Namatjira Drive, half-way between Ormiston Gorge and Serpentine Gorge. The east-west extent was between Ellery Creek and Redbank Gorge.

The central rock-rat was not trapped at monitoring sites around Ormiston Gorge or elsewhere in the West MacDonnell NP between mid-2002 (following the onset of drought conditions) and 2010 (Edwards 2013a). Targeted surveys at 48 sites in Tjoritja (West MacDonnell) NP, carried out between July 2009 and June 2010, and concentrated on previous rock-rat locations, located the species at only one site; in a long-unburnt spinifex/heath community near the summit of Mt Sonder (McDonald et al. 2013). They were not previously known from this location. Subsequent live- and camera-trapping surveys have established that rock-rat core refuge habitat is higher elevation (>950 m) quartzite mountains and ridges. All recent (post-2002) records are on this landform type and most are on the Heavitree and Chewings Ranges between Ellery Creek and Ormiston Pound (McDonald et al. 2015b; Figure 1). The Mt Sonder sub-population has not been detected since 2012 when one animal was live-trapped, despite subsequent camera-trapping (McDonald et al. 2015b). A further isolated sub-population was located in 2013 near Mt Edward, an outlier of quartzite range on Haast's Bluff Aboriginal Land Trust, 70 km west of Mt Sonder (McDonald et al. 2015a; Figure 1).

Data collected since 1996 suggest that the central rock-rat can undergo large population fluctuations with marked increases occurring in response to rainfall-driven resource pulses, and contractions to core refuge areas during more typical dry periods. For example, the central rock-rat was the most frequently trapped small mammal at some sites around Ormiston Gorge in 2000 and 2001 (Edwards 2013a). By contrast, they were not recorded in the area during 1991-1993 despite over 20 000 trap-nights of effort (Pavey 2007), and have not been trapped there since 2002 despite considerable effort (Pavey et al. 2010; Edwards 2013a; McDonald et al. 2013). Importantly, the central rock-rat did not irrupt in response to high rainfall in 2010-11,

demonstrating that large rainfall events alone are not a reliable predictor of population increases. Alternatively, the central rock-rat may be suffering an ongoing decline that is resulting in reduced occupancy in refuge habitat over time and therefore a reduced ability to respond numerically to resource pulses.

With the absence of any post-1970 records from outside the west MacDonnell Ranges, it appears that the central rock-rat has suffered a contraction in extent of occurrence of >95% over the past 50 years. This possibility should be tested with further surveys at former locations when rock-rats are irruptive in known sub-populations.

2.5 Important Populations

The most recent central rock-rat monitoring data (Winter 2016) showed ~13% occupancy in core refuge mountain habitat in Tjoritja (West MacDonnell) National Park, down from ~24% occupancy in Winter 2015. The 2016 occupancy extrapolates to a total area occupied of 285 ha in the National Park. The status of the population on Haast's Bluff ALT is unknown, as it has not been sampled since its discovery in 2013 (McDonald et al. 2015a). However, given the limited area of suitable refuge habitat on Haast's Bluff ALT, this population is almost certainly smaller than the Tjoritja NP population; suggesting global area occupied by the species was <500 ha in 2016. Also of concern, the central rock-rat may now be extinct from the isolated Mt Sonder ridgeline, where the species was rediscovered in 2010. Extensive sampling on this ridgeline has resulted in no rock-rat records since 2012, when a single individual was live-trapped (McDonald et al. 2015b). Therefore, all remaining sub-populations should be considered important and refuge habitat must be managed to ensure it remains occupied between irruptive periods.

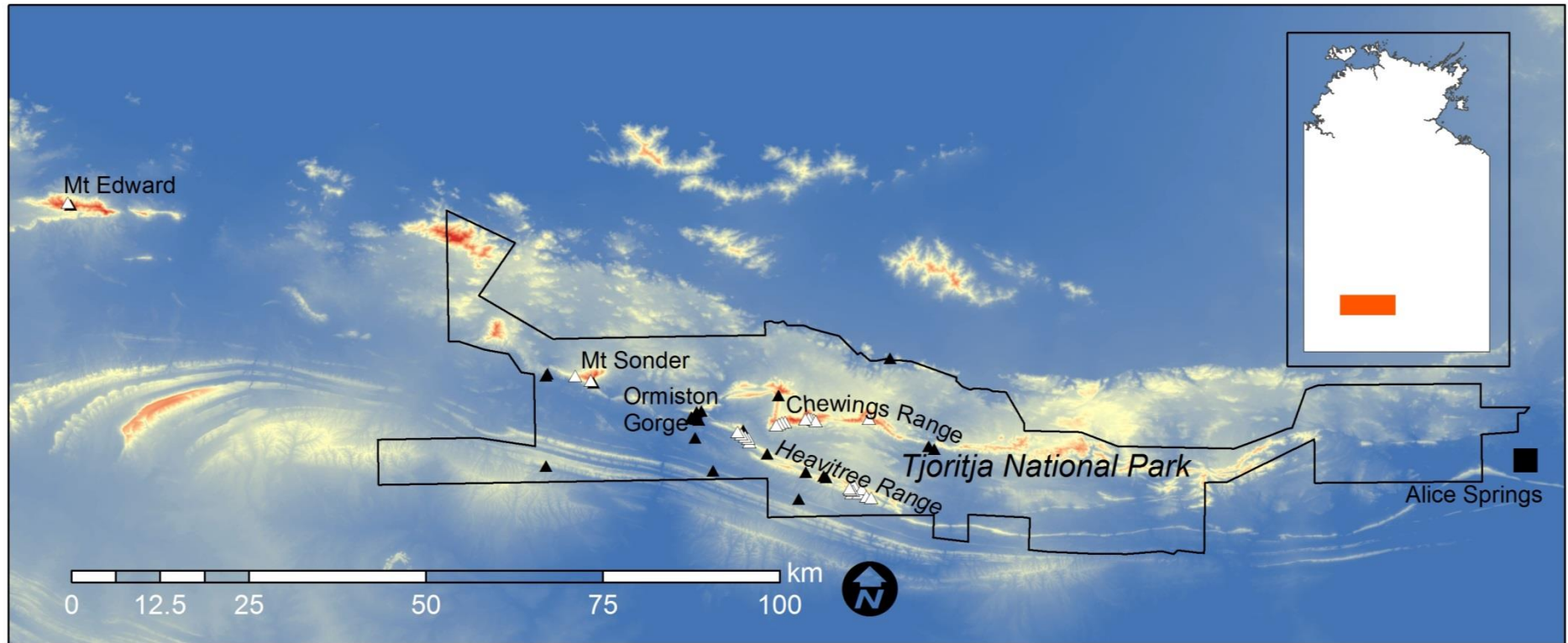


Figure 1. Location of sites where the central rock-rat, *Zyzomys pedunculatus*, has been recorded from 1996 to present. White triangles represent 2010-2016 locations and black triangles represent 1996-2002 records. Inset map shows location of enlarged area in the Northern Territory, Australia. Background 1-sec DEM courtesy of Geoscience Australia.

2.6 Habitat critical to survival

Current information suggests that the central rock-rat is confined to the MacDonnell Ranges IBRA region. The species has been recorded from a range of vegetation types, on a variety of geological substrates and in landforms from mountain-summits to valley floors. However, many of the previous records and associated locations for the species are likely to have occurred during irruptive phases of the species' population cycle and do not represent critical refuge habitat. Core refuge habitat occupied during contracted population phases should be a focus of recovery actions.

After a 36-year absence from the trapping record, the species was rediscovered in 1996 on a ridgetop of the Heavitree Range. This was presumably at a time of transition between contracted and irruptive phases, as the species was captured at a range of locations and landforms in the following six years. Presently (Winter 2016 data), the species is only known from higher-elevation ridgetops of the western Chewings and Heavitree Ranges in the West MacDonnell NP and west of Mt Edward on Haast's Bluff ALT. Given the substantial recent survey effort at lower elevations and on other geologies (McDonald et al. 2013), we conclude that higher elevation quartzite ridgetops provide core refuge habitat critical to the species during contracted phases of the population cycle.

The quartzite ridge-top and mountain habitats where rock-rats have been recently caught are characterised by shallow gravelly soils and exposed outcrop, frequently with abundant rock-crevices. Vegetation has a mallee-heath-like form, with a ground layer of spinifex grasses (typically hillside spinifex *Triodia brizoides* or *T. spicata*) and a mixture of forbs and subshrubs (e.g. goodenia *Goodenia ramellii*, round-leaved mallee *Ptilotus sessilifolius*). The shrub layer is variable, but common species include *Gastrolobium brevipes*, *Mirbelia viminalis* and the Central Australian guinea-flower *Hibbertia glaberrima*. Species usually present in the sparse canopy include the tall shrubs MacDonnell mulga *Acacia macdonnellensis* and mountain hakea *Hakea grammatophylla*, and the mallee species mallee bloodwood *Corymbia eremaea*, mallee red gum *Eucalyptus gillennii* and round-leaved mallee *Eucalyptus minniritchi*. Mt Sonder (Figure 2) was characterized by mature unburnt vegetation while most of the other sites were in areas burnt within the last 10 years (McDonald



Figure 2. An example of core refuge habitat for the central rock-rat on Mt Sonder, West MacDonnell National Park, August 2010. This population may now be extinct as rock-rats were last detected here in June 2012.

et al. 2015b, McDonald et al. 2016). Higher occupancy of longer-unburnt vegetation may coincide with infrequent spinifex mast seeding events (McDonald et al. 2015b, McDonald et al. 2016, Wright et al. 2014).

2.7 Captive breeding

Captive breeding for translocation is potentially a major component of recovery for the central rock-rat. The captive breeding undertaken between 1996 and 2007 was ultimately unsuccessful (refer to Appendix 2). The major issue that arose during the captive breeding program, which eventually led to the demise of the captive population (and the failure of the aim to maintain an insurance population long-term), was the low breeding success achieved from successive generations of captive-bred animals. With a 23.7% success rate overall and only a 13.3% success rate among captive-born individuals, a rapid loss of genetic variation occurred to the point that the F_3 generation consisted of the offspring of only one adult pair.

Any proposal to re-establish a captive breeding colony will require removal of rock-rats from wild populations. The impact of such removal is dependent on the size of the wild population, which fluctuates according to rainfall patterns and food availability –

the impact of removal while the population is contracted will be much greater than removal during a population increase phase. Appendix 4 is an assessment of the risks associated with a) not having a captive colony and b) establishing a captive colony (or colonies), using three approaches to collect founder animals from the wild.

From Appendix 4, it is apparent that there are risks associated with not having an insurance population—core wild populations may continue to contract resulting in local, and possibly total, extinction. There are also significant risks associated with removal of rock-rats to establish a captive colony. The least attractive option is probably to remove small numbers as they become available – it poorly serves the objectives of both the wild and captive populations. So establishment is best done either by a concerted effort as soon as possible to collect enough rock-rats (minimum of 12 adults; Appendix 3), or to delay collection until the next increase phase of the population cycle (at an unknown time). Since the size of the population in the wild is unknown but likely to be small, a concerted effort to remove several animals to captivity will potentially be of great risk to the wild population. Waiting for the next increase phase to remove rock-rats has the same short-term risks as not having an insurance captive colony, but potentially has no impact on the wild population once a population increase occurs. While the time to the next increase phase of the population cycle is unknown, preliminary data suggest high rainfall in the previous winter (such as has occurred in winter 2016) may be an important predictor of increased rock-rat occupancy.

The recovery plan currently recognises captive breeding only as a possible short-term (12-18 month) action in order to facilitate any translocations. Ideally, such translocations will be wild-to-wild with no reliance on captive bred stock – this would minimise costs and stress to animals, and likely increase the chance of a successful translocation.

There is however, now sufficient information available on the habitat requirements, diet and population dynamics of the central rock-rat to prepare a strategy for translocation for the species and this is a priority action in this Recovery Plan. This strategy should consider the benefits and risks of establishing long-term ex situ breeding colonies (noting that previous captive breeding programs were unsuccessful; see Appendix 2).

3. THREATS

Each threatening process was evaluated under a risk assessment framework, with threats ranging from minor to extreme risk of extinction (see Appendix 6).

3.1 Key threats

3.1.1 Predation (*very high to extreme risk*)

Predation by feral cats is a key threat to the central rock-rat and poses a very high to extreme risk of extinction (Woinarski et al. 2014; McDonald et al. 2015a). Central rock-rat remains have been recovered from cat scats collected in core rock-rat habitat and there is evidence that cats target rock-rats over alternative small mammal prey (McDonald et al. 2015a; DENR unpublished data). Recent camera trapping data suggest that cats are resident in core refuge habitat, with a predicted occupancy of close to 1.00 at a 500 m grid scale and an observed density of 0.12 cats per km² (Appendix A in Legge et al. 2016; McDonald et al. 2016;). However, it is possible that the ruggedness characteristics of this habitat result in reduced hunting efficiency for feral cats (see McGregor et al. 2015) and/or that cat densities are lower than in other habitats in the MacDonnell Ranges. For example, the observed density for cats on the alluvial plains south of Simpson's Gap in autumn 2015 was 0.17 cats per km² (Appendix A in Legge et al. 2016).

Stable dingo populations occur in the West MacDonnell NP where there is abundant surface water and they are not subject to population management. Dietary data from 98 scats, including numerous scats collected in and around core rock-rat refuge habitat, showed no evidence of dingo predation on the central rock-rat in Tjoritja (West MacDonnell) NP (DENR, unpublished data). This data also shows that dingoes prey on feral cats and cat remains were found in 9% of dingo scats. Foxes are rare in the MacDonnell Ranges and absent from core refuge habitat (DENR unpublished data).

Observations from other arid Australian systems suggest that predators increase rates of rodent population decline during post-irruption phases of population cycles (Newsome and Corbett 1975; Dickman et al. 1999; Pavey et al. 2008) and it is likely that this will be a critical time to implement predator control.

3.2.2 Wildfire (high risk)

Fire impacts on the central rock-rat are poorly known, but may vary with season, severity and extent, as well as soil moisture and post-fire rainfall patterns. Periods of prolonged high rainfall in Central Australia lead to major flushes of seed-bearing grasses and forbs. This increased resource supply underpins rock-rat population increases and the species can expand into a range of habitats, including lower slopes. Fire frequency and extent usually increases at the tail end of these high productivity events, or fires can also occur at smaller scales during protracted dry periods. Several fire-encouraged plant species have been recorded in central rock-rat diet (Nano et al. 2003; Edwards 2012b) and fire may therefore play an important role in the persistence of foods for this species. Consequently there may be scope to manipulate food resources through controlled fire management.

Conversely, negative impacts may arise from the occurrence of severe, large-scale fires in rock-rat habitat. In 2002 and 2011-2012, most of the species' range within the West MacDonnell Ranges was burnt by wildfire. While it is unknown whether these fire events are a 'natural' event that occurred prior to European colonisation, they could have dramatic population effects given that food availability would be diminished over an extensive area in the short term. Landscape-scale fires may also increase the hunting efficiency of predators such as feral cats (McGregor et al. 2014; McGregor et al. 2015, Leahy et al. 2015).

Management of wildfire is likely to be one of the most tractable methods for the conservation management of the central rock-rat and should be a focus of further experimental research.

3.2 Additional threats

3.2.1 Habitat degradation by large introduced herbivores (low risk)

Horses and cattle potentially threaten the central rock-rats through habitat modification and competition for food. Feral horses in particular thrive in rugged terrain. These animals cause erosion and soil compaction, damage vegetation, and, because they

consume mainly grasses and forbs, possibly have considerable dietary overlap with the central rock-rat. Horses are regularly managed by the Parks and Wildlife Commission of the NT in the West MacDonnell NP and are currently absent from the majority of the park. Horses occur at high densities in the area surrounding the Mt Edward population on Haast's Bluff ALT, however there is no evidence that they frequent higher elevation quartzite landforms (DENR unpublished data).

3.2.2 Environmental weeds (low risk)

The widespread occurrence of the introduced invasive perennial grass *Cenchrus ciliaris* (buffel grass) into the MacDonnell Ranges poses a potential threat to the central rock-rat. This grass species increases both the frequency and the intensity of fire (Butler and Fairfax 2003; Franks 2002) and frequently outcompetes native vegetation. Seeds of buffel grass have not been recorded in the diet of the Central Rock-rat (Edwards 2012a).

Presently, buffel grass occurs in comparatively low density in quartzite range habitat, where the majority of recent rock-rat records occur. Consequently, the threat level associated with this grass should be low in the majority of cases. Other habitat types within the distribution of rock-rats at the peak of the population cycle are, however, expected to be affected by this species. Examples include lower range slopes and drainage lines at Ormiston Gorge and in the Alice Valley, as well as low limestone and gneissic hills, throughout the MacDonnell Ranges (C. Nano pers. obs. 2008). Buffel grass may be further advantaged in the future by processes such as altered fire regimes and climate change, so has the potential to invade other areas of central rock-rat habitat within the West MacDonnell Ranges. The greatest impact of this environmental weed may be in these other, non-core, areas by interrupting the natural spread of the species during irruptive phases of the population cycle and preventing them from recolonising potential core areas of habitat.

3.2.3 Parasites and disease (low risk)

Parasites and disease may affect rock-rat population densities. Roundworms *Aspiculuris tetraptera* have been recorded in captive central rock-rat individuals. This

species is common in rodents. Post-mortem examination of captive animals showed the presence of species such as lymphosarcoma, a common neoplasm in rodents. Post-mortem examinations of wild and captive-bred animals have shown that specimens in good body condition are susceptible to Acute Respiratory Distress Syndrome (ARDS). ARDS has implications for husbandry in the captive breeding of the central rock-rat. The level of risk and strategies to deal with this threat should be considered in more detail in the translocation strategy developed for the Central Rock-rat.

3.2.4 Climate change (moderate risk)

Global climate change is likely to have significant impacts on Australia's arid zone, including the MacDonnell Ranges IBRA region. Projected trends within the next 20 years include: an increase in average temperatures in Central Australia, an increase in numbers of hot days (temperature $\geq 40^{\circ}\text{C}$), and an increase in numbers and lengths of heatwaves (i.e. consecutive days with temperature $\geq 40^{\circ}\text{C}$) (Hughes 2003; Bastin 2014). Average rainfall is also projected to decrease (Hennessy et al. 2004). Decreased rainfall combined with an increase in potential evaporation will lead to a general decrease in available atmospheric moisture. In turn this will result in more frequent and more severe droughts (Hennessy et al. 2004). There is also a prediction of fewer but more extreme high rainfall events (e.g. Letnic and Dickman 2010).

Taken together these changes in climate are likely to lead to longer periods between resource pulses and more periods of extreme fire danger. Both of these processes may challenge the ability of the central rock-rat to persist in the MacDonnell Ranges. If increase phases of the central rock-rat's population cycle occur only after multiple years of above-average rainfall, the species is particularly susceptible to the potential impacts of climate change. The central rock-rat population did not irrupt outside of core refuge habitat during the most recent above-average rainfall period in 2010-2011; this was unexpected and is a source of considerable concern for rock-rat conservation.

4. RECOVERY

4.1 Existing conservation initiatives

Current initiatives include experimental feral cat control (using 1080 poison baits) and fine-scale burning in Tjoritja (West MacDonnell) NP, aligning with Recovery Actions 1 and 2. These actions have been funded by the Australian Government until June 2017 as part of the 'emergency intervention' for priority threatened species, with substantial cash and in-kind contributions from the NT Government. The results of these actions will be available in the second half of 2017. An annual monitoring program has been implemented for central rock-rats and feral cats since June 2015. The experimental cat and fire management have been applied to this monitoring framework and the design includes four sites, allowing for treatments and controls.

4.2 Recovery objectives, performance criteria and actions

4.2.1 Recovery Plan Objectives

1. The conservation status of the central rock-rat (currently listed as Critically Endangered nationally and by the IUCN) is improved.
2. Targeted research has addressed key knowledge gaps such that management options are better informed and management actions are more effective.
3. Appropriate management actions are implemented to ensure suitable habitat is available for the central rock-rat
4. A viable central rock-rat population at Newhaven Wildlife Sanctuary and/or on a Western Australian island is established, subject to the translocation strategy.
5. Effective and adaptive implementation oversight of the recovery plan, and monitoring of the species' status and effectiveness of management and research activities, is undertaken.
6. Stakeholders support and, where appropriate, are engaged in the implementation of the recovery plan.

4.2.2 Criteria for success

This recovery plan will be deemed successful if, within 10 years, all of the following have been achieved:

1. The conservation status of the central rock-rat has improved.
2. Targeted research has addressed key knowledge gaps and, as a result, management options are better informed and management actions are more effective.
3. Management actions to address threatening processes for the central rock-rat have been implemented and, as a result, current and future suitable habitat has been effectively managed to maximise its suitability for the central rock-rat.
4. A viable central rock-rat population has been established and is being maintained at Newhaven Wildlife Sanctuary and/or on a Western Australian island.
5. Effective and adaptive implementation and management oversight of the recovery plan has occurred. A monitoring program has been effectively implemented and is being maintained.
6. Stakeholders are supportive of the plan and are engaged in the implementation of the recovery plan where appropriate.

4.2.3 Actions

The current recovery plan comprises five actions that combine on-ground management of probable threatening processes with monitoring and research to refine our knowledge and further target management. Due to the unpredictable nature of the boom-and-bust population cycle of central rock-rats, the timing of the actions must be more flexible than the tables of annual costings imply. However, the on-ground management actions (1 and 2) need to be implemented as soon as possible (see Appendix 6 - Risk framework assessment).

1. Investigate the impacts of fine-scale fire on core central rock-rat populations
2. Undertake experimental management of feral cats around core central rock-rat populations and measure response through changes in occupancy.
3. Determine global area of occupancy and monitor subsequent changes in occupancy of the central rock-rat in core refuge habitat.
4. Investigate the spatial ecology of central rock-rats and feral cats in core refuge areas.

5. Assess the feasibility and risks of possible combinations of translocation and captive breeding (temporary vs insurance population vs none) to identify the most appropriate strategy for translocation, then implement as required.

4.3 Details of actions

Action 1 – Investigate the impacts of fine-scale fire on core central rock-rat populations.

Aim – To develop a framework for fire-management decision-making (what to burn and when) for the benefit of the central rock-rat on and around quartzite ridges and mountains in the West MacDonnell Ranges.

Methods – Finer-scale experimental habitat manipulation should be directed at dense spinifex grassland communities in areas adjacent to known rock-rat sub-populations. The objective should be to maintain the protective cover of spinifex while promoting food resources. This may be achieved through mechanical removal or fine-scale burning (following rainfall) to create food-rich patches embedded within the matrix of dense spinifex grassland. Occupancy patterns of rock-rats and cats pre- and post-manipulation should be measured using camera trapping across areas recently burnt by wildfire, manipulated dense spinifex and un-manipulated dense spinifex habitats.

Costs (\$1000s)

Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Total
80	40	40	40	40	240

Action 2 – Undertake experimental management of feral cats around core central rock-rat populations and measure response through changes in occupancy.

Aim – To reduce feral cat occupancy/density and increase central rock-rat occupancy in core rock-rat refuge habitat.

Methods – Although cats are notoriously difficult to control, other states have had substantial success using poison baits in semi-arid regions where rabbit or small mammal numbers (alternative food) are low (rabbits are absent from the quartzite

ridges). Baiting with 1080 or PAPP in winter (low reptile activity) during times of low rainfall (low mammal activity) is likely to have the greatest chance of success in controlling cats. Strategies to minimise impacts on dingoes should be trialled; dingoes are likely infrequent visitors in these higher altitude habitats so any off-target loss of dingoes is expected to be low and outweighed by the positive benefits of controlling cat numbers. Camera traps provide the most efficient technique to monitor the pre- to post-bait response from rock-rats and predators (through changes in occupancy).

Costs (\$1000s)

Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Total
50	50	50	50	50	250

Action 3 – Determine global area of occupancy and monitor subsequent changes in occupancy of the central rock-rat in core refuge habitat

Aim – To determine the extent of currently-used core refuge habitat for central rock-rats and to monitor shifts in the proportion of habitat occupied.

Methods – Distribution modelling (e.g. using MAXENT) may assist in directing further survey work to locate additional central rock-rat refuges. Preliminary MAXENT modelling suggests suitable refuge habitat may occur: on Mt Zeil and the Chewings Range between Hugh Gorge and Jay Creek in the Tjoritja (West MacDonnell) NP, in the vicinity of Meerenie Bluff and near Mt Liebig on Haast's Bluff ALT, on Mt Leichardt in the southern Tanami Desert, and in the Mordor Pound area of the East MacDonnell Ranges. Preliminary camera trapping at Mt Zeil, Mordor Pound and Mt Liebig in 2015-16 have resulted in no rock-rat detections.

Costs (\$1000s)

Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Total
40	40	0	0	0	80

Action 4 – Investigate the spatial ecology of central rock-rats and feral cats in core refuge areas.

Aims – To determine home range size and space use of central rock-rats and feral cats in and around core refuge habitat.

Methods – A sample of adult male and female central rock-rats and feral cats from at least two rock-rat sub-populations will be caught and fitted with VHF transmitter harnesses and GPS units, respectively. Rock-rats will be captured using Elliott box metal traps and cats with cage and soft-jaw leg-hold traps. The nightly movement and den-site locations of collared rock-rats will be recorded using radio-telemetry by observers on foot. Cat location fixes will be recorded on the GPS devices and retrieved by VHF transmitter. Movements will be monitored on individuals for up to 12 months (over 3-4 night sessions for central rock-rat) over a 1-2 year period. Home range data for both species will be calculated using GIS software and habitat selection in relation to fire history and other environmental variables will be determined (e.g. Discrete Choice Modelling). This project would be ideally suited to a PhD student, potentially through the NESP threatened species hub.

Costs (\$1000s)

Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Total
100	100	100	0	0	300

Action 5 – Assess the feasibility and risks of possible combinations of translocation and captive breeding (temporary vs insurance population vs none) to identify the most appropriate strategy for translocation, then implement as required.

Aim – Extend the risk assessment presented in Appendix 4 of this document to determine the most appropriate procedures for translocating (reintroducing or reinforcing) populations of Central Rock-rats and to identify the most likely locations, costs and risks.

Methods – Information on core populations, diet, habitat requirements and general ecology collected from the previous Actions will be collated to assess the feasibility of different translocation options (e.g. reintroduction to Newhaven Wildlife Sanctuary, a predator-free island off the Western Australian Pilbara coast, previously occupied core sites, reinforcement of current core populations, or other). Translocations into habitat used in the increase phase of the population cycle are unlikely to be successful in the long-term unless feral cats can be successfully managed. The considerable literature on translocation of mammals in Australia (e.g. Short 2009) and rodents internationally will be reviewed, as well as two failed attempts to translocate Carpentarian Rock-rats, to determine the methods most likely to be successful and the associated risks.

Appendix 4 is a risk assessment of removal of animals from the wild. To fully inform the strategy for translocation, this needs to be extended to assess the risks associated with all aspects of establishing and maintaining i) an interim (12-18 months) captive breeding colony, or ii) a long-term captive insurance population. Associated with this should be an estimate of annual costs of the various captive-breeding and translocation options, and the likelihood of maintaining funding for a long-term captive colony.

All stakeholders in the recovery process need to be involved in the preparation and endorsement of the strategy for translocation. Once a strategy for translocation is completed, translocation plans for the best options should be drafted and implemented when conditions are appropriate.

Costs (\$1000s)*

Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Total
50	50	50	0	0	150

*Potential costs of different options for translocation differ by orders of magnitude, and the most appropriate times (dependent on multi-year climate and population cycles) cannot be forecast. Consequently, no costs of implementation of the strategy for translocation have been included here but are potentially in the hundreds of thousands per year.

5. MANAGEMENT PRACTICES

The recovery of the central rock-rat is primarily dependent on reducing the impacts of feral cats and determining and then applying favourable fire management practices. Because the current known distribution is entirely restricted to the most rugged landscapes in arid Australia, threats such as land clearing and mining-associated development are less likely to apply to this species. However, given the highly limited nature of rock-rat refuge habitat, any proposals to develop within or close to this habitat could be catastrophic for the central rock-rat.

While more research needs to be undertaken to determine the most suitable fire management regimes, landscape-scale wildfires (e.g. 1000's of hectares) are likely to be unfavourable for the central rock-rat. In the short term, fire removes food resources and potentially increases predation risk from feral cats, through the loss of groundcover. Extensive wildfire also results in relatively homogenous landscapes, limiting the potential to apply favourable fine-scale fire management. Minimising the extent and severity of wildfire is already a management priority for the NT Parks and Wildlife Commission in Tjoritja (West MacDonnell) NP and for CLC across other Aboriginal land. However, achieving this aim during high rainfall La Niña events (e.g. 2000-01, 2010-11) remains a considerable challenge and requires mobilisation of resources at those critical times.

6. IMPLEMENTATION, DURATION AND EVALUATION

Implementation of the recovery plan will be coordinated by a national recovery team to include representatives from the Commonwealth, NT and Western Australian Governments, Alice Springs Desert Park, Perth Zoo, conservation NGOs (such as the Australian Wildlife Conservancy) and other stakeholders. Major evaluation of the recovery plan will be undertaken halfway through the plan (5 years) by the Commonwealth Government. Evaluation of existing actions (see Table 1) will determine actions and costing for the remaining five years of the plan and a

supplementary document outlining these will be produced. Ongoing evaluation of actions will also be undertaken by the National Recovery Team under an adaptive management framework.

Table 1. Indicative time frames, priorities and estimated costs (\$1000s) of recovery actions over the first five years of implementation

Action	Priority	Primary responsibility	Potential Implementation partners	Indicative cost and timing					
				Year 1	Year 2	Year 3	Year 4	Year 5	Total
1. Investigate the impacts of fine-scale fire on core central rock-rat populations.	Urgent	NT Government (DENR)	NT Parks and Wildlife Commission, Central Land Council	80	40	40	40	40	240
2. Undertake experimental management of feral cats around core central rock-rat populations and measure response through changes in occupancy.	Urgent	NT Government (DENR)	NT Parks and Wildlife Commission, Central Land Council, Indigenous rangers	50	50	50	50	50	250
3. Determine global area of occupancy and monitor subsequent changes in occupancy of the central rock-rat in core refuge habitat.	Urgent	NT Government (DENR)	NT Parks and Wildlife Commission, Central Land Council, Indigenous rangers, Pastoral Industry	40	40	0	0	0	80
4. Investigate the spatial ecology of central rock-rats and feral cats in core refuge areas (including home range and movements patterns in relation to fire history).	Urgent	NT Government (DENR)	NT Parks and Wildlife Commission, Central Land Council, NESP	100	100	100	0	0	300
5. Assess the feasibility and risks of possible combinations of translocation and captive breeding (temporary vs insurance population vs none) to identify the most appropriate strategy for translocation, then implement as required..	Urgent	NT Government (DENR)	NT Parks and Wildlife Commission, Central Land Council, Australian Wildlife Conservancy	50	50	50	0	0	150
Total Costs				320	280	240	90	90	1020

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APPENDIX 1. EVALUATION OF THE 2000 CENTRAL ROCK-RAT INTERIM RECOVERY PLAN

The interim plan contained five specific objectives, six recovery criteria, and seven recovery actions (three actions had two components). The interim plan was written to cover only a two year period however 15 years have now elapsed. Therefore this assessment covers actions completed over the full extent of this 15 year period. As part of the evaluation process of the previous recovery plan (Cole, 1999) each recovery action was assessed and scored as:

- 0 No progress/recovery action not contributing to recovery
- 1 Insufficient action or action failed
- 2 Significant action undertaken but not completed
- 3 Action fully completed

	Specific Objective 1	Clarify the distribution, population size and trends and specific habitat requirements	
	Recovery Criterion 1	Production of a map of known current distribution	
	Recovery Criterion 2	A description of the habitat of known central rock-rat sites	
Action 1	Conduct biophysical mapping and establish the extent of central rock-rat distribution	Comments	Score
1.1	Conduct biophysical mapping	Biophysical mapping has been completed in the West MacDonnell National Park. However, it is now understood that this mapping has little predictive/explanatory value for crr occurrence.	3
1.2	Investigate further sites	To a limited degree this work was undertaken by Parks and Wildlife Rangers based at Ormiston Gorge. However, this action was not carried out in a thorough and co-ordinated manner and the extent of this species distribution was not resolved.	1
	Recovery Criterion 3	Estimates of population size and trends	
Action 2	Establish the size of some known sub-populations, monitor	Comments	Score

	those sub-populations and investigate the processes threatening them		
2.1	Establish the size of some known sub-populations and monitor those sub-populations	Monitoring and estimate of sub-population size was only carried out at one site – Ormiston Gorge. This is a serious short-coming in the plan's implementation because it did not enable tracking of large-scale range extension or contraction. The interim plan could have been more specific in identifying sub-populations for monitoring.	1
2.2	Investigate threatening processes	Some limited work has been undertaken in this regard including assessments of predator diets within the range of the central rock-rat.	1
	Specific Objective 2	Develop and implement appropriate management strategies to secure the known sub-populations	
	Recovery Criterion 5	Implementation of a fire management strategy for ecological communities associated with rare and fire-sensitive plants and fire shadow areas in the MacDonnell Ranges	
Action 3	Implement a fire management strategy for rare and fire sensitive plants and fire shadow areas	Comments	Score
		It is unclear why fire management should target fire shadow areas and rare and sensitive plants. There is no evidence that central rock-rats use refuges as defined in this action. Survey and dietary work has shown that the central rock-rat a) feeds extensively on fire weeds and b) does not occur in fire shadow areas. It has no association with rare or fire sensitive plants. The wildfire events of 2002, which lead to the local extinction of the species at multiple sites, illustrates that an adequate fire management strategy was not in place to protect critical habitat within the known distribution of the species. A fire	0

		management strategy is currently being completed for the West MacDonnell National Park which specifically targets the requirements of this species.	
	Specific Objective 3	Maintain captive populations	
	Specific Objective 4	Investigate those aspects of the biology of the central rock-rat which can be carried out on captive animals	
	Recovery Criterion 4	A knowledge of diet and reproduction	
Action 4	Capture additional animals for the captive breeding programme and maintain the captive population	Comments	Score
4.1	Capture additional animals for the captive breeding programme	This work was successfully undertaken. Six additional animals were captured in 2001 to establish a captive population at Perth Zoo.	3
4.2	Maintain the captive population	The captive population was maintained successfully in the medium term (refer Appendix 2). However, ultimately this action failed as there is now only one animal left in captivity.	1
	Specific Objective 5	Raise the profile of central rock-rat in the community	
	Recovery Criterion 6	Increase community awareness and involvement in the conservation of the central rock-rat	
Action 5	Implement education and extension work	Comments	Score
		Some useful education and extension work has been undertaken over the past decade highlighting the conservation status of the central rock-rat. These include media releases and incorporation of the species in public talks within the West MacDonnell National Park. Unfortunately, the central rock-rat is not on display at the ASDP. Such a display is highly desirable and appears the most effective way of educating the public about the species given the ASDP has up to 100,000 visitors per year.	2
Action 6	Operate recovery team	Comments	Score

		The last meeting of the recovery team was in early 2003. The team operated successfully over the period 2000-2003 but has been inoperative since.	2
Action 7	Produce reports and update the interim recovery plan to a full recovery plan	Comments	Score
		The interim recovery plan was not updated into a full recovery plan. A limited number of reports on the species have been produced including papers published in 2003 (Nano et al.) and 2013 (McDonald et al).	1

APPENDIX 2: SUMMARY AND REVIEW OF THE CAPTIVE BREEDING PROGRAM 1996-2011

(Prepared by Peter Nunn)

Following re-discovery of the central rock-rat in the West MacDonnell Ranges in 1996, eight individuals (four males, four females) were brought into captivity at Alice Springs Desert Park (ASDP) for work on the husbandry and breeding of the species. The 2000 interim recovery plan had as one of its actions the maintenance of a captive population; therefore, the captive effort was continued and enlarged by the inclusion of Perth Zoo. Six central rock-rats (four males, two females) were collected from the wild and sent to Perth. A summary of the main events in the captive husbandry of the central rock-rat from 1996 to the present appears below.

Timeline of Captive Husbandry

- 1996-8 8 animals (4 males, 4 females) brought into captivity at ASDP from the wild. 2 females pregnant from wild matings; one litter surviving captive-birth.
- 1997-8 A female at ASDP was successfully mated with 2 different males, producing a total of 4 litters, all of which were successfully raised to weaning. A litter consisting of one pup was born to another pair but it was dead on discovery (stillborn/ abandoned).
- 2000-1 A pair of captive-born animals at ASDP raised 2 litters, the first successful breeding of captive-raised animals. This pair bred again in 2002.
- 2001 6 animals (4 males, 2 females) collected from the wild and sent to Perth Zoo for captive husbandry and breeding. One female pregnant from a wild mating gave birth to and successfully raised one pup.
- 2001-2 Perth Zoo bred from 2 pairs of rock-rats. 6 litters produced, with a total of 22 pups. All pups successfully raised.
- 2002 Perth Zoo separated wild-caught pairs to stop breeding due to a shortage of housing spaces. An additional litter of 3 pups was born and fully raised from the pairing of a wild-caught male to a captive-born female.
- 2002 The first and only successful breeding of 2nd generation captive-bred animals occurred in an outdoor trial of a small group at ASDP (1 male, 2 females). 7 litters with 16 pups born to both females in a 7 month period, with weaned animals left in the group. Low survivorship occurred due to inappropriate group structure. Ultimately only 4 of the 27 animals housed or bred in the group survived.

- 2002 Last litter (one pup) produced at ASDP from a pair housed indoors, despite continued effort over the following years. ASDP received additional captive-bred animals from Perth Zoo.
- 2003-4 Perth Zoo re-paired animals to restart the breeding program. Only one pair, which had previously produced a litter together, successfully bred. This pair produced a further 3 litters. No further breeding was achieved at Perth Zoo.
- 2003-4 ASDP focused efforts on breeding male-female pairs indoors, with no success.
- 2004 Perth Zoo and ASDP exchanged several animals.
- 2004-7 ASDP trialed male-female pairs housed outdoors, and one trio (M.M.F). One female bred twice with different males, but pups were dead on discovery (either stillborn/abandoned).
- 2007 Due to lack of breeding success Perth Zoo sent all remaining animals to ASDP.
- 2007-8 ASDP housed a group of rock-rats in a large, landscaped outdoor enclosure. Initially 2 males and 1 female were introduced, then a further 2 males and 1 female. One male and 1 female were removed due to aggression-related injuries. Monitoring animals was problematic because of natural hiding sites that were impossible for keepers to access. Predators (goannas, snakes) were able to climb into the enclosure; several had to be removed during the project. Of the 4 rock-rats left long-term in the enclosure, only 1 male was recovered after 6 months.
- 2009 Only 2 males remaining in captivity at ASDP.
- 2010 1 male central rock-rat remaining in captivity at ASDP.
- 2011 Last captive male died at ASDP

Summary of Information Collected from Captive Animals

1. Lifespan

The oldest captive-born individual died at 6 years 7 months of age. One wild-caught male survived for 6 years 10 months in captivity and was estimated at 7 years 3 months of age at death. Another wild-caught female, which was pregnant on capture, survived for 6 years, 4 months in captivity. Although a reliable estimate of age-at-capture was not possible the fact that she was pregnant indicates an age of at least 8 months, giving her a minimum age-at-death of 7 years 3 months. The estimated maximum lifespan of the central rock-rat in captivity therefore is about 7 years.

2. Breeding success by institution

A summary of breeding success is outlined below (Table A2.1). Reproductive success was low at both institutions, with less than ¼ of adults successfully rearing young.

Note that several individuals were housed at both ASDP and Perth Zoo during their adult life.

Table A2.1 Breeding success of captive central rock-rats in colonies at the Alice Springs Desert Park and Perth Zoo.

	ASDP ¹	Perth ²	Total
No. adults housed (total)	35	30	59
No. adults bred ³	13	6	19
No. adults that raised litters ⁴	8	6	14
% breeding success	22.9	20.0	23.7

¹ Includes animals sent from Perth in 2002 and 2004;

² Excludes animals sent to ASDP as juveniles in 2002 and 2004;

³ Excludes wild matings;

⁴ At least one pup survived to weaning

3. Breeding success by generation

The following table (A2.2) shows the decline in breeding success over successive generations of captive central rock-rats. While the initial success rate with wild-caught founders was relatively high, these results could not be repeated with captive-bred animals, and the reduced rate at each generation resulted in all F₃ individuals being full siblings (only one of which survived to adulthood).

Nine of the 10 matings of captive-born animals occurred at ASDP.

Table A2.2 Decline in reproductive success of central rock-rats over successive generations (F) in captivity.

	No. adults (total)	No. adults bred	No. adults bred successfully ¹	% success
F ₀	14	9	8	57.1
F ₁	32	8	4	12.5
F ₂	12	2	2	16.7
F ₃	1	0	0	0.0

¹ At least one pup survived to weaning. All figures exclude wild matings.

4. Litter size versus age for captive females

It was speculated that age was a contributing factor to the lack of breeding success in the captive central rock-rat colonies, particularly in later years of the program. Analysis of litter size versus breeding age shows that optimal breeding was achieved for females less than 750 days old (average litter size = 3.0). For females over 800 days old the average litter size dropped to 2.3. One female which bred multiple times at ASDP for example gave birth to litters of 3, 2, 2, and 1 over an 18 month period.

A higher rate of stillbirths and abandoning of pups prior to weaning occurred in females over 800 days old, resulting in a survival rate of only 1.4 pups per litter. For example, one female bred at Perth Zoo maintained high litter sizes throughout her breeding life (3, 3, 3, 4) but the survival rate within these litters steadily dropped (100%, 67%, 67%, 50%) as she was observed pushing pups from later litters out of the nest box.

The optimum breeding window therefore, at least for females, is estimated as 8-25 months of age.

5. Breeding lifespan

The maximum breeding age of captive central rock-rats is estimated at 5 years. This is based on a litter which was produced from the pairing of a male who was 4 years 9 months with a female who was 4 years 11 months old. However, all pups in this litter were stillborn. The oldest animals to produce viable litters were a 4 year 6 month-old female and a 4 year old male.

6. Breeding season

As illustrated below, litters were born in 10 out of 12 months of the year, showing the ability of the species to breed year-round in captivity (Figure A2.1).

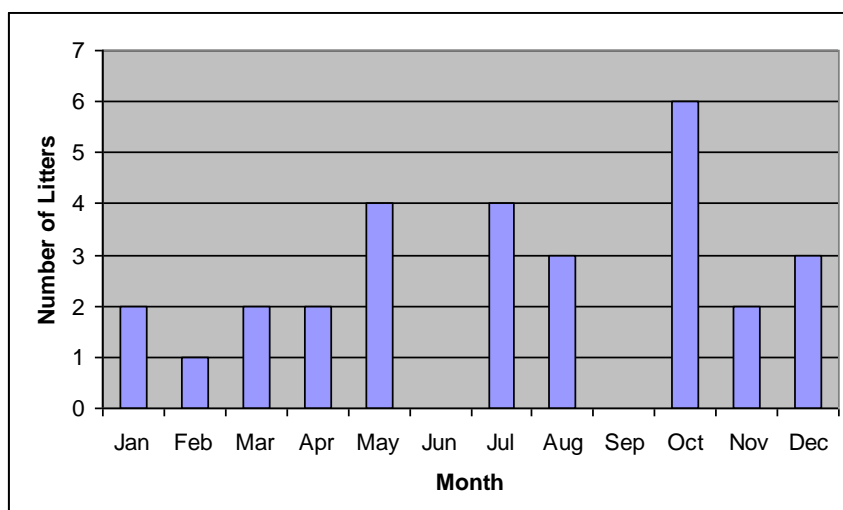


Figure A2.1 Frequency distribution of births of central rock-rats in captivity.

7. Survivorship of young

The table below (Table A2.3) shows survivorship of both litters and individual pups born in captivity. Perth Zoo achieved excellent success in raising rock-rat pups. The survivorship of pups to weaning age at ASDP was very low; however these results are skewed due to the high mortality rate of pups born to females housed in a small social group during 2002 (attributed to conspecific aggression). If these litters are removed from the calculations then the percentage success of pups surviving to sexual maturity at ASDP climbs to 60%. It must also be noted the ASDP figures include several litters of stillborn pups born to quite old females.

Table A2.3 Survivorship of litters and individual pups in captive populations of central rock-rats in the Alice Springs Desert Park and Perth Zoo.

	ASDP	Perth
Litters born	19	11
Litters raised ¹	10	11
% success (litters)	52.6	100.0
No. pups born	48	36
No. pups weaned	23	32
No. pups surviving to adult	16	29
% success (pups to adult)	33.3	80.6

¹ At least one pup from litter successfully weaned

Summary

Initial captive breeding of central rock-rats in the late 1990s at ASDP involved considerable trial-and-error as husbandry procedures and techniques were refined, since no previous work had been done with the species. One key element of this was the discovery that central rock-rats can be extremely aggressive when housed together and are particularly susceptible to stress through disturbance (e.g. capture and restraint), which in either case can result in the death of individuals. With this in mind Perth Zoo implemented a successful strategy to manage the animals they acquired in 2001 and achieved extremely high survival rates (over 80%).

A major aim of the captive breeding program was to gather information on life history and breeding parameters (as per specific objective 4 of the interim recovery plan). In this regard the program was very successful in providing important data on gestation, litter size, development of young, age at weaning, occurrence of post-partum oestrus, breeding season timing, lifespan, and maximum breeding age.

The major issue that arose during the captive breeding program and which eventually led to the demise of the captive population (and the failure of the aim to maintain an insurance population long-term), was the low breeding success achieved from successive generations of captive-bred animals. With a 23.7% success rate overall and only a 13.3% success rate among captive-born individuals, a rapid loss of genetic variation occurred to the point that the F₃ generation consisted of the offspring of only one adult pair. Unfortunately, due to overcrowding Perth Zoo ceased efforts to breed the species within 12 months of acquiring their original founders. Despite considerable effort they were never able to restart breeding within the colony (except for one pair who had previously bred). The reasons for this pattern are unknown.

APPENDIX 3: CAPTIVE BREEDING RECCOMENDATIONS

(Prepared by Peter Nunn)

Purpose

The main purpose of maintaining a captive population(s) of the central rock-rat is to provide a temporary captive population for translocation.

Secondary Aims

Crucial to the maintenance of a small captive population is the ability to reliably breed the species in a controlled environment. More work is needed on the captive breeding of central rock-rats before this can be consistently achieved. Historical work with the species, which began in 1996, failed long-term with the exact cause(s) of poor reproductive success largely undetermined (refer to Appendix 2). Initial future work should focus on achieving consistent and reliable breeding results from a small number of founding animals over several generations.

Previous captive work on the central rock-rat contributed a large amount of information on life history and reproductive parameters (summarised in Appendix 2), so that gathering of further biological data is not considered critical. However, additional data on minimum and maximum age of breeding, and age-specific fecundity will be useful if population modelling is to be considered in the future to assist in managing wild populations.

Previous captive breeding strategy

Past captive breeding focused on indoor housing of 1:1 pairs of the species. This involved housing the animals in adjoining enclosures which were connected by a series of pipes to allow for easy introduction and separation of the 2 individuals. This design was favoured due to the issues of capture stress and intraspecific aggression. However, such a set-up requires considerable space; ASDP devoted an entire room to the maintenance of eight breeding pairs (16 individuals), with additional enclosures required for juveniles. All cost estimates for future captive breeding are based on such a housing strategy.

Future breeding and management strategy

Past difficulties in establishing breeding condition in captive-bred rock-rats indicate that there should be a focus on maximising breeding, at least in the first 2 years of an animal's life, to ensure successful maintenance of both population size and genetic diversity. This can be achieved by identifying key animals for breeding at a young age and establishing pairs as soon as sexual maturity is reached. A strategy of "trickle breeding" to produce small numbers of offspring each year while maintaining a stable population size appears doomed to fail unless significant advancements are achieved in captive breeding success.

The approach of aiming for maximum breeding output gives the best possible chance of all genetically-important individuals producing young. However, such a strategy invariably results in overpopulation (each generation effectively lasting for around 2 years, while individuals can live for up to 7 years), hence a management euthanasia policy would need to be implemented at any institutions involved in the program in order to effectively manage population size. This policy will provide the space necessary to continue breeding successive generations at a young age by removing animals that are old and/or over-represented genetically. For many Australian zoological institutions this would be a major issue due to fear of public outcry, particularly since it involves a critically endangered species.

Population Size

A minimum stable captive population of 20 adults, with a sex ratio of 1:1, is considered to be the most appropriate compromise between maximising genetic diversity and minimising husbandry costs. This would allow for the rapid expansion of population size at any given time should animals be required for wild release (group size for release is estimated to be >50). The establishment of a studbook to manage the captive breeding of the species long-term will be needed. The studbook should be maintained by a single keeper who makes animal management recommendations to all zoological institutions involved to ensure that breeding is carried out to maintain maximum genetic diversity over successive generations.

It must be noted that to maintain a breeding population of 20 adults ultimately requires housing more than this number as recently-bred juveniles must also be housed. This consideration has been factored into cost projections.

Founders

The establishment of such a population would require the removal of at least 12 founding animals from the wild.

APPENDIX 4. RISK ANALYSIS OF REMOVING CENTRAL ROCK-RATS FROM THE WILD TO ESTABLISH A CAPTIVE POPULATION

(Prepared by Simon Ward)

Purpose

The re-establishment of a captive breeding colony will require removal of rock-rats from wild populations. The impact of such removal is very dependent on the size of the wild population, which fluctuates in a boom and bust cycle – the impact of removal while the population is contracted will be much greater than removal during an expanded phase. Table A4.1 is an assessment of the risks associated with a) not having a captive colony and b) establishment of a colony (or colonies), using three approaches to collecting founder animals from the wild. This risk assessment is based on the following general objectives, criteria and action options for maintenance of the wild and of captive populations:

Long-term objective: To have confidence that, during contracted periods of the population cycle, the meta-population in the wild is distributed across sufficient locations and there are sufficient numbers at each location for the species to persist.

Objective 1. To maintain the species in the wild

Criterion of success 1. Sufficient numbers of breeding individuals remain at enough core refuge sites to support the meta-population until the next boom phase (number of individuals needed and number of sites unknown).

action option 1¹. Do not remove CRR into captivity

Objective 2. To have a captive population to support reintroduction programs

Criterion of success 2. Minimum of 20 adult breeding individuals (sex ratio 1:1) managed in captivity

action option 2a. Remove all CRR that can be captured ASAP

action option 2b. Remove small numbers of CRR from the wild to maintain both wild and captive populations

¹ these 'action options' are mutually exclusive and are separate from this National Recovery Plan's Recovery Actions

action option 2c. Remove CRR from expanding populations during the break-out phase.

This risk assessment discusses only the ecological impacts of the actions; it does not cover the logistic or social (financial) risks. For example, if money were found to establish facilities for a captive colony (preferably two locations) and to send out staff to collect animals, we currently don't know the likelihood that the funding will continue and that the institutions will maintain their enthusiasm for the captive population well beyond the life of this plan. The following assessment also does not consider the risk of the captive breeding colony being unsuccessful (the ultimate fate of the previous captive population). Action 5 in the National Recovery Plan is to draft a comprehensive strategy for translocation of the species that includes a risk assessment of these more social / financial factors.

Risk analysis of the influences of pursuing each potential action on the ability for the recovery plan to meet the population objectives (see above)

Translocation objective	Criteria/ Action	Influences on the opportunity to meet the wild population objective (1)				Influences on the opportunity to meet the captive population objective (2)			
		Beneficial outcomes	Likelihood	Detrimental outcomes	Likelihood	Beneficial outcomes	Likelihood	Detrimental outcomes	Likelihood
<u>Objective 1</u> Maintain the species in the wild	<u>Action 1.</u> Do not remove CRR into captivity	Major Maximises population in the wild short-term	Almost Certain As no animals will be removed from the wild	Moderate Some local populations in core areas may collapse Major All local populations in core areas may collapse	Unlikely Rare	Nil	Almost Certain	Major No captive population established	Certain
<u>Objective 2.</u> To have a captive population as an insurance policy against extinction in the wild and to support reintroduction programs	<u>Action 2a.</u> Remove all CRR that can be captured ASAP	Minor The wild population will be bolstered by translocations in the future from captive stock	Unlikely Presumes that sufficient numbers are taken into captivity to establish a genetically viable population and the captive breeding program is successful	Major Removal of animals may jeopardise the long-term viability of the source core populations	Likely Current size of these core populations is not known, so impact on them will be unknown	Major Trapping to identify the location and extent of wild populations followed by intensive trapping to remove as many animals as possible	Unknown (Likely) In the short-term, this approach is most likely to result in a viable captive breeding population. However, the number that can be collected is uncertain.	Moderate May not result in viable genetic diversity in captive population if insufficient animals can be caught.	Unknown (Unlikely) Don't know how many individuals will be caught
								Major Expensive - Will require considerable costs in people time, helicopter time, transportation, etc.	Almost Certain this section is not coloured in Red as this is a logistic constraint, not a biological influence on the objective.

	Action 2b. Remove small numbers of CRR from the wild to maintain both wild and captive populations	Minor The wild population will be bolstered by translocations in the future from captive stock	Rare Presumes that sufficient numbers are taken into captivity to establish a genetically viable population and the captive breeding program is successful	Major Removal of animals may jeopardise the long-term viability of the source core populations	Unlikely Current size of these core populations is not known, so impact on them will be unknown	Minor RRs will be removed from wild populations as encountered in trapping to monitor the population and in general biodiversity surveys	Likely It may take several years to collect sufficient RRs for a viable captive population	Moderate Will result in lower genetic diversity in the captive population and a slow increase in size of the captive population	Likely If only a small number of RRs are caught initially, the genetic diversity will be more strongly biased towards these few individuals
								Major The previous captive breeding program failed, partly because of declining enthusiasm and commitment. Without long-term commitment of funding to agreed translocation goals, the captive program may collapse again.	Likely This will be exacerbated if there is only a slow trickle of founder CRR into the captive population. This section is not coloured in Red as this is a logistic constraint, not a biological influence on the objective.
	Action 2c. Remove CRR from expanding populations during the	Minor During the boom phase, sufficient CRRs will be in the population to support both a wild and a	Almost Certain	Major Wild population may crash before the next boom phase	Unlikely The wild population has 'disappeared' in the past, but core populations are currently	Major In a boom phase it will be much easier to collect the numbers of CRRs needed to	Likely In the long-term, this approach is most likely to result in a viable captive	Moderate Delay (for unknown time) in establishment of captive population	Likely Don't know when the next boom will occur – climate dependent.

	boom phase	captive population			persisting on at least 2 high ranges	for a viable captive pop- ulation with good genetic variation.	breeding population.		
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Colour scheme for assessing the influence (outcome x likelihood) of the potential Actions on the wild/captive objectives (from SEWPaC).

Positive outcomes					Negative outcomes				
Likelihood	Nil	Minor	Moderate	Major	Nil	Minor	Moderate	Major	Likelihood
Almost Certain									Almost Certain
Likely									Likely
Unlikely									Unlikely
Rare									Rare
Unknown									Unknown

APPENDIX 5. RISK ASSESSMENT FRAMEWORK USED TO DESCRIBE THREATENING FACTORS, AND PRIORITISE MANAGEMENT RESPONSE.

			consequence of threat operating (intensity of impact)				
			catastrophic <i>likely to cause complete population loss, where operating</i>	severe (major) <i>results in 25-75% reduction in population, where operating</i>	moderate <i>results in 10-25% reduction in population, where operating</i>	minor <i>results in some small (<10%) reduction in population, where operating</i>	unknown <i>threat is possible, but its impact uncertain</i>
extent to which threat operates	entire range	<i>threat operates across entire range of taxon</i>	extreme risk of extinction	very high risk	high risk	moderate risk	
	large extent	<i>threat operates across 50-99% of taxon's range (e.g. controlled in conservation reserves, or islands)</i>	very high risk	high risk	moderate risk	minor risk	
	moderate extent	<i>threat operates across 25-50% of taxon's range</i>	high risk	moderate risk	minor risk	minor risk	
	minor extent	<i>threat operates across 10-25% of taxon's range</i>	moderate risk	minor risk	minor risk	minor risk	
	localised	<i>threat occurs, but in only small areas (<10% of range)</i>	minor risk	minor risk	minor risk	minor risk	