

RECOVERY, MANAGEMENT AND MONITORING PLAN

BRUSH-TAILED RABBIT-RAT *Conilurus penicillatus*

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1. Introductory information: conservation status and rationale

Species: Brush-tailed rabbit-rat (or brush-tailed tree-rat) *Conilurus penicillatus*

Relevant taxonomic issues

The specific status is not contested. Based on minor morphological differences (but with no genetic comparisons), three subspecies are recognised (Kemper and Schmitt 1992):

- *C. p. melibius* occurring on Bathurst and Melville Islands (collectively the Tiwi Islands), Northern Territory;
- *C. p. randi* occurring in New Guinea; and
- *C. p. penicillatus* for all other populations.

This Plan relates particularly to the two Australian subspecies.

This Brush-tailed Rabbit-rat is the only extant member of its genus. Its sole historically-known congener, the white-footed rabbit-rat *C. albipes* of south-eastern Australia became extinct in the 1860s. A third species, *C. capricornensis*, has been described recently, from late Pleistocene, Holocene and recent fossils from north-eastern Queensland, with the dating of some of that material suggesting that its extinction occurred after European colonisation of Australia (Cramb and Hocknull 2010).

Conilurus is one of a small set of “old endemic” (conilurine) Australian rodent genera, thought to have originated from arrival in Australia at least 4-5 million years ago, with subsequent radiation (Van Dyck and Strahan 2008).

Brief description

The Brush-tailed Rabbit-rat is a small-medium rodent (ca. 100-250 g), with thickset body and long (100-240 mm) tail supporting distinctively longer hairs around the tail tip (“brush tail”). The body colour is mostly grey-brown with pale undersides. The tail is black, or black with a white tip, with the colour ratio varying geographically. The eyes and ears are large.

It is readily distinguishable from all other species, being appreciably smaller than the two closely related species of tree-rats *Mesembriomys* spp., and with “brush-haired” tail distinguishing it from similar-sized *Rattus* species.

EPBC Act Conservation status (date listed)

Vulnerable (6 December 2008)

Listing criteria

Criterion 1 – Estimated past, current and projected declines of >30% over periods of 10 years, based on monitoring data and continued threats.

Conservation status in states/territories

Northern Territory – Listed in the ‘Classification of Wildlife’ under the *Territory Parks and Wildlife Conservation Act 2000* as **Endangered**

Western Australia – Schedule 1 of the Specially Protected Fauna Notice under the *Wildlife Conservation Act 1950* with a conservation status of **Vulnerable** (2011).

Queensland - Listed under Schedule 6 of the Nature Conservation (Wildlife) Regulation 2006 with a conservation status of **Vulnerable**

IUCN status

Vulnerable (Burbidge & Woinarski 2016).

Overarching objective

With limited management, the species has a high likelihood of persistence in nature for the next 100 years, and no longer qualifies to be listed as threatened within 30 years.

Interim objectives for the life of the plan

Two primary objectives are set for the life of this national recovery plan (ten years):

1. The primary driver(s) of decline are clearly resolved, and guidelines applied for their effective management.
2. The overall population trend for this species is stable then increasing (and hence the species no longer qualifies for listing as threatened).

These objectives are likely to be met if, and only if, two secondary objectives are also achieved:

3. Relevant landholders and other stakeholders are aware of the species and involved in its conservation management.
4. Implementation of this plan is coordinated, adaptive and effective.

Explicit objectives are also set for defined subpopulations.

Recovery plan and adaptive management cycle

This is the first recovery plan for this species.

2. Biological information relevant to species' management

Habitat

Habitat specificity

Moderate habitat specificity. Most records of this species are from lowland eucalypt forests and woodland, particularly those dominated by *Eucalyptus miniata* (Darwin woollybutt) and/or *E. tetradonta* (Darwin stringybark) (Fig. 1). Modelling analysis of survey records (from a total of 351 sample sites) on the Tiwi Islands (Firth *et al.* 2006a) showed that it preferred tall eucalypt forests away from wet areas in sites that had not been exposed to recent severe fires. In a Kimberley study, it was recorded more from coastal woodlands than from tall open forest (Bradley *et al.* 1987). However, it has also been recorded in other vegetation types, including coastal she-oak *Casuarina equisetifolia* open woodlands (Fig. 1) and coastal grasslands (adjacent to woodlands) (Taylor and Horner 1971; Frith and Calaby 1974), and it has been recorded foraging along beaches (Frith and Calaby 1974). "Recent" fossil records extend its distribution to the Camooweal area, north-western Queensland, suggesting that it may have extended into semi-arid open woodlands (Cramb and Hocknull 2010).



Figure 1. Typical habitat for Brush-tailed Rabbit-rat - tropical eucalypt open forest (left); and less typical habitat (*Casuarina* woodland) (right) also used at some coastal sites.

Particular environmental features required

Brush-tailed Rabbit-rats shelter during the day in tree hollows (particularly of rough-barked species, and in larger trees) and hollow logs (Firth *et al.* 2006b). Such denning sites are also important for the successful raising of litters. Rabbit-rats may also occasionally shelter in *Pandanus* canopies (Dahl 1897). Recent studies in the Kimberley indicate that they are associated particularly with forests that have large trees and abundant tree hollows (Radford *et al.* 2011).

Extent to which habitat is a limiting factor

Lowland eucalypt forests occur extensively across northern Australia. However the extent of forests subject to infrequent fire regimes and, perhaps consequently, of taller, hollow-rich forests, may be increasingly limited (Williams *et al.* 1999; Woinarski 2004c).

Habitat critical to survival

No habitat can be clearly circumscribed as being critical to the survival of this species, because it occurs (or occurred) extensively across a habitat that is extremely wide-ranging (tropical eucalypt open forests), because it occupies (or occupied) a range of habitats, and because in most cases, its survival is dependent upon the management of threats within a habitat, rather than retention of a defined habitat *per se*. A case could be made that relatively long-unburnt forest provides habitat critical to the survival of this species, however the location of such areas will change across the landscape between years.

Diet

Degree of dietary specialisation

The Brush-tailed Rabbit-rat primarily eats seeds, particularly of grass species (Morton 1992; Firth *et al.* 2005). Seeds of the native perennial cockatoo grass *Alloteropsis semialata* may be particularly preferred (Firth *et al.* 2005). Other dietary items include grass, termites, fruits and foliage (Morton 1992; Firth *et al.* 2005). It forages in trees and on the ground (Kitchener *et al.* 1981).

Extent to which food availability is a limiting factor

Cockatoo grass is considered a sensitive indicator of land management, likely to decline with over-grazing, pig occurrence and too frequent (but possibly also too infrequent) fire (Crowley and Garnett 2001; Crowley 2008; Bateman and Johnson 2011).

Firth *et al.* (2005) recorded fewer fruit items in their assessment of faecal matter at Northern Territory sites than that reported in a somewhat comparable study in the Kimberley (Morton 1992), and conjectured that fleshy fruits may be less abundant in the Northern Territory sites (although recognising also that this contrast may have been due to seasonal or sampling differences). The abundance and productivity of understorey plants producing fleshy fruits is greatly affected by fire regimes, and fruits may be declining and limiting in areas subject to frequent intense fires (Friend and Taylor 1985; Kerle 1985; Friend 1987; Russell-Smith *et al.* 2003; Woinarski *et al.* 2004a; Atchison *et al.* 2005).

Reproductive biology

Age to maturity

Six weeks (Dion Wedd, Territory Wildlife Park, *pers. comm.*). Watts and Aslin (1981) noted that rabbit-rats had perhaps the most precocious young of the old endemic rodent group, and their development to weaning age is extremely rapid.

Longevity

Uncertain, but probably 2-3 years (Firth 2007).

Reproductive period/Breeding season

Breeding has been recorded from March to October, with peak between May and August (Taylor and Horner 1971; Kitchener *et al.* 1981).

Reproductive output

Litter size is relatively low (1-4 young, but typically two (Taylor and Horner 1971)). There may be several litters per season.

Critical factors limiting reproductive success

None demonstrated, but reproductive success may be affected by (i) availability of preferred denning sites; (ii) maintenance of “colonial” social system, of high density populations; and (iii) availability of abundant food resources before, during and after the breeding season, with this potentially being affected in the short-term by fire.

Sociality

At some sites, Brush-tailed Rabbit-rats have been recorded at very high densities (e.g. up to 6.3 animals/ha: PWCNT 2001), with small (0.3 ha) and overlapping home ranges (PWCNT 2001). Dispersion appears to be clustered or colonial (PWCNT 2001; Firth *et al.* 2006b).

Captive breeding

This species is relatively easy to maintain in captivity, with breeding populations maintained over several years in Adelaide (Watts and Aslin 1981), and over a 6 month period by the Territory Wildlife Park (Dion Wedd, Territory Wildlife Park, *pers. comm.*). To our knowledge, there are no captive populations currently maintained.

Extent to which gaps in knowledge of ecology impair management

There are two main inadequacies in the existing biological information base:

- (i) *dietary preferences* Currently, the diet of the species is poorly known. A research priority is to determine whether any preferred food sources are limiting, and the factors that cause that limitation.
- (ii) *the cause of low survivorship* (as identified in the most intensive demographic study: Firth *et al.* 2010). A research priority is to determine the relative importance of putative mortality factors, with particular attention to the role of cat predation.

These two gaps in knowledge constrain optimal management responses in that they result in difficulty prioritising among alternative management activities (e.g. reducing predation or improving food availability via fire management), because they blunt habitat management objectives, and because they cause large uncertainties in predictive distributional or life table modelling.

3. Distribution and abundance

Abundance

Estimated total population size

50,000 mature individuals (Woinarski *et al.* 2014).

Reliability of estimate

low (Woinarski *et al.* 2014).

Distribution

Broad description of current Australian distribution

The Brush-tailed Rabbit-rat is known from the monsoonal tropics of northern Australia, including parts of Queensland, Northern Territory and Western Australia (Fig. 2).

In Queensland, the only record (of living animals) comes from Bentinck Island in the Wellesley group, Gulf of Carpentaria (Kemper and Schmitt 1992). This record (and hence its recorded occurrence in Queensland) may merit scrutiny, given that the collectors had visited Groote Eylandt (where this species was common) prior to Bentinck (K. McDonald, Queensland 2012, *pers. comm.*)

In Western Australia, it is restricted to the north Kimberley. Its distribution there has not been tightly circumscribed, but it is known to be present in near coastal areas from near King Sound (in the SW) to the Mitchell Plateau (in the NE), a distributional range of about 400 km (Kemper and Schmitt 1992). It is not known from any Kimberley islands (Abbott and Burbidge 1995). Most (of the relatively few) Kimberley records are from the Mitchell Plateau and nearby Prince Regent Nature Reserve (McKenzie *et al.* 1975; Kitchener *et al.* 1981; Bradley *et al.* 1987; Friend *et al.* 1992; Abbott and Burbidge 1995; Start *et al.* 2007; Radford *et al.* 2011; Corey *et al.* 2013; Corey *et al.* 2016).

Its distribution in the Northern Territory is well defined with the Top End of the Northern Territory considered the stronghold of this species (Kemper and Schmitt 1992). In the Northern Territory, most (especially recent) records are from islands and peninsulas, in higher rainfall areas. Northern Territory records are from: (i) Centre Island (Sir Edward Pellew group); (ii) Groote Eylandt; (iii) coastal and near-coastal south-east and eastern Arnhem Land; (iv) one island (Inglis) in the English Company islands group off north-eastern Arnhem Land; (v) Cobourg Peninsula (Ramsar Wetland¹); (vi) the Tiwi Islands; (vii) Kakadu (Ramsar Wetland); and (viii) a small number of sites in the Darwin-Daly region, extending west to near the mouth of the Victoria River. It is probably still extant at only five of these sites (see next section: Fig. 2).

This apparent fragmentary and restricted distribution is not a reflection of limited survey effort. A substantial systematic vertebrate survey effort has sampled widely over the last 20 years across the Top End of the Northern Territory, and there is a reasonable legacy of

¹ Ramsar wetlands are those that are representative, rare or unique wetlands, or are important for conserving biological diversity. These are included on the List of Wetlands of International Importance developed under the Ramsar convention.

historical records before this (Parker 1973). For example, Woinarski *et al.* (1999) surveyed 49 islands in the English Company and Wessel Island groups off north-eastern Arnhem Land, and noted its absence from all but one island; Johnson and Kerle (1991) sampled all large islands in the Sir Edward Pellew group, and noted it to be absent from all but one island; and more recent intensive and extensive fauna sampling failed to record the species from Arnhem Land (Gambold *et al.* 1995; Brennan *et al.* 2003), the Mary River catchment (Armstrong *et al.* 2002), Litchfield area (Woinarski *et al.* 2004b), the Daly catchment (Price *et al.* 2000), and many other mainland regions.

Likewise, it was unrecorded in many surveys across the lower rainfall areas of the Kimberley, and on Kimberley islands (McKenzie *et al.* 1977, 1978, 1995; Kitchener 1978; McKenzie 1983; Woinarski 1992; Abbott and Burbidge 1995; Start *et al.* 2012; Gibson and McKenzie 2012).

Its characteristically fragmented distribution has been reported by Kemper and Schmitt (1992).

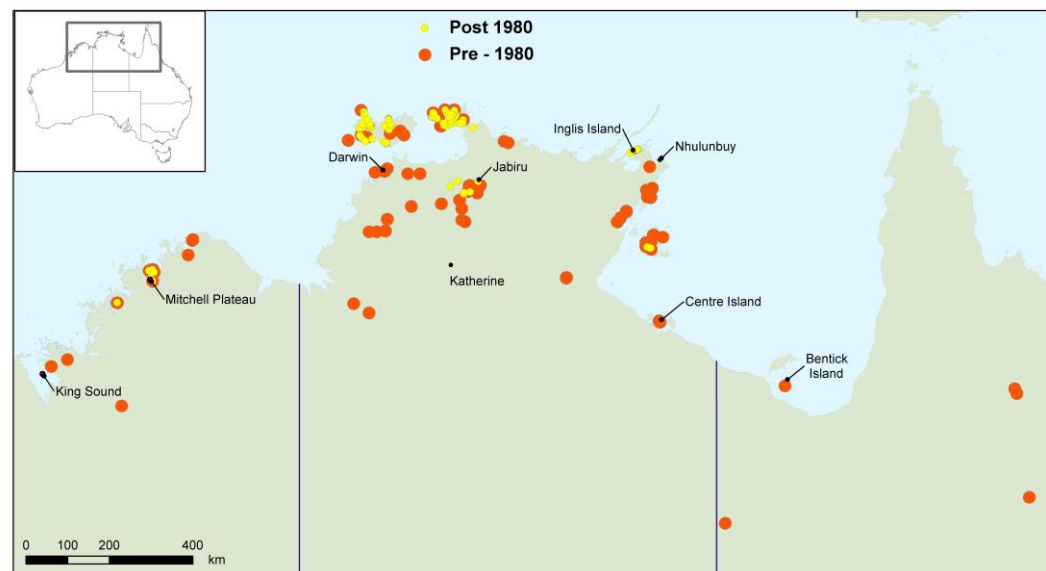


Figure 2a. Records of Brush-tailed Rabbit-rat across entire national range.

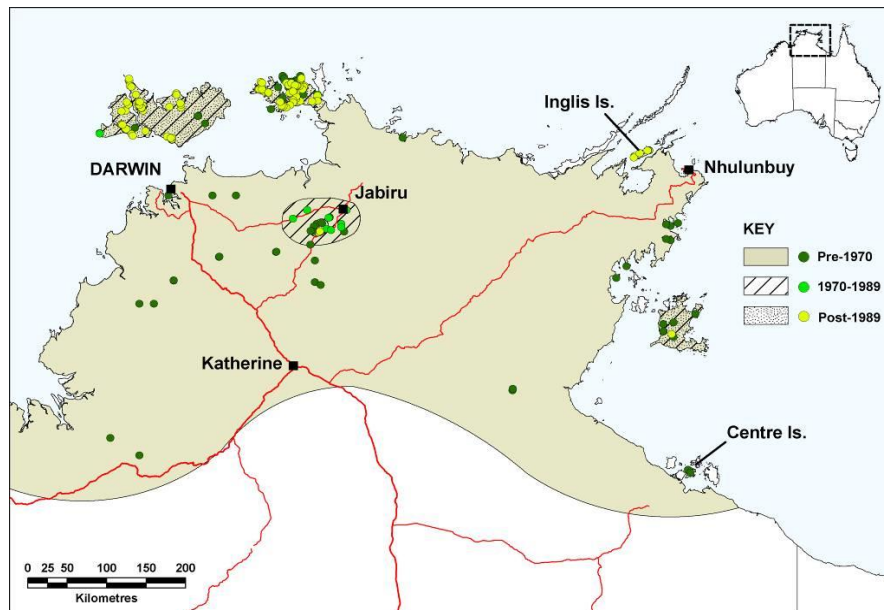


Figure 2b. Interpretation of historical contraction of distributional range of Brush-tailed Rabbit-rat in the Northern Territory.

Former Australian distribution

The historic range of this species is poorly known.

In Queensland, with the exception of Bentinck Island (Wellesley group, Gulf of Carpentaria), there are no records of live animals. However recent assessments of fossils and sub-fossils indicate a former broad distribution across northern Queensland, including Chillagoe, Camooweal Caves and Broken River (Cramb and Hocknull 2010). These records have been dated as mid Pleistocene, mid to late Pleistocene, and, tentatively, as “Holocene?” and “recent?”, demonstrating a very extensive decline, possibly since European settlement. Its continued persistence on Bentinck Island is uncertain, with the last (and only) record in 1963.

There is little information about changes in distributions in Western Australia, where it is now restricted to the higher rainfall near-coastal north Kimberley. McKenzie (1981) noted no records of live animals in the lower rainfall south-east or south-west Kimberley, but reported sub-fossils from the Napier Range (annual rainfall ca. 700 mm.), south-west Kimberley, suggesting contraction of range, possibly since European settlement. Further sub-fossil records from lower rainfall areas of the Kimberley are described in Start *et al.* (2012), corroborating the pattern of recent decline to higher rainfall areas.

In the Northern Territory, there are recent (post 1990) records from only the Tiwi Islands, Groote Eylandt, Inglis Island, Cobourg Peninsula and Kakadu, with presumed loss of subpopulations formerly known from Centre Island (Woinarski *et al.* 2011a), Arnhem Land, the Daly Basin area and the Victoria River District (Fig. 2). Its range in Kakadu has contracted rapidly: from 2005, the sole known area in which the species was known to persist was monitored annually, with declining trend to apparent extirpation by 2009.

Extralimital range

Two specimens of the Brush-tailed Rabbit-rat have been collected (10 km, and 37 years, apart) in savanna woodlands in southern Papua New Guinea (Tate and Archbold 1938; Tate 1951; Flannery 1990). The conservation status of the New Guinea subspecies is unknown.

IBRA regions

North Kimberley, Tiwi-Cobourg, Victoria-Bonaparte (presumed extinct), Daly Basin (presumed extinct), Darwin Coastal, Pine Creek, Arnhem Coast, Gulf Coastal (presumed extinct), Gulf Plains.

NRM regions

Rangelands (WA), Northern Territory, Southern Gulf (Queensland).

Major populations

Table 1 lists the only known extant subpopulations (and some subpopulations that have probably been extirpated recently). These are ordered broadly by conservation importance, based on genetic/taxonomic distinctiveness (notably for the subspecies endemic to the Tiwi Islands), relative population size and trends, geographic representation and degree of conservation security.

Given the near pervasive decline of this species, and the limited number of known subpopulations, *all* extant subpopulations are considered important for the long-term recovery or survival of the species, and areas of recent extirpation may be important for re-introductions should the critical threats be managed more successfully.

Table 1. Extant and recently extirpated subpopulations of Brush-tailed Rabbit-rats, in priority order.

location	tenure	significance	population size	population trends
Tiwi Islands (Bathurst, Melville)	Aboriginal land	probably largest remaining subpopulation; endemic subspecies; isolation may give some greater security	locally abundant (and abundance indices available from >300 quadrats)	Melville declining; compared to 2002 but still in relatively high numbers (Davies <i>et al.</i> 2017). Bathurst persisting; trend unknown but present from surveys in 2014 (DENR <i>unpublished</i>)
North Kimberley	Mix of Aboriginal land and National Park	North Kimberley is recognised as a refuge for declining north Australian mammals; conservation reserve	relatively few records and locations; surveys from 2011 to 2016 showed local areas of high abundance (Mitchell Plateau & Prince Regent NP)	Populations appear to be stable (though fluctuating) during the survey period from 2011 to 2016 (see Figs. 6 & 7).
Cobourg Peninsula	Aboriginal land, managed as Garig Gunak Barlu National Park	largest known mainland subpopulation; conservation reserve; type locality	no overall estimate, but can be locally abundant (and abundance indices available from >100 quadrats)	Declined between 2004 and 2005 following a cyclone; currently appears to be stable at low numbers (surveys from 2005-2014)
Groote Eylandt	Aboriginal land, managed as	IPA;	recent camera trapping (2016)	Unknown; knowledge on

	Anindilyakwa Indigenous Protected Area	isolation may give some greater security	study shows rabbit-rats present in four woodland areas, including a significant location not previously recorded	distribution has increased with targeted survey (J. Heiniger <i>pers comm</i> 2016)
Inglis Island	Aboriginal land, within Marthakal IPA	IPA; isolation may give some greater security; possibly the only cat-free locality	unknown	persisting, but trends unresolved
Bentinck Island	Aboriginal land	this is the only known recent location in Qld; isolation may give some greater security	no information	unknown; most recent (only) sampling was in 1963.
Kakadu	Aboriginal land, managed as National Park	large conservation reserve (World Heritage); existing Plan of Management stipulates that threatened species management is a priority	possibly extirpated	rapid decline: last record in 2008. Not detected in more recent surveys in 2016
Centre Island	Aboriginal land	isolation may give some greater security	probably extirpated	probably extinct: last record in 1966 (Woinarski <i>et al.</i> 2011a)

Taxonomic differentiation among subpopulations

There has been no assessment of genetic variation across the range of this species, which may identify subpopulations of particular genetic distinctiveness. Given the currently highly fragmented nature of the species' distribution, it is likely that there may be genetic divergence in isolated subpopulations. This may be particularly so for island subpopulations (as demonstrated for subpopulations of northern quoll on Kimberley islands: How *et al.* 2009). Genetic analysis may be an important precursor to any translocation or relocation activities.

Further survey

The distribution of the species in the Kimberley is relatively poorly known, and management options, effectiveness and prioritisation may be improved if there was a more precise circumscription of its known distribution. The highest priority for further survey may be on previously unsampled islands, although recent sampling has included many of the most prospective islands (Gibson and McKenzie 2012). Remote sites in the Prince Regent National Park on volcanic geologies could also yield further subpopulations.

In the Northern Territory, the major priority areas for further survey include the vicinity of the mouth of the Victoria River (near the site of historical collections), parts of the Daly River area (including from areas where formerly reported, such as the Douglas Hot Spring area, and Hermit Hill), and eastern Arnhem Land.

In Queensland, the priority for survey is to re-sample Bentinck Island to establish whether the species persists. Recognising that the recently published fossil and sub-fossil record of this species extended broadly across northern Queensland, there is merit in targeted survey in extensive woodlands of currently poorly-surveyed mainland areas, and other islands in the Wellesley group (Mornington Island).

Survey should target relatively unmodified eucalypt woodlands, however given that a range of habitats is known to be used by the species, it is considered unlikely that distributional modelling would provide a reliable base for selecting survey areas.

Standard survey protocols (including for EIS)

If present, this species is readily captured in standard Elliott or possum-sized cage traps, baited with universal peanut butter-oats-honey mixture. Comparative assessment of abundance can be determined readily using the standard wildlife survey protocols adopted in the Northern Territory (Firth *et al.* 2006a).

From 2006 to 2009, Mark Ziembicki (NRETAS) used a collection of stuffed mammals as aids to solicit Aboriginal information about the occurrence and status of this and other mammal species in the Top End of the Northern Territory. This approach may be useful for identifying further subpopulations in the Kimberley and Queensland, and as a mechanism for engagement with Indigenous landowners with respect to the conservation management of this species.

Camera trapping is increasingly used across northern Australia, and has advantages of allowing for relatively long sampling duration, portability, and no requirement to need wildlife handling training; and hence may be particularly suitable for sampling and monitoring by some Indigenous ranger and community groups. Brush-tailed Rabbit-rats are highly detectable by camera traps. Research by Gillespie *et al.* (2015) have recommended a trapping array with five cameras at a site for general biodiversity sampling that is effective for Brush-tailed Rabbit rats. This sampling method has been highly effective when used in collaborative research and monitoring programs with Indigenous ranger groups. Brush-tailed Rabbit-rats are not difficult to distinguish from other rodent species, which makes them an ideal species for camera trapping. The placement and set up of camera traps to detect small mammals is still being refined. Preliminary results from research on Groote Eylandt has shown that detection of smaller mammals (including Brush-tailed Rabbit-rats) increases when cameras are set closer to the ground (Heiniger *pers comm.*). Data are available to recommend species-specific minimum requirements for detection using camera traps. The analysis has not yet been completed (DENR *unpublished data*).

Geyley (2015) applied occupancy analysis to historic cage trapping data and recent camera trapping data. An analysis of the feasibility of detecting decline in rabbit-rats on the Tiwi Islands by each method was undertaken and found that camera trapping was slightly cheaper to detect a 30% change in occupancy (the threshold applied for a vulnerable listing under the IUCN criterion).

4. Threats risk

Prioritised risks relative to conservation security

In this Recovery Plan, we adopt a risk assessment and mitigation framework as the basis for prioritisation of management response. The rationale and terminology of this approach is described in Appendix A. The prioritisation measure (risk of extinction) is a product of the consequence of the threat and the extent over which the threat operates.

Table 2. Prioritised list of threats to Brush-tailed Rabbit-rats.

threat factor	risk of extinction	consequence rating	extent over which the threat operates	evidence base
cat predation	high to very high	severe to catastrophic	large extent: almost certain for all mainland subpopulations, and for most islands (Tiwi, Groote, maybe Centre, Bentinck)	recent research on Melville Island (Davies <i>et al.</i> 2017) suggests a negative relationship between detection of feral cats and rabbit-rat occupancy and a positive correlation between cat detection and the probability of rabbit rat extinction
frequent, intense, extensive fire*	high	severe	large extent: likely for all mainland subpopulations; some islands (Tiwi, Centre)	few studies, but some correlative and experimental evidence
habitat change due to exotic herbivores	moderate	moderate	large extent: likely for most mainland subpopulations, and some islands (Tiwi)	not demonstrated, but increase in some Kimberley subpopulations following cattle removal
habitat change due to exotic invasive grasses	minor	severe	minor extent: currently mostly in the Darwin-Kakadu area	not demonstrated, but plausible
vegetation clearance & other intensive development	minor	catastrophic	localised (especially Tiwi islands, Groote Eylandt)	explicitly demonstrated on Tiwi islands
disease	uncertain	unknown	uncertain, possibly large extent	not demonstrated

Competition with introduced rodents, particularly black rats	minor	severe	Island subpopulations	not demonstrated but possible.
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* Fire regimes may vary in frequency, intensity, patchiness, regularity and timing. Those considered unsuitable for Brush-tailed Rabbit-rats are: (i) Intense fires resulting from high fuel loads. These can be infrequent but follow periods of fuel build up (ii) Intense fires under extreme fire weather such as high temperatures in the late dry season or strong winds in the mid-dry season; (iii) frequent fire events.

Note that there may be some interactions and synergies amongst the above listed factors. For example there is recent evidence to suggest that hunting efficiency of feral cats is increased after fire (McGregor *et al* 2015, Leahy *et al* 2016)

Risks from some of these threats (e.g. cat predation, livestock, fire) may be exacerbated compared with many other native mammals in northern Australia because the Brush-tailed Rabbit-rat does not occur in rugged rocky landscapes, which would otherwise offer some protection from some of these threats.

Risk mitigation, and current best-practice management

Predation

The most immediate risk mitigation measure for this threat is to maintain the cat-free status of some islands containing subpopulations of Brush-tailed Rabbit-rats (notably Inglis Island). This may be most effectively achieved through awareness-raising undertaken by Indigenous ranger groups. At other sites, broad-scale cat control may be expensive and challenging. Greater certainty about the impact of cat predation is required to more reliably assess the need for increased resourcing for cat control. The role of wild dogs/dingoes in overall predation pressure on Brush-tailed Rabbit-rats is unknown, and should be considered in further research design. It is feasible that dogs may add to predation pressure, or they may reduce the abundance and impacts of feral cats, thereby reducing predation pressure, or impacts may most likely be a combination of the two i.e. some release from cats and some predation. Work by McGregor *et al.* (2015, 2016) shows that cats preferentially hunt in open areas after fire. Interactions between fire, vegetation cover and vulnerability of Brush-tailed Rabbit-rats to predation should be investigated further. This may provide further options for management other than cat control that are less resource-intensive and probably more achievable in the long-term.

Fire

There is reasonable evidence available, mostly from habitat modelling (Firth *et al.* 2006a,b) and population modelling (Firth *et al.* 2010), that Brush-tailed Rabbit-rats are responsive to fire. The evidence suggests that they are detrimentally affected particularly by “hot” late dry season fires, and, less so, by frequent (annual) fire regimes. Preliminary results from current Kimberley studies suggest that the species there may be associated particularly with “old-growth” forests, where large trees provide suitable hollows and many fallen logs persist: such sites may be maintained or their area increased through protection from fire or use of low intensity patchy fires to prevent more intense late dry season fires (Radford *et al.* 2011). Managers should aim (i) for fire return intervals of at least 3 years; (ii) where fire is applied, to use it in the early dry season, at low intensities; (iii) to establish greater

heterogeneity (of finer-scale mosaic) of fire “patch size”; and (iv) to minimise risks of large wildfires, especially where these occur in areas with high fuel loads. Further well-designed monitoring and research - especially to clarify the consequences of different fire regimes to food availability and habitat suitability - is desirable, and should seek to refine that management advice.

Livestock and feral herbivores

Brush-tailed rabbit-rats are not known to persist in any areas subjected to intensive livestock production, but several subpopulations occur in areas subject to grazing by feral stock (e.g. Cobourg Peninsula, Kakadu, Tiwi Islands, and the Kimberley) or low-intensity grazing by livestock. Grazing by stock is likely to reduce the abundance of food for Brush-tailed Rabbit-rat, and to reduce vegetation cover, making the species more susceptible to predation. Recent cattle culls (2009-2012) in the North Kimberley (Mitchell Plateau) have been associated with increased trap success for this species at some historical survey sites (Radford *et al.* 2011). Feral pigs may also reduce habitat suitability and food resources for the Brush-tailed Rabbit-rat, particularly because they use and destroy a preferred food source, Cockatoo Grass *Alloteropsis semialata* (Crowley 2008). However, reflecting a somewhat complex ecological management situation, low to moderate densities of cattle may give advantage to this grass species by reducing other more vigorous grass species (Bateman and Johnson 2011). Until the information base is better resolved, managers should aim to reduce livestock or feral herbivore numbers to a level that has no significant impact on ground cover.

Black Rats (Rattus rattus)

Black Rats have invaded many islands around the world (including some in northern Australia) and are known to have significant detrimental impacts on native biota. They could outcompete, or introduce novel diseases to, native rodents such as the Brush-tailed Rabbit-rat, on islands. Island quarantine measures should be implemented to prevent the introduction of Black Rats (and other potential predators, such as cats) to islands.

Invasive grasses

Recent research in Australia’s tropical savannas has demonstrated that some invasive grasses (notably Gamba Grass *Andropogon gayanus* and mission grasses *Cenchrus* spp.) develop fuel loads much greater than native grasses, and hence support fires of far greater intensity (Rossiter *et al.* 2003; Setterfield *et al.* 2010). Such high intensity fires are most likely to be detrimental for Brush-tailed Rabbit-rats as the fires can kill the large old trees that provide hollows and change the vegetation communities that support the species’ diet. Managers should aim to prevent the spread of these (and comparable) grasses to areas where they are not currently present (particularly some of the islands supporting populations of Brush-tailed Rabbit-rat), and seek to control invasive grasses in or near any known rabbit-rat subpopulations.

Habitat loss

Any development involving forest clearance at sites currently supporting Brush-tailed Rabbit-rats will be detrimental to this species. Given that the current distribution of this species is imperfectly known, intensive survey targeting this species should be undertaken for any substantial development proposal within its broad potential range. In broad ranging sampling on the Tiwi islands, this species was found to be absent in recently cleared areas, and plantations of non-native *Acacia* and *Pinus* species (Woinarski *et al.* 2003). Further research on the Tiwi Islands could provide more detailed information on the response of this species to forest fragmentation, and could provide more evidence-based management

guidelines about assessment of impacts of development proposals. In addition to possible increases in plantation development on the Tiwi Islands, intensive development is possible in areas occupied by Brush-tailed Rabbit-rat on Groote Eylandt (through expansion of mining) and the Kakadu area (expansion of Ranger uranium mine).

Disease

Brush-tailed rabbit-rats were one of the target species in a study into potential diseases associated with mammal decline in the NT. The study found evidence that several pathogens, capable of impacting population health, are circulating in Top End small mammal populations, but did not find compelling evidence that a single pathogen is responsible for, or a risk factor in, the decline of small mammals in the Top End of the NT (Reiss *et al.* 2015).

Other research has examined the disease status of a large sample (ca. 100 individuals) of non-native Black Rats *Rattus rattus* in the Kakadu and Darwin areas where Rabbit-rats are no longer extant (to assess the likelihood that these may be acting as a vector for disease spread to native mammals), and found zero incidence of those diseases most likely to cause decline in native mammals (Jackson *et al.* 2010).

Final note

This species has declined (or been extirpated) in some national park areas (notably Kakadu), in areas exposed to a range of management objectives (notably including pastoralism), and in areas with little or no management investment (including Centre Island and much of Arnhem Land); and these trends are likely to be repeated or exhibited in remaining subpopulations: that is, active management focused on mitigation of threats to this species will be needed to secure subpopulations or to deliver population increase.

5. Management response

Past and current management

There has been relatively little management directed specifically towards the conservation of this species. Parks Australia and the Tropical Savannas Cooperative Research Centre supported a research and monitoring program in Kakadu National Park (Firth 2007); the Tiwi Land Council and Sylvatech supported a broad-based wildlife survey of the Tiwi Islands (Woinarski *et al.* 2003); the Northern Territory Government supports a broad-based wildlife survey and a monitoring program for this species in Garig Gunak Barlu National Park; and the WA Department of Parks and Wildlife is supporting a current research and monitoring program on this species in the Kimberley (Radford *et al.* 2011; Corey *et al.* 2013; Corey *et al.* 2016).

The species has been subject to a moderate amount of recent research (most notably Firth *et al.* 2005, 2006a,b, 2010), directed mostly at aspects of its ecology (diet and habitat requirements, and responses to fire). An experimental translocation of this species was attempted near Darwin in 2006, with 59 individuals released at four locations, with contrasting fire histories (Woinarski *unpubl.*). Individuals in at least two of the sites reproduced in the wild, but the maximum known length of population persistence was 170 days after release. One of the four translocated populations disappeared immediately after a fire at its release site. All translocation sites were unfenced, such that individuals may

have simply dispersed from the point of release, and the experimental management was unable to control feral predators (cats) effectively.

Research is currently underway across northern Australia into the drivers of mammal decline. Specific to the Brush-tailed Rabbit-rat are a broad scale survey of Melville Island, allowing comparison previous data sets, and studies of threats and habitat features and research on the distribution of threatened species on Groote Eylandt. One of the outcomes of the Groote Eylandt work will be a threatened species management plan for the Anindilyakwa Land Council.

Along with other species, the management requirements of the Brush-tailed Rabbit-rat are considered explicitly within management plans and/or Integrated Conservation Strategies for some conservation reserves (e.g. Garig National Park); and within Healthy Country plans by aboriginal groups in the Kimberley (e.g. Dambimangari; Wanambal Gaambera Corporation 2010). Along with other small mammals, the species is considered within an ongoing monitoring program in Garig Gunak Barlu National Park, and within research aimed at assessing the impacts of fire regimes in the Kimberley (I. Radford, WA DBCA *pers.comm*).

A program to control feral cats on the Sir Edward Pellew Islands is being coordinated through the Mabunji Aboriginal Resource Association in conjunction with the li-Anthiwirriyarra Rangers and Desert Wildlife Services (R. Paltridge, DWS *pers. comm.*). The potential for cat control and eradication from Groote Eylandt is currently being investigated (G. Gillespie, NT DENR *pers. comm.*)

Management objectives, activities and targets

This species is now characterised by a small and diminishing set of increasingly isolated subpopulations, mostly with decreasing population size. There is sufficient contrast in the information base, management capability and threat matrix for each of the subpopulations to merit particular attention and a different mix of research and management priority actions for each of those subpopulations; along with an over-arching conservation management framework for the species as a whole. Recommendations for priority actions within this adaptive management framework are described for each subpopulation in Appendix B, and summarised for the species as a whole in Table 2.

Note that in this account, “feasibility” is ranked subjectively as the likelihood of the action being successfully implemented and contributing to the successful achievement of the overall objective(s) for the population. One objective, repeated at most sites, is to reduce the intensity of predation pressure by feral cats. It is recognised here that, based on current knowledge and management resources, actions to achieve this objective are unlikely to be feasible. This is a management problem that is pervasive across much of Australia, and will not be resolved simply within the workings of this Plan.

The broad adaptive management framework for research, monitoring and management of this species is presented in Fig. 3.

Table 3. Consolidated table of management objectives and performance criteria. See Appendix B for more detailed actions for each subpopulation.

Objective	Subsidiary objectives	Performance criteria	Subpopulations
1. The primary driver(s) of decline are clearly resolved, and guidelines applied for their effective management	a. Reduce the impacts of priority known threats	<ul style="list-style-type: none"> • fire regimes become increasingly favourable (fewer high intensity late fires, greater extent of long-unburnt forest, greater heterogeneity of fire mosaic); • where practicable, the abundance and impact of cats are reduced around sites of highest rabbit-rat density within priority subpopulations (Table 1). 	Tiwi, Kimberley, Cobourg Peninsula, Inglis, Groote
	b. Fill critical knowledge gaps that currently inhibit optimal management	<ul style="list-style-type: none"> • site-specific optimal fire regimes are established, based on assessment of responses of rabbit-rats to a range of fire regimes; • research has clarified response to grazing pressure in at least one site; • research at more than one site has determined whether any preferred food sources are limiting, and the factors that cause that limitation; • research at more than one site has determined the relative importance of putative mortality factors, with particular attention to the role of cat predation; • baseline samples of disease status are taken; • the nature of 'habitat critical to the survival of the species' is known and mapped across the species' range. 	Tiwi, Kimberley, Cobourg Peninsula, Inglis, Kakadu
	c. Apply new knowledge to refine management	<ul style="list-style-type: none"> • site-specific management guidelines are modified in light of new information; • refinements result in enhanced population status. 	all extant subpopulations; potential reintroduction sites

Objective	Subsidiary objectives	Performance criteria	Subpopulations
2. The overall population trend for this species is stable then increasing	a. Monitor and report on trends in population, threats, and the effectiveness of management inputs	<ul style="list-style-type: none"> an integrated and robust monitoring program is established, and reporting demonstrates population stability or increase. 	all extant subpopulations
	b. Resolve any uncertainty as to whether the species persists at known historical locations	<ul style="list-style-type: none"> Any uncertainty on the species persistence at historical locations is resolved. 	Bentinck I, Centre I
	c. Survey for new populations in suitable habitat	<ul style="list-style-type: none"> Surveys completed in suitable habitat to identify any new populations. 	Qld, NT, WA
	d. Identify efficient and cost effective monitoring techniques for this species	<ul style="list-style-type: none"> guidelines on how to survey for Brush-tailed Rabbit-rats available to the public; monitoring methodology refined so that population trends or an index is available, that is comparable to historic data with sufficient power to detect change. 	Kimberley, Cobourg Peninsula, Tiwi, Groote
	e. <i>In situ</i> conservation of the species is complimented by an <i>ex situ</i> program	<ul style="list-style-type: none"> a captive insurance population established at one facility, with stable or increasing population. 	
	f. Prepare and endorse a translocation program, and implement if required	<ul style="list-style-type: none"> protocols and processes (including risk assessment, cost-benefit analysis, assessment of suitability of and prioritisation for prospective release sites, release and follow-up monitoring methodology, ethics and other approvals, consultation process) for translocation program developed; if required, at least one translocation established successfully. 	Pellew Islands, Wessel Islands, Field Island, Kakadu NP
3. Relevant landholders and other stakeholders	a. Develop effective collaborative management across responsible agencies and groups	<ul style="list-style-type: none"> an effective and representative recovery team (or similar body) is established, with responsibilities clarified for all participants; information flows effectively across stakeholder groups; 	all sites

Objective	Subsidiary objectives	Performance criteria	Subpopulations
are aware of the species and increasingly involved in its conservation management		<ul style="list-style-type: none"> the number of episodes of collaborative research, monitoring and management activities increases. 	
	b. Increase the extent, capacity and authority of Indigenous landholders, ranger groups and other community groups in this management	<ul style="list-style-type: none"> the number of Indigenous groups involved in management for this species increases; the capability of Indigenous groups is demonstrably enhanced; Indigenous management knowledge is applied effectively to enhance conservation outcomes. 	all sites
	c. Increase awareness of, and concern for, this species amongst landholders and other stakeholders	<ul style="list-style-type: none"> a range of appropriate communication mechanisms result in increased profile for this species amongst relevant communities; conservation outcomes for this species are increasingly reported by relevant agencies and other involved groups. 	all sites
4. Implementation of this plan is coordinated, adaptive and effective	a. Establish and operate effectively a recovery team that represents key stakeholder groups and responsible agencies	<ul style="list-style-type: none"> an effective and representative recovery team (or similar body) is established, and operates effectively to coordinate research, management and monitoring. 	all sites
	b. Implement this recovery plan and report on its effectiveness	<ul style="list-style-type: none"> actions described in this recovery plan are implemented and produce measurable benefit. 	all sites
	c. Improve existing management, in light of increased knowledge and increased stakeholder involvement and capability	<ul style="list-style-type: none"> at plan's review, the extent of success for all actions is measurable, and improvements can be made based on consolidated information base and measurements of performance effectiveness. 	all sites

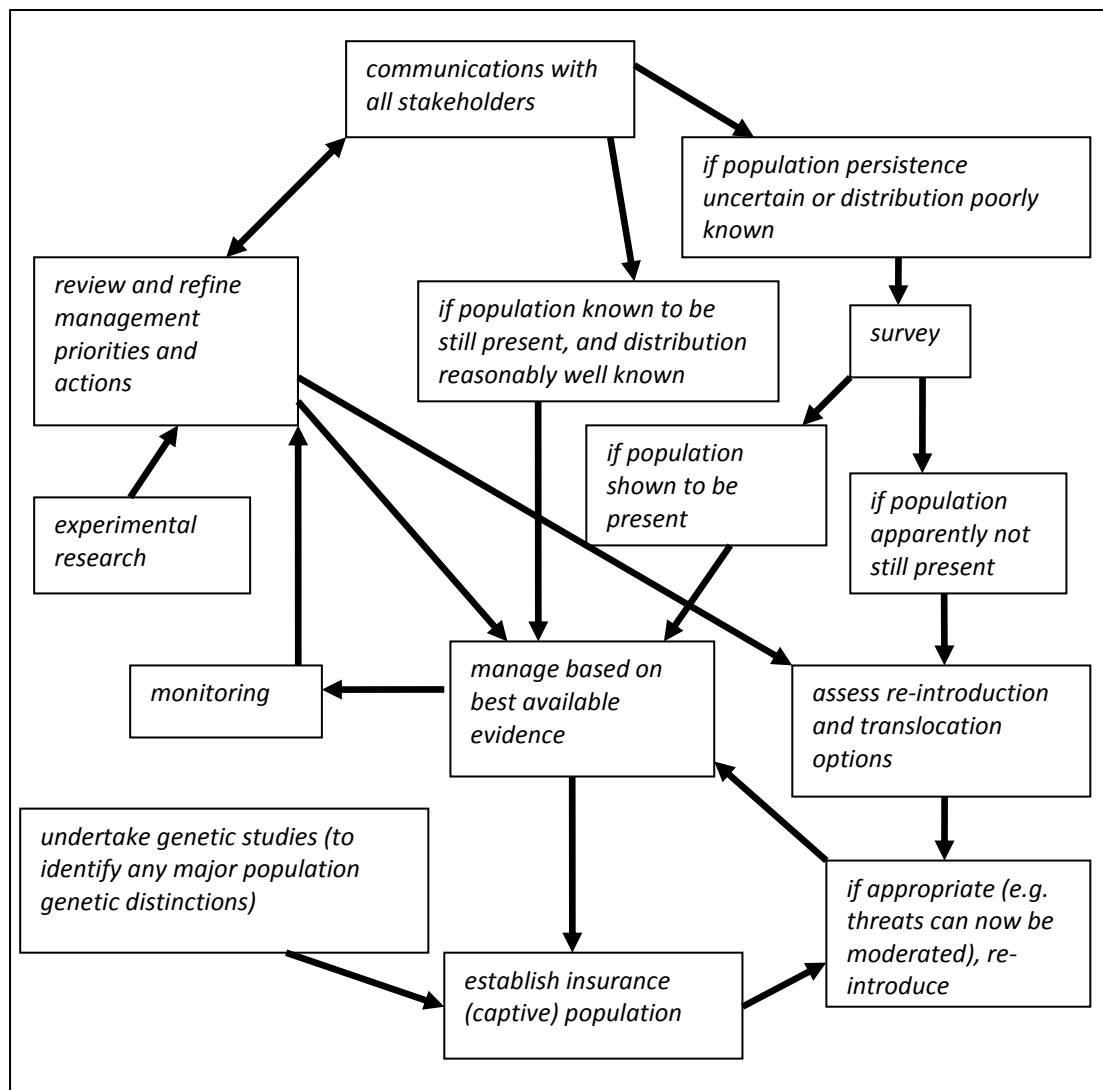


Figure 3. Broad framework for adaptive conservation management for Brush-tailed Rabbit-rat. Priorities for actions within this framework may vary between subpopulations.

6. Monitoring, assessment and reporting

Extent, history, integration, adequacy and effectiveness of current monitoring activities

There are five recent monitoring activities, none of which is yet substantially formally documented.

- (i) Garig Gunak Barlu NP. A broad-scale wildlife survey of Cobourg Peninsula was undertaken by NRETAS (now DENR) in 2004, using standardised sampling in quadrats (as per Firth *et al.* 2006a). Thirty of these quadrats were re-sampled in 2005, 2007, 2009, 2011 and 2014 (in 2014, 27 sites were surveyed, 12 of the 30 re-sampled sites were surveyed and a set of those from 2004 total 27 sites) of which rabbit-rats were recorded in 20 quadrats). The results show a significant decrease in the mean numbers captured per trap night between 2004 and 2005, coinciding with Cyclone Ingrid passing across the peninsula (Fig. 4). The data are stored with DENR, and will be made available through a data request to the department via the website.

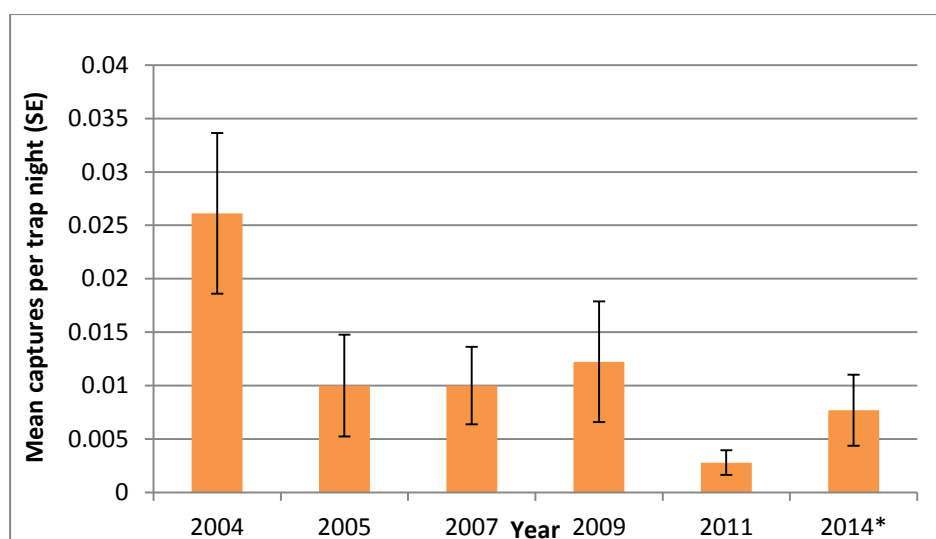


Figure 4. Monitoring results from Garig Gunak Barlu NP (Cobourg Peninsula)
[mean number of captures per trap night *n = 12 sites in 2014 (see text above)].

- (ii) Garig Gunak Barlu NP (Cobourg Peninsula). As with (iii) below, this monitoring program represents a somewhat fortuitous extension from the ecological studies undertaken during the PhD project of Firth (2007). Firth sampled four 20x20 grids on Cobourg Peninsula. The sampling protocol and location are described in Firth (2007) and Firth *et al.* (2006b, 2010). The sites were sampled quarterly in 2001 and 2002, and two of the sites were sampled in June 2009 and June 2010 (R. Firth *pers. comm.*). The Northern Territory Government re-sampled all of Firth's sites. The two from 2009 and 2010 in 2011 and the other two in 2013. The monitoring data are not yet stored in any publicly accessible location. The 2011 and 2013 data is available from the Northern Territory Government via a data request.

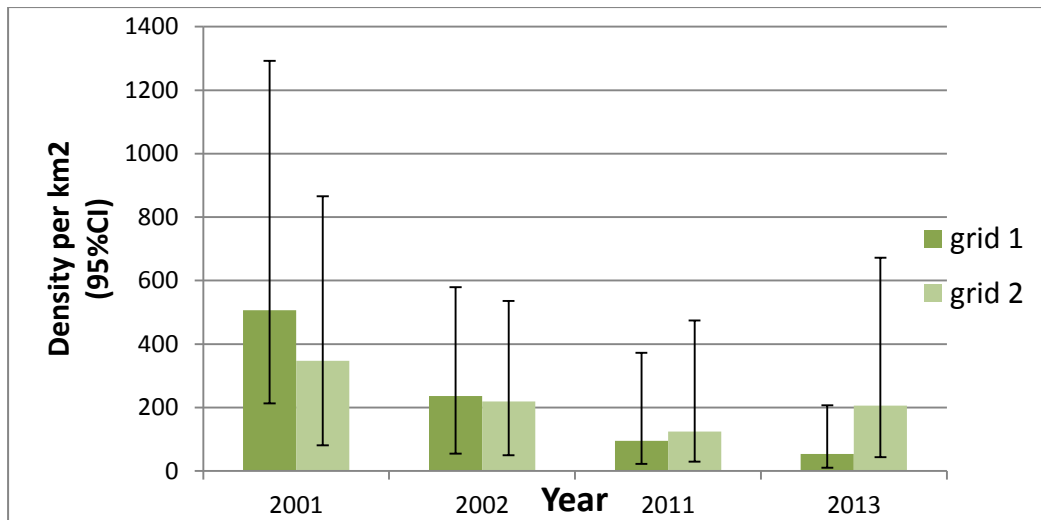


Figure 5. Population density estimates from Garig Gunak Barlu.

- (iii) Kakadu NP. Parks Australia contracted Dr Ron Firth (EWL Science) to monitor the abundance of Brush-tailed Rabbit-rats at Mardugal area (the then only known site in Kakadu for which the species had persisted), extending from an ecological study undertaken in his PhD (Firth 2007). This site was sampled in 2001 and 2002 for that study, and re-sampled annually (for monitoring) in 2007, 2008, 2009 and 2010. The sampling protocol is described in Firth (2007). The monitoring data are not yet stored in any publicly accessible location. No rabbit-rats were recorded on either of the last two sample periods, providing an indication of the timing of local extirpation.

A more substantial wildlife monitoring program is established in Kakadu NP, based on 133 fixed plots, re-sampled typically at five year intervals, with sampling commencing in 1996 (for some of the quadrats). This program has been successful in demonstrating trends for many native mammal species in Kakadu (Woinarski *et al.* 2010), but is ineffective for monitoring rabbit-rats, as the species has been recorded at too few quadrats for statistical analysis.

- (iv) Kimberley. Start *et al.* (2007) described results from re-sampling a set of 16 north Kimberley sites in 2003-04 that were previously sampled in the 1970s and 1980s. However, Brush-tailed Rabbit-rats were recorded at only three of these sites (with a total of three individuals) in the 2003-04 sampling.

An annual monitoring program conducted from 2011 to 2016 by the Department of Parks and Wildlife WA (Radford *et al.* 2015; Corey *et al.* 2016) has revealed higher (though variable) trap success than in previous regional surveys from 1981 through to 2008 (Bradley *et al.* 1987, Start *et al.* 2007, 2012) (Fig. 6).

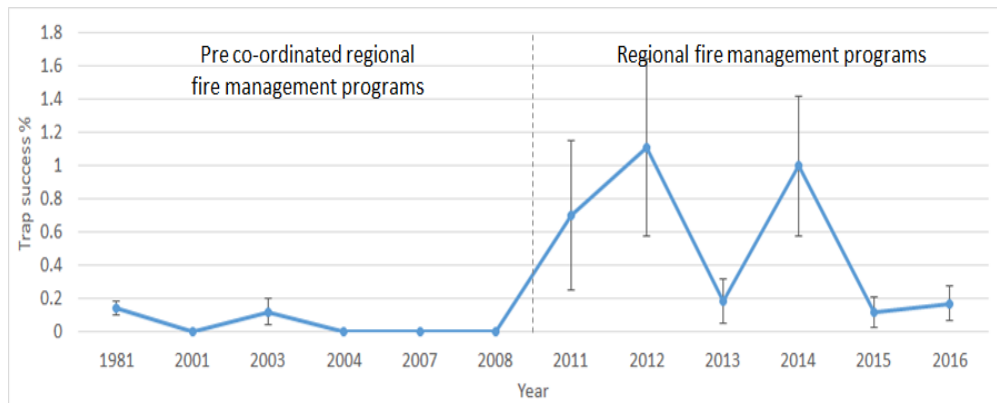


Figure 6. Mean trap success results across north Kimberley survey sites (1981-2016).

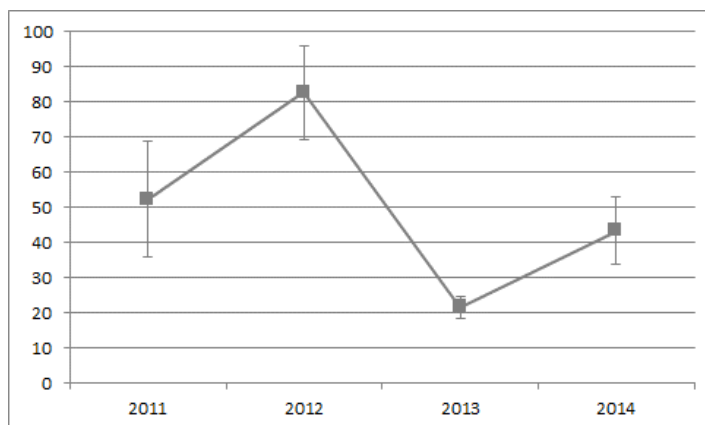


Figure 7. Estimated population densities of *Conilurus penicillatus* from the northern Mitchell Plateau.

Mark-recapture population estimates of *C. penicillatus* at six Mitchell Plateau survey sites (K.H. Pollock and I.J. Radford, unpublished data, Fig. 7) and home range data (Firth *et al.* 2006) was used to estimate population densities of between 20 and 85 animals km⁻² from 2011 to 2014.

- (v) Island populations. Brush-tailed Rabbit-rats were recorded on Centre Island (Sir Edward Pellew group) by Calaby in 1966 (Calaby 1976). This island was re-sampled in 1988, 2003 and 2005, without subsequent capture of rabbit-rats (Johnson and Kerle 1991; Woinarski *et al.* 2011a).

In broad-scale wildlife survey of the Tiwi Islands (Woinarski *et al.* 2003), a total of 351 quadrats was sampled (each over a 3-night period), over the period 2000-2002. In 2016, 86 of the sites from Melville Island were re-sampled. Eighty-two were live trapped using the same methods as Woinarski *et al.* (with 4 nights) and 86 sites were camera-trapped using the 5 camera array designed by Gillespie *et al.* (2015). Many of the original survey sites have been cleared for forestry activities. The resampling showed a decline in the number of sites where rabbit-rats were recorded. Camera trapping was proven to be an effective way to survey Brush-tailed Rabbit-rats and on-going monitoring at these sites is feasible and probably more cost-effective.

In a broad-scale wildlife survey of the Wessel and English Company Islands off north-eastern Arnhem Land (Woinarski *et al.* 1999), a total of 26 quadrats was

sampled on Inglis Island (each over a 3-night period) in 1996. Eleven of these quadrats (and a set of 12 new quadrats) were re-sampled by Gummurr Marthakal rangers in 2012. Given the precise geo-location of all quadrats, the standardised methodology, and the moderate incidence of rabbit-rats in the sampling (recorded in 13 of the original quadrats), this would make a foundation for ongoing monitoring.

Future monitoring

A monitoring program is needed to cover the top five subpopulations listed in Table 1 and undertaken at intervals of not more than 2-3 years, be designed to measure responses to management inputs and threat incidence, and will build on the previous episodes of monitoring (or inventory surveys for the sites at which no previous monitoring has been undertaken).

The standard quadrat-based wildlife survey protocols used in the Northern Territory (e.g. Firth *et al.* 2006a; Woinarski *et al.* 2010) has provided an effective index of abundance suitable for the purpose of monitoring. This sampling protocol has been used at Kakadu, Cobourg Peninsula, Inglis Island and the Tiwi Islands. It forms the basis of one of the monitoring programs at Cobourg Peninsula. However, as this species has declined this method has less power for monitoring trends over time. Brush-tailed Rabbit-rats are highly amenable to camera trapping as outlined under *Standard survey protocols* above and camera trap methods using arrays at a site probably provide a more powerful tool for monitoring trends at low population densities.

A more intensive sampling and monitoring protocol was used by NRETAS (2001) and Firth (2007; Firth *et al.* 2010), based on fewer sites and a large grid of traps, sampled over at least four nights, with mark-recapture. This allows an estimate of population size, but the method is more labour-intensive, which makes it unsuitable for more extensive sampling. The population estimates available from this data have a high degree of uncertainty (see figure 5) and require a much larger trapping effort to improve the precision of the estimate.

The Northern Territory Government has a monitoring program for six NT national parks, including Cobourg Peninsula. Each park is sampled once every three years. The program for Garig Gunak Barlu will incorporate monitoring of Brush-tailed Rabbit-rats.

For the Kimberley, Start *et al.* (2007) used a monitoring program comparable with the Northern Territory standard quadrat-based surveys, but also allowed for comparisons with the previous protocols for sampling in the north Kimberley. These sites are now being re-trapped annually by WA Parks and Wildlife to assess trends in critical weight range mammal populations (Radford *et al.* 2015; Corey *et al.* 2016).

7. Planning and policy context

Links to existing park management, regional management planning or other plans

This Plan is influenced by, responds to, complements and/or overlaps a range of other strategies and plans, operating from national to property level, and with contrasting specificity of focus. A very broad conceptual context for this Plan is shown in Fig. 5.

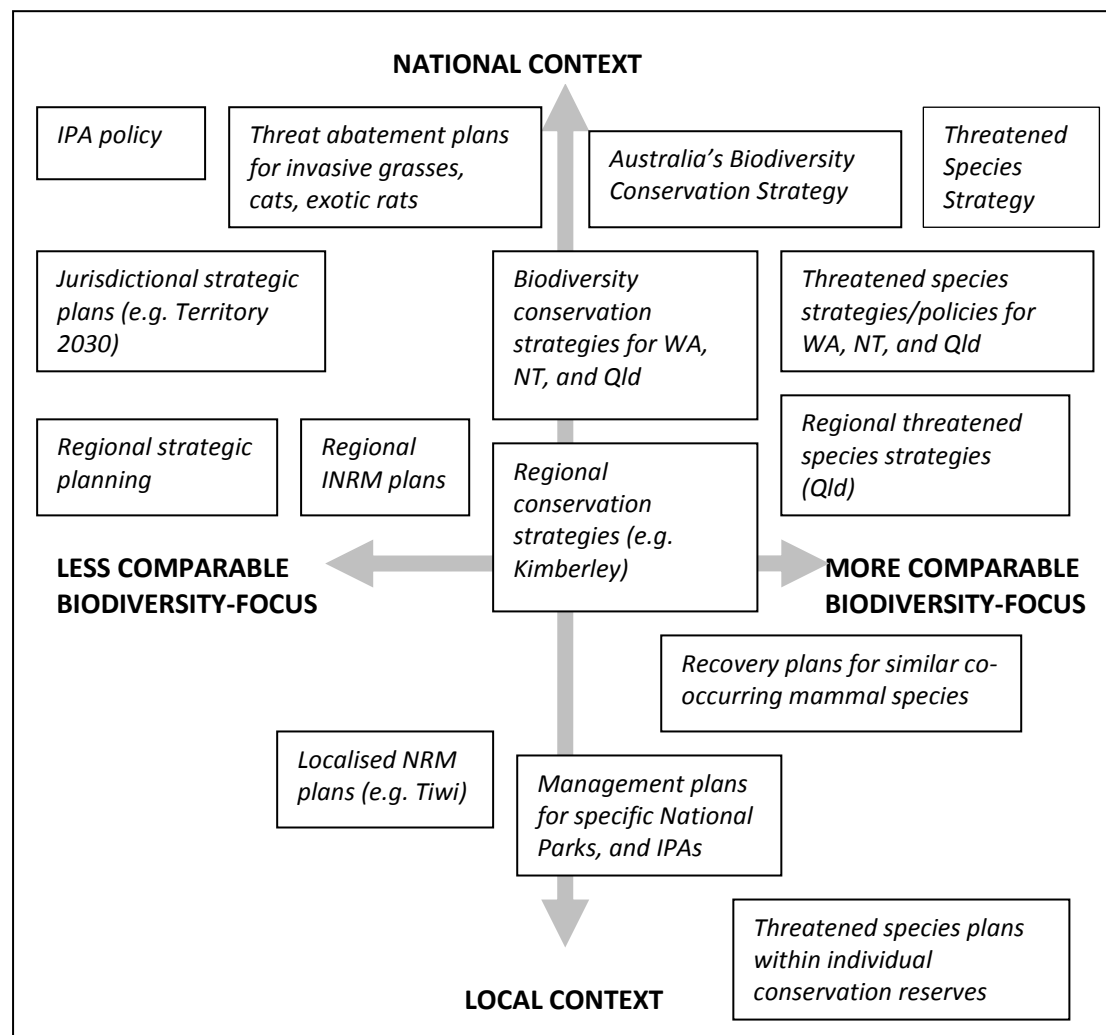


Figure 5. Broad policy, strategic and planning context for this Plan.

In turn, the objectives and results of actions in this Plan should help inform priorities and objectives in forthcoming relevant local and regional planning documents.

The most immediate connections of this Plan are to Plans of Management for individual conservation reserves in which the Brush-tailed Rabbit-rat occurs. These include the *Kakadu National Park Management Plan 2007-2014*, *Anindilyakwa IPA Groote Eylandt Archipelago Management Plan 2006* and the draft *Marthakal IPA Stage 1 Plan of Management 2011-2016*.

Note that most of these Plans of Management do not include specific references to conservation actions taken for the Brush-tailed Rabbit-rat, but rather provide more general commitments to management for the conservation of threatened species. In at least the case of Kakadu, such commitments were not effective in preventing the extirpation of this species in the park, perhaps in part because the actions were too general, or the threatening processes unmanageable. Nonetheless, these protected area Plans of Management provide

a mandated framework and foundation into which the more specific actions described in this Recovery Plan can fit.

At a broader (national) level, this Plan conforms closely with priority actions, targets and outcomes specified in *Australia's Biodiversity Conservation Strategy, 2010-2030*. The Brush-tailed Rabbit-rat is also a priority species in the National Threatened Species Strategy.

This Recovery Plan links directly to the national Threat Abatement Plan for Predation by Feral Cats, and many of the actions described in this Recovery Plan will also contribute to the cat Threat Abatement Plan, and vice-versa.

This Recovery Plan links less directly with a 'Threat abatement plan to reduce the impacts on northern Australia's biodiversity by the five listed grasses.'

This Recovery Plan will link to regional fire management plans already developed or in preparation across much of the range of the Brush-tailed Rabbit-rat, and regular liaison will be maintained with those preparing and implementing such fire management strategies.

This Recovery Plan is consistent with the Kimberley Science and Conservation Strategy, and actions taken under this Recovery Plan will contribute to that Strategy.

Activities defined in this Recovery Plan will be brought to the attention of planners responsible for the development of future plans of management (in general, or for specific management issues, such as fire) for affected areas and regions, such that they can be explicitly included, or encompassed within broader activities, in such plans.

Biodiversity (and other) benefits or detriments of proposed management actions.

The recent fate of the Brush-tailed Rabbit-rat is part of a broader syndrome of mammal declines in northern Australia (Woinarski *et al.* 2001, 2010, 2011b). There is likely to be broad commonality in the factors driving the decline for these species, with recent research most strongly implicating inappropriate fire regimes and predation by feral cats (Woinarski *et al.* 2010, 2011). This Plan will provide significant benefit to many other mammal species in northern Australia (Table 3), through (i) clearer definition of the operation and relative significance of these, and other, threats; (ii) evidence-based refinement of management response; (iii) greater confidence of agencies and managers in investing in such management, following demonstration of its need and effectiveness; and (iv) increased awareness of conservation need and outcomes across a broad set of stakeholders.

Table 4. List of some co-occurring threatened mammal species likely to benefit from research and management actions within this Plan.

common name	scientific name	EPBCA status (if listed)	state-based status (if listed)
Northern Brush-tailed Phascogale	<i>Phascogale pirata</i>	Vulnerable	Endangered (NT)
Northern Quoll	<i>Dasyurus hallucatus</i>	Endangered	Critically Endangered (NT); Endangered (WA)
Butler's Dunnart	<i>Sminthopsis butleri</i>	Vulnerable	Vulnerable (NT); Vulnerable (WA)
Carpentarian Antechinus	<i>Pseudantechinus mimulus</i>	Vulnerable	
Golden Bandicoot	<i>Isoodon auratus</i>		Endangered (NT)
Golden Bandicoot	<i>Isoodon auratus auratus</i>		Endangered (NT); Vulnerable (WA)
Common Brush-tail Possum	<i>Trichosurus vulpecula</i>		Least concern (Qld)
Common Brush-tail Possum	<i>Trichosurus vulpecula vulpecula</i>		Endangered (NT)
Golden-backed Tree-rat	<i>Mesembriomys macrurus</i>	Vulnerable	Critically Endangered (NT)
Black-footed Tree-rat	<i>Mesembriomys gouldii</i>		Vulnerable (NT)
Black-footed Tree-rat (mainland)	<i>Mesembriomys gouldii gouldii</i>	Endangered	Endangered (WA)
Black-footed Tree-rat (Melville Is)	<i>Mesembriomys gouldii melvillensis</i>	Vulnerable	
Northern Hopping-mouse	<i>Notomys aquilo</i>	Vulnerable	Vulnerable (NT); Vulnerable (Qld)
Pale Field-rat	<i>Rattus tunneyi</i>		Vulnerable (NT)

Better management of feral cats and of fire, and increased capacity and interest from stakeholders, is also likely to benefit a range of threatened birds and reptiles in northern Australia, particularly including partridge pigeon *Geophaps smithii* [EPBCA-listed as vulnerable], Gouldian finch *Erythrura gouldiae* [EPBCA-listed as endangered], and yellow-snouted gecko *Lucasium occultum* [EPBCA-listed as vulnerable].

Involvement in active research, management and monitoring programs for this species is likely to help build capacity amongst Indigenous ranger groups

Similar or linked recovery plans (or management activities) for similar species.

There are several existing national recovery plans for native mammals in northern Australia with comparable management concerns. The closest parallels are with the multi-species recovery plan for golden bandicoot *Isoodon auratus* and golden-backed tree-rat *Mesembriomys macrurus* (Palmer *et al.* 2003), Butler's dunnart *Sminthopsis butleri*, Carpentarian antechinus *Pseudantechinus mimulus*, and northern hopping-mouse *Notomys aquilo* (Woinarski 2004a), and the single species recovery plan for northern quoll *Dasyurus hallucatus* (Hill and Ward 2010). There are also some similar management recommendations in recovery plans for some threatened birds in northern Australia (Woinarski 2004b).

Extensions to policy

The actions in this Plan relate to broader policy about threatened species conservation, Indigenous land management, translocation, and management of feral cats, weeds and fire. In some cases, existing policy may need to be re-considered or extended to more effectively implement this Plan. In the Northern Territory, this may include consideration of policy development relating to controlling the introduction of cats to offshore islands, and to translocations for threatened species.

8. Community engagement and responsibilities

Primary management responsibilities

Primary responsibility for management of this species is with state conservation agencies of Western Australia (Department of Biodiversity Conservation and Attractions: DBCA), Northern Territory (Department of Environment and Natural Resources: DENR), and Queensland (Department of Environment and Heritage Protection: DEHP), with coordination through the Australian Department of the Environment and Energy, recognising that national listing of this species as threatened qualifies this species as a matter of National Environmental Significance under the *Environment Protection and Biodiversity Conservation Act*, and the responsibility of Parks Australia in management of Kakadu National Park. Across Indigenous lands, that make up almost all of the range of this species, complementary management responsibility lies with Indigenous landowners and their agencies, and particularly with Indigenous ranger groups especially in Indigenous Protected Areas.

Other affected Interests

Landholders and their representatives. Carpentaria Land Council (Bentinck Island, Queensland), Northern Land Council (Centre Island, Inglis Island, Cobourg Peninsula, Kakadu), Anindilyakwa Land Council (Groote Eylandt), Tiwi Land Council (Tiwi Islands), Kimberley Land Council.

Land management groups. The Wellesley Island Rangers (Bentinck), li-Anthawirriyarra rangers (Centre Island), Anindilyakwa ranger group (Groote Eylandt), Gumurr Marthakal Indigenous ranger group (Inglis Island), Tiwi Land Management rangers (Tiwi), Parks Australia (Kakadu), Cobourg Board of Management and The Parks and Wildlife Commission of the NT, Kimberley Land Council ranger program (Kimberley), Wunambal Gaambera Aboriginal Corporation (Uunguu), Balanggara Aboriginal Corporation, Dambimangari Aboriginal Corporation and joint management arrangements with the Miriuwung-Gajerrong and Wilinggin Aboriginal Corporations.

Other. Department of Defence (Yampi), Environment Centre of the Northern Territory, Environs Kimberley, Charles Darwin University, Energy Resources Australia (ERA - Ranger uranium mine), GEMCO (Groote Eylandt manganese mine), Territory Wildlife Park,

Australian Wildlife Conservancy, North Australian Indigenous Land and Sea Management Alliance (NAILSMA), North Australian biodiversity hub (through the National Environment Research Program: NERP), Territory NRM, Southern Gulf Catchments Ltd., Rangelands NRM Coordinating Group.

Any captive-breeding activities may involve the Territory Wildlife Park and Perth Zoo, with collaboration through ZAA.

Indigenous interests

There is some documentation of Indigenous knowledge of this species – notably including reporting of such information by Dahl at the time of its scientific discovery (Dahl 1897; Collett 1897), and by Thomson in the 1930s (Dixon and Huxley 1985); however recent collaborative surveys and targeted oral history documentation suggest that relatively little Indigenous information about this species has persisted, and it is not regarded as of particular cultural significance (M. Ziembicki, NT DENR, *unpubl.*).

There is much scope for ongoing and enhanced Indigenous involvement in the conservation management of this species, not least because most or all subpopulations occur on Aboriginal lands. To date, Indigenous ranger groups and traditional owners have been involved in collaborative surveys with DENR in the Pellew Islands, English Company Islands, Groote Eylandt, Kakadu, Tiwi islands and Cobourg Peninsula; and with DBCA in recent surveys of the Kimberley islands. Some of these Indigenous rangers have been playing and will continue to play an important role in raising awareness amongst traditional owners, school children and homeland/island residents and visitors.

Recently developed or developing management plans for a set of Indigenous Protected Areas and other Indigenous-owned lands provide more explicitly for an enhanced involvement and responsibility for Indigenous rangers in conservation management for this species.

Opportunities for off-reserve conservation

Currently, all or almost all of the extant subpopulations of this species occur in conservation reserves or Indigenous lands (with many of these managed as Indigenous Protected Areas). At this stage there is no immediate scope for activities on pastoral lands or private landholdings, but in the medium-term future there may be opportunity for re-introductions to such landholdings.

Community participation

Most subpopulations occur on Aboriginal lands. Where Indigenous ranger groups exist, these would provide an appropriate group to undertake monitoring and management, where appropriate in collaboration with state conservation agencies and/or other researchers. Such collaborative models are described in the draft Plan of Management for the proposed Marthakal IPA.

There is some scope for participation of other community groups and volunteers in broad-scale survey activities, captive-breeding, intensive research activities, communications, and monitoring.

Communication

Actions concerning, and progress towards, the conservation of this species will be reported regularly through the communications media of all relevant stakeholder groups; and updates will be maintained on the websites of all involved conservation agencies. Wherever possible and appropriate, print, radio and television media will be invited to participate in key activities.

Coordination

A project coordination group (recovery team), comprising representatives of the relevant state agencies, the Australian Government and key Indigenous groups will be established at the Plan's inception. This group could either focus specifically on the recovery of the Brush-tailed Rabbit-rat or seek to broaden the focus to declining mammals generally in northern Australia.

9. Costs, and opportunities for investment

Estimated costs are detailed in Appendix C. The recovery plan has been costed for the first five years; costings for the second five years of this plan will be assessed at the review at the end of the first five years. Note that the costings in Appendix are indicative, because the need for some actions is contingent upon the outcomes of other actions. Furthermore, some of the costings could reasonably be expected to be incorporated within the management budgets of some of the involved agencies, but these can't be fixed or committed at this time. Costs for the largest single items are already partly covered within the NERP North Australian Hub activities.

The total program costs are high (\$6,065,000, over the first five years of the program), largely because of the remote nature of much of the work, and the need to undertake and integrate actions over three jurisdictions.

10. Review and evaluation

Success criteria for this plan

The ultimate success criterion of this Plan is the extent to which it meets the explicit objectives defined in section 1 above:

1. The primary driver(s) of decline are clearly resolved, and guidelines applied for their effective management.
2. The overall population trend for this species is stable, or increasing.

Both of these targets are measurable, and such measurement provides an appropriate overall gauge of the Plan's success.

Furthermore, progress against every activity described for every subpopulation in Appendix B can be assessed, and the extent to which the activity has been completed, and has been influential can be assessed as part of the overall Plan evaluation.

A range of other, less tightly focused, measures may also be considered in an evaluation of the success of this Plan, including:

- the extent of active involvement in, and increased capacity for, conservation management by Indigenous ranger groups;
- the extent of collateral benefit for other co-occurring mammal (and other) species;
- the extent to which pervasive threatening processes (fire, weeds, feral animals) have been more effectively controlled, over specified areas;
- the extent to which integration and reporting of monitoring results for this species have been included within broader State of the Environment or other environmental trend reporting;
- the extent to which management actions taken for this species are specifically included in forthcoming Plans of Management for conservation reserves or other lands;
- the extent to which private industry or non-Government agencies contribute to activities in this Plan;
- the extent to which the community is aware of, and interested in, the conservation of this species.

Processes and timeframes for review and assessment of the effectiveness of management actions, and of auditing the effectiveness of this overall plan

Annual reporting will describe the resourcing, activity and progress against all identified actions in this Plan, with this reporting serving to re-prioritise or refine actions, if necessary. In the event that a national coordinating facility becomes available to collate and display monitoring information for threatened species, this facility will serve as the central location

for monitoring data for this species. Otherwise, the NT Department of Environment and Natural Resources is willing to provide collated monitoring information on its website.

A more formal assessment of the effectiveness of the Plan will be undertaken by major stakeholders at the end of Year 5, with external audit at end of Year 10.

11. Sources for more information

More information about the conservation of the Brush-tailed Rabbit-rat is available on the Australian Department of the Environment and Energy website, at: www.environment.gov.au/biodiversity/threatened/species/pubs/132-listing-advice.pdf (for listing advice); and www.environment.gov.au/biodiversity/threatened/species/pubs/132-conservation-advice.pdf (for conservation advice).

An account of the conservation status of this species in the NT is also presented on the DENR website <https://nt.gov.au/environment/animals/threatened-animals>

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Appendix A. Risk management framework for threats.

Threatened species typically face a number of factors that are contributing to their decline, or to their lack of recovery. For recovery management to be most effective, the relative impacts of these threats should be assessed, and actions prioritised to address particularly those threats that are contributing most to the endangerment of the threatened species. This risk-assessment and risk-management approach is a typical operational mechanism in most businesses.

However, there are a number of complicating issues with a risk assessment for threatened species. These include:

- (i) the time period over which the assessment is contextualised. Some threats may be episodic or have impacts that are discontinuous or inconstant. Some threats may have only minor impacts when assessed over a limited period (such as the typical duration of a recovery plan), but that impact continued inexorably over longer periods may eventually become catastrophic. In considerations here, the time period is taken to be the ten year duration of this recovery plan.
- (ii) the interplay between separate threats. Many threats operate synergistically, becoming more severe when in combination than the simple sum of their individual impacts. For example, predation by cats may be more severe in areas exposed to frequent fire.
- (iii) some threats may be more feasible to control than others. Hence, it may not always be appropriate to attempt to manage the threat deemed to be having greatest impact on a threatened species, if such management is doomed to be unsuccessful.
- (iv) some threats may be more expensive to manage than others. Hence, it may not always be appropriate to attempt to manage the threat deemed to be having greatest impact on a threatened species, if the funding of such management empties the available budget, such that no other threatening factors can be managed.
- (v) threat management may vary in the need for control. In some cases, it may be sufficient (in terms of the recovery of a threatened species) to simply reduce the incidence of a threat; but in other cases it may be necessary (in terms of the recovery of a threatened species) to completely eliminate the threat.
- (vi) the operation of threatening factors may vary depending on the species' population size, and species may adapt to the threat. For example, some threats operate particularly (or have most intense impacts) when a species is above or below a particular population threshold. Furthermore, evolution may work to select individuals with traits that minimise the detrimental impacts of particular threats, ultimately resulting in lower population-level impacts of such threats.
- (vii) collateral benefits and detriments. For the recovery of a particular threatened species, a particular priority may be determined for management investment across a range of threatening factors. However, in some cases, such prioritisation may

need to be contextualised more broadly for other biodiversity conservation objectives (for example, fire management may be considered to be a higher priority if several other threatened species with similar requirements for fire management co-occur).

(viii) risk assessment will be most reliable when the threats, and effectiveness of amelioration of those threats, can be assessed with mathematical precision and confidence. For most threatened species, the information base is insufficient for such quantification, and informed “best guesses” must initially be used as substitutes.

Notwithstanding these considerations, we adopt here a risk assessment approach, recognising that it is likely to be more informative than a simple textual description of all the possible threats to a threatened species. The risk assessment approach is set out in Table A1, where the relative likelihood of extinction forms the prioritisation for management actions, and that likelihood is calculated as the product of the extent over which a particular threat operates and the intensity of the threat’s impact in the area in which it operates.

These ratings are also annotated by a brief description of the evidence underlying our assessment (i.e. the likelihood of the threat operating). It is notable that the evidence base is meagre in many cases, reflecting lack of knowledge of the factor(s) responsible for the decline of many Australian threatened species.

Table A1. Risk assessment framework used to describe threatening factors, and prioritise management response.

			consequence of threat operating (intensity of impact)				
			catastrophic	severe (major)	moderate	minor	unknown
			<i>likely to cause complete population loss, where operating</i>	<i>results in 25-75% reduction in population, where operating</i>	<i>results in 10-25% reduction in population, where operating</i>	<i>results in some small (<10%) reduction in population, where operating</i>	<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	

Appendix B. Management recommendations, objectives and actions for subpopulations

Numbers next to objectives below refer to the objectives listed in Table 3 of the national Recovery Plan. Where an objective has a number in parentheses, that objective is specific to the subpopulation and a component of the objective with that number in Table 3.

(i) Tiwi Islands.

Primary objective:

2. The population trend for Brush-tailed Rabbit-rat is stable then increasing over the period of this Plan

Performance measure: a robust monitoring program detects no decline.

Feasibility: if the management actions described in this plan are implemented, then this objective should be achievable (although we note here (and generically throughout) that any landscape-wide reduction in the impacts of feral cats will represent a formidable challenge).

Secondary objectives:

(3a,b,c) Indigenous landowners have an increased awareness of the conservation status and requirements of this species, and are increasingly involved in its management

Performance measure: increasing trends in Indigenous land owners' support for and engagement in threatened species' management.

(1a) The impact of cat predation is reduced

Performance measure: reduction in the impact of cats in representative sampled areas.

(1a) The detrimental impact of fire is reduced

Performance measure: increase in extent of longer-unburnt (at least 3-5 years) forest areas.

Table B1. **Tiwi Islands:** Actions

theme	priority	Actions	Justification	feasibility
communication:	high	1.1. include consideration of implementation of this plan in meetings of Land Council and Indigenous ranger groups; produce articles for local media; ensure collaboration of rangers and school groups in survey and monitoring	there is relatively little awareness amongst stakeholders of the conservation significance of this species in this area (and about potential threats posed by feral cats)	moderate-high
survey:	high	1.2. assess the abundance of feral cats	there is no information available on the abundance and impacts of feral cats on these islands	high
	low	1.3. undertake more intensive surveys, especially in less accessible areas of eastern Melville Island	Bathurst and Melville Island have already been subject to intensive wildlife survey	high
management:	moderate	1.4. enhance existing fire management (reduce incidence of extensive fires)	Existing fire regime is not optimal for this species across much of the islands' area	moderate
	moderate	1.5. enhance control of, and quarantine for, exotic invasive grass species	if unmanaged, these will spread and increase fire impacts	moderate
monitoring:	moderate	1.6. establish monitoring program, compatible with previous survey quadrats	there is no existing monitoring for this population, but the existing baseline survey information provides a robust foundation	high
research:	moderate	1.7. re-sample quadrats across subsequent clearing and fragmentation gradient, and analyse results	recent clearing and development of plantation forestry provides significant opportunity to assess responses to habitat alteration and fragmentation	high
review process:	moderate	1.8. assess need for any feral cat control	If monitoring data show declining trends, or survey data show high abundance of cats	moderate-high

(ii) North Kimberley

Primary objective:

2. The population trend for Brush-tailed Rabbit-rat is stable then increasing over the period of this Plan

Performance measure: a robust monitoring program detects no decline.

Feasibility: if the management actions described in this plan are implemented, then this objective should be achievable.

Note that a recently established WA DBCA annual monitoring program for Brush-tailed Rabbit-rat and other critical weight range mammal populations will allow assessment of population trends and report on the effectiveness of prescribed fire management and cattle culling initiatives.

Secondary objectives:

(3a,b,c) Indigenous landowners have an increased awareness of the conservation status and requirements of this species, and are increasingly involved in its management

Performance measure: increasing trends in Indigenous land owners' support for and engagement in threatened species' management; and increasing trends in, and mutual satisfaction with, collaborative partnerships between government management agencies and Aboriginal land owners in threatened species management

(1a) The impact of cat predation is reduced

Performance measure: reduction in the impact of cats in representative sampled areas.

(1a) The detrimental impact of fire is reduced

Performance measure: increase in extent of longer-unburnt (at least 3-5 years) forest areas; and reduction in the number of large intense fires within the habitat of Brush-tailed Rabbit-rat, to be achieved in part through reduction in the incidence and extent of intense unmanaged wildfire events and increase in heterogeneity in fuel ages (or increase in fine resolution mosaic) of fire imprint on the landscape.

(1b) The distribution, habitat preferences and key sites for the species in this region are clarified

Performance measure: based on information from more detailed sampling and survey, the locations of key sub-populations are circumscribed.

Table B2. North Kimberley: Actions

theme	priority	Actions	justification	feasibility
communication:	moderate	2.1. include consideration of implementation of this plan in meetings of Land Council and Indigenous ranger groups; produce articles for local media; ensure collaboration of rangers and school groups in survey and monitoring; and establish agency, ranger group and landowner responsibilities for all actions	there is relatively little awareness amongst stakeholders of the conservation significance of this species in this area	moderate-high
survey:	high	2.2. undertake broad-scale inventory to resolve current distribution, and important populations, including on offshore islands	relatively few sites have been sampled; and lack of knowledge of the most important sites for this species impedes effective management. Occurrences on offshore islands would represent significant populations	moderate-high
management:	high	2.3. develop more benign fire regimes (fewer areas burnt annually; fewer late dry season burns; greater patchiness in fire cover)	While fire management in this region has improved in recent years, across much of this region the existing fire regime is not optimal for this species	moderate
	high	2.4 develop more effective control of cats, either through local-scale enclosure-fencing or intensive cat control measures at key sites Alternatively, consider island translocation	current levels of cat predation may be the major factor driving the decline of this species; currently this region has no effective cat control	low-moderate
	high	2.5 implement island quarantine procedures where extant populations discovered	occurrences on offshore islands would need to be protected from introduced predators	moderate
monitoring:	high	2.6. maintain or enhance recently developed monitoring programs	currently there are insufficient data to reliably determine trends; and a monitoring program will be necessary to measure management effectiveness	moderate-high
research:	moderate	2.7. assess viability and cost-effectiveness of fire and cat management options	need to have evidence-based management, informed by realistic cost assessments	moderate-high
	moderate	2.8. investigate ecology (habitat requirements, diet, causes of mortality, etc.)	need to have more detailed information on this species' ecological requirements in this region	moderate-high

review process:	high	2.9. review all priorities within 2-3 years, based on project information	knowledge of the current status provides an insecure foundation for management choices	moderate
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(iii) Cobourg Peninsula

Primary objective:

2. The population trend for Brush-tailed Rabbit-rat is stable then increasing over the period of this Plan

Performance measure: a robust monitoring program detects no decline.

Feasibility: if the management actions described in this plan are implemented, then this objective should be achievable.

Secondary objectives:

(3a,b,c) Indigenous landowners are aware of the conservation status and requirements of this species, and are involved in its management

Performance measure: increasing trends in Indigenous land owners' support for and engagement in threatened species' management.

(1a) The impact of cat predation is reduced

Performance measure: reduction in the impact of cats in representative sampled areas.

(1a) The detrimental impact of fire is reduced

Performance measure: increase in extent of longer-unburnt (at least 3-5 years) forest areas.

Table B3. **Cobourgh Peninsula: Actions**

theme	priority	Actions	Justification	feasibility
communication:	moderate	3.1. address all aspects of the conservation management of this species with Board of Management, and Indigenous groups; seek to involve them in all activities.	all actions in this area require approvals from Board of Management. While the management needs are recognised in the developing Park Management Plan (and hence known to key stakeholder groups), there is opportunity for considerably more engagement from landowners and Indigenous rangers	moderate-high
survey:	low	3.2. survey offshore islands	the distribution is reasonably well known on the Peninsula, but there has been little sampling on most satellite islands (although note that Croker Island has been sampled without records for this species: Firth and Panton 2006)	moderate-high
	high	3.3. assess the abundance of feral cats	there is no information available on the abundance and impacts of feral cats, preliminary camera trapping detected no cats	high
management:	moderate	3.4. maintain or improve existing fire management	current fire management is reasonably benign, but could be even more favourable	moderate
	moderate	3.5. enhance control of exotic invasive grass species	currently low incidence of these weeds, but any increase may result in more detrimental fire regimes	moderate
	moderate-low	3.6. manage feral cats	current levels of cat predation may be the major factor driving the decline of this species; currently this region has no effective cat control	low-moderate
	low	3.6. maintain or enhance existing management of feral stock	the impacts on this species of relatively high density of feral buffalo and banteng are unknown	moderate
monitoring:	high	3.7. maintain sampling of existing monitoring program(s), and more effectively analyse and report on data that may be informative about responses to management (including fire, feral stock and feral cat impacts)	this is probably the most secure mainland population, but monitoring is necessary to provide timely warning of any decline, and to measure management effectiveness. Currently, this site has the best established monitoring program for this species in the NT	moderate
review process:	high	3.8. after 2-3 years, engage all stakeholders in update of information and project progress; review forward priorities	to report monitoring and research results to stakeholders and managers, in order to refine management priorities and actions	moderate-high

(iv) Groote Eylandt

Primary objective:

2. The population trend for Brush-tailed Rabbit-rat is stable then increasing over the period of this Plan

Performance measure: a robust monitoring program detects no decline.

Feasibility: if the management actions described in this plan are implemented, then this objective should be achievable.

Secondary objectives:

(3a,b,c) Indigenous landowners are aware of the conservation status and requirements of this species, and are involved in its management

Performance measure: increasing trends in Indigenous land owners' support for and engagement in threatened species' management.

(1a) The impact of cat predation is reduced

Performance measure: reduction in the impact of cats in representative sampled areas.

(1a) The detrimental impact of fire is reduced

Performance measure: increase in extent of longer-unburnt (at least 3-5 years) forest areas.

(1b) The distribution, habitat preferences and key sites for the species in this region are clarified

Performance measure: based on information from more detailed sampling and survey, key sites are circumscribed.

Table B4. **Groote Eylandt:** Actions

theme	priority	actions	Justification	feasibility
communication:	high	4.1. include consideration of implementation of this plan in meetings of Land Council and Indigenous ranger groups; produce articles for local media; ensure collaboration of rangers and school groups in survey and monitoring	there is relatively little awareness amongst stakeholders of the conservation significance of this species in this area	moderate-high
survey:	moderate	4.2. undertake broad-scale inventory to resolve current distribution, and important populations	there has been a reasonable level of previous survey, but lack of knowledge of the most important sites for this species impedes effective management	moderate-high
management:	moderate	4.3. develop more benign fire regimes (fewer areas burnt annually; fewer late dry season burns; greater patchiness in fire cover)	existing fire regime is not optimal for this species	moderate
	moderate	4.4. enhance control of, and quarantine for, exotic invasive grass species	if unmanaged, these will spread and increase fire impacts	moderate-high
	high	4.5. maintain and extend current cat control program	a range of existing cat control measures provide benefit to this species, but greater intensity of cat control may be advantageous	moderate
monitoring:	high	4.6. establish a monitoring program	necessary to provide information on trends, and timely warning of any decline; and to measure management effectiveness. Note that it may be feasible to include this species as an indicator of post-mining rehabilitation success	moderate-high
research:	moderate	4.7. experimental manipulation of fire, and feral cats (exclosure fencing); recovery post-mining 4.8. experimental manipulation of habitat (potentially by fire) to reduce vulnerability to predation	tractable site to devise optimal fire regimes for this species, and to assess the extent to which feral cats are driving decline	moderate
review process:	moderate	4.9. after 2-3 years, engage all stakeholders in update of information and project progress; review forward priorities	knowledge of the current status provides an insecure foundation for management choices	high

(v) Inglis Island

Primary objective:

2. The population trend for Brush-tailed Rabbit-rat is stable then increasing over the period of this Plan

Performance measure: a robust monitoring program detects no decline.

Feasibility: the implementation of the management actions described in this plan should result in the achievement of this objective.

Secondary objectives:

(3a,b,c) Indigenous landowners are aware of the conservation status and requirements of this species, and are involved in its management

Performance measure: increasing trends in Indigenous land owners' support for and engagement in threatened species' management, including all actions below.

(1a) The Island remains cat-free

Performance measure: no the impact of cats in representative sampled areas.

(2e) A translocation proposal to other nearby islands is considered

Performance measure: extent of stakeholder consultation and endorsement; risk-assessment completed.

Table B5. **Inglis Island:** Actions

theme	priority	Actions	Justification	feasibility
communication:	high	5.1. include consideration of implementation of this plan (especially quarantine issues) in meetings of Indigenous ranger groups; produce articles for local media; ensure collaboration of rangers and school groups in survey and monitoring	to increase awareness of species amongst Indigenous landowners and ranger group, and involve them in monitoring and management	moderate-high
survey:	low	5.2. undertake more intensive survey to describe distribution, and assess population size	broad distribution pattern on this island have been partly described in 1996, with some re-sampling in 2012	moderate-high
management:	high	5.3. establish agreements and implement quarantine procedures to prevent cat importation	to maintain feral-free status	moderate
	moderate	5.4. with landholders and rangers, develop and implement fire management plans	to ensure fire is managed appropriately	low-moderate
monitoring:	moderate	5.5. transform the 1996 baseline survey to a continuing monitoring program, with indigenous ranger involvement	no trend data currently available	moderate
research:	moderate	5.6. assess options for and desirability of translocation to other nearby islands	in response to risk of threats reaching this single island	moderate
	high	5.7 determine relationship between fine scale burning and changes in population distribution on Inglis island from 1996 – 2012	Anecdotal evidence suggests that fire regimes have changed since people are no longer inhabiting the island; potentially the current distribution of the species has changed in response.	high
review process:	high	5.8. review population trends and all management requirements (undertaken by or with Indigenous ranger group and landowners)	existing information is insufficient to reliably establish management requirement; based on newly derived information, re-assess conservation significance of this population; and hone management priorities	moderate

(vi) Bentinck Island

Primary objective:

2b Resolve any uncertainty as to whether the species persists

Performance measure: If a population can be substantiated and is found to have persisted, further sampling detects ongoing presence.

Feasibility: persistence (or even, original occurrence) is uncertain; if it persists at this location, then the implementation of the management actions described in this plan should result in the achievement of this objective.

Secondary objectives:

(3a,b,c) Indigenous landowners managing this Island and nearby mainland habitats are aware of the conservation status and requirements of this species, and are involved in its management (if it is found to be extant)

Performance measure: increasing trends in Indigenous land owners' support for and engagement in threatened species' management.

(4c) Evidence is collected and the species is recommended for listing as appropriate – likely endangered or extinct in the wild in Queensland (to provide a greater level of protection and notification for the species should it be discovered in new sites or rediscovered within previous (near fossil) distribution)

Performance measure: the species is listed in Queensland and included as a species known to occur/have occurred.

Table B6. **Bentinck Island:** Actions

Theme	priority	actions	Justification	feasibility
communication:	high	6.1. include consideration of implementation of this plan in meetings of Indigenous ranger groups and NRM groups; produce articles for local media; ensure collaboration of rangers and school groups in survey and monitoring	to increase awareness of species amongst Indigenous landowners and other stakeholders; and seek knowledge of this species	moderate-high
survey:	high	6.2. undertake broad-scale survey of Island	to establish whether still present	moderate-high
	moderate	6.3. undertake broad scale survey of nearby islands	to assess whether present on other nearby islands	moderate-high
management:	indeterminate	6.4. maintain or enhance quarantine	priority depends upon whether population is still present	moderate
monitoring:	indeterminate	6.5. establish a monitoring program	priority depends upon whether population is still present	moderate
research:	indeterminate	6.6. determine habitat requirements and threats	priority depends upon whether population is still present	moderate
review process:	high	6.7. if survey demonstrates that the species is still present, initiate management and monitoring programs	lack of recent assessment of status inhibits good management investment	moderate

(vii) Kakadu

Primary objective:

(2f,3a,b) With landholder support, establish a re-introduction program to a favourable and favourably-managed site

Performance measures: adequate degree of landholder support; completion of risk assessment; a re-introduced population is stable or increasing.

Feasibility: uncertain.

Secondary objectives:

(1a) The impact of cat predation is reduced

Performance measure: reduction in the impact of cats in representative sampled areas.

(1a) The impact of feral herbivores is reduced

Performance measure: reduction in the impact of feral herbivores in representative sampled areas.

(1a) The detrimental impact of fire is reduced

Performance measure: increase in extent of longer-unburnt (at least 3-5 years) forest areas.

Table B7. **Kakadu:** Actions

theme	priority	Actions	Justification	feasibility
communication:	high	7.1. engage Board of Management, Indigenous landholders, and Parks staff with respect to conservation needs of this species, and interest in re-introduction	any proposed re-introduction may be a significant activity requiring full support of Indigenous landholders and Kakadu Board.	low-moderate
survey:	low	7.2. respond to any <i>ad hoc</i> records with targeted sampling	much recent survey activity has been unsuccessful at re-locating this species in Kakadu, but possible sightings may indicate persistence of some population	moderate
management:	moderate	7.3. maintain or enhance benign (presumed to be low intensity low frequency) fire management	around sites of most recent records	moderate
	moderate	7.4. enhance control of exotic invasive grass species	if unmanaged, these will spread and increase fire impacts	low-moderate
monitoring:	moderate	7.5. maintain existing monitoring program	but may be futile if it continues to record zero animals.	moderate
research:	high	7.6. within experimental re-location trial, experimentally manipulate (or model) fire and cat predation	to devise optimal fire regimes for this species and to assess the extent to which predation is driving decline	moderate
review process:	high	7.7. if re-location occurs, annual review of progress and management implications, with key stakeholders	major project requiring ongoing communication to stakeholders, and ongoing refinement of management options.	moderate

(viii) Centre Island

Primary objective:

2b Resolve any uncertainty as to whether the species persists

Performance measure: further sampling detects ongoing presence; a robust monitoring program detects no decline.

Feasibility: persistence is uncertain (unlikely); if it persists at this location, then the implementation of the management actions described in this plan should result in the achievement of this objective.

Secondary objectives:

(3a,b,c) Indigenous landowners are aware of the conservation status and requirements of this species, and are involved in its management

Performance measure: increasing trends in Indigenous land owners' support for and engagement in threatened species' management.

(2f) Translocation proposal to re-establish population if required is prepared and endorsed

Performance measure: extent of stakeholder consultation and endorsement of proposal; risk assessment completed; translocation implemented if risk acceptable.

Table B8. **Centre Island:** Actions

theme	priority	actions	Justification	feasibility
communication:	low	8.1. include consideration of implementation of this plan in meetings Indigenous ranger groups; produce articles for local media; ensure collaboration of rangers and school groups in survey and monitoring	increased awareness and involvement for landowners and Indigenous range group, but note that these have been substantially involved in recent sampling	moderate-high
survey:	moderate	8.2. survey in sites not recently sampled	To assess whether population has persisted (but note several recent such (unsuccessful) samples)	moderate
management:	moderate	8.3. establish or maintain ongoing cat control or quarantine	if it is assumed (or demonstrated) that some population persists	moderate
	moderate	8.4. maintain "safe" fire regime (reduce fire intensity, extent and frequency)	if it is assumed (or demonstrated) that some population persists	moderate
monitoring:	low	8.5. if population (re-) discovered, establish a monitoring program	action contingent on rediscovery	low- moderate
research:	moderate	8.6 trial options for effective cat control or eradication	necessary if re-introduction is to be undertaken (note that such action is currently proposed for nearby West Island)	low- moderate
review process:	moderate	8.7. assess re-introduction options	if ongoing sampling gives a high probability that this population has been extirpated, it may be desirable to consider feasibility and desirability of re-introduction; if sampling locates persistent population, then more intensive management would be appropriate	low- moderate

(ix) Other areas within historical range, but with no recent (>1970) records.

Primary objective:

2c Survey for new populations in suitable habitat

Performance measure: areas with highest likelihood of presence/persistence have been sampled; “new” populations have been detected.

Feasibility: the likelihood of detecting “new” populations is low to moderate.

Table B9. Prospective sites: Actions

theme	priority	actions	Justification	feasibility
communication:	moderate	9.1. develop broad-scale publicity across major interest groups, that may help elicit new sightings; and help provide support for existing management	to increase community awareness of this species, in order to increase likelihood of ad hoc reporting	moderate
survey:	moderate	9.2. undertake survey program in priority areas (see “further survey” section above)	it is plausible that there are currently unknown populations	moderate
management:	low	9.3 implement broad-scale fire management programs, aimed at reduction in intensity, extent and frequency of fire	improvements in current fire regime will benefit this species (including at any currently unknown population sites)	low- moderate
monitoring:	nil	9.4.	given no known persistent population (would be revised if populations discovered)	n/a
research:	low	9.5. collate habitat data across all previous, current and future surveys to help develop habitat models	even absences may help refine distributional models	low
review process:	high	9.6. respond with management program should any “new” populations be located	would allow timely management response	moderate-high

(x) Over-arching activities

Primary objective:

(4) Implementation of the plan is coordinated, adaptive and effective

Performance measure: There is a high and sufficient degree of effective transfer of knowledge between agencies; there is a high and sufficient extent of application of adaptive management to refine recovery priorities and actions.

Feasibility: high likelihood of effective communication between major management agencies across jurisdictions.

Secondary objectives:

(4c) Monitoring, management and research protocols are effectively integrated

Performance measure: Protocols, monitoring information and other research results are disseminated in a timely and appropriate manner between participating groups.

2e In situ conservation of the species is complimented by an ex situ program

Performance measure: The extent to which a viable captive breeding or larger fenced/island population has been established, and is stable or increasing.

(1c) Priorities among populations are refined, based on population trends and new information

Performance measure: extent to which variation in the extent of recovery or management success between different populations is used to refine inter-population priorities at review of this Plan.

Table B10. **Over-arching activities:** Actions

theme	priority	actions	Justification	feasibility
communication:	high	10.1. initiate and maintain network linking researchers and managers across populations	to maintain effective flow of information across managers, to apply learnt lessons.	high
survey:	moderate	10.2. assess the efficacy of camera-trapping, and calibrate results with conventional survey and monitoring protocols	some Indigenous and community groups prefer use of camera trapping to conventional wildlife survey techniques, and application of camera trapping may facilitate their involvement in survey, management and monitoring	moderate-high
management:	high	10.3. establish an ex situ “insurance” population	as guard against rapid loss of wild populations	moderate-high
monitoring:	high	10.4. integrate monitoring components from separate populations, report nationally on population trends, and provide evidence-based advice on management reviews.	to establish consistent monitoring protocols, and provide whole-of-species population trends	moderate -high
research:	high	10.5. investigate options for cost-efficient and effective broader-scale management of feral cats or management actions to reduce their predation impact	to provide the most effective, cost-efficient and evidence-based conservation management	low- moderate
research:	moderate	10.6. undertake some genetic sampling and analysis to identify whether any populations have pronounced genetic distinctiveness	genetic distinctiveness may give some populations greater priority for conservation; knowledge of genetic variation may help inform translocation options and protocols.	moderate
research:	low	10.7. undertake preliminary assessment of the disease status of at least 3 sub-populations (including at least one that has been subject to recent decline)	the relative impacts of this possible threat are poorly known	low-moderate
research:	moderate	10.8. implement a study that measures the impact of livestock grazing on habitat quality and abundance. (note that such a study could be	the relative impacts of this possible threat are poorly known. (note that such a study could be conducted most effectively at	moderate-high

theme	priority	actions	Justification	feasibility
		developed through a well-targeted monitoring program)	Garig Gunak Barlu NP, where densities of buffalo and banteng vary appreciably)	
research:	moderate	10.9. Identify and map habitat critical to the survival of the species across all known habitat	habitat critical to the survival of the species has not been identified and mapped	low-moderate
review process:	high	10.10. re-assess management options and priorities for management of feral cats	targeted research should provide incisive assessment of impacts of cats, and options for their management	moderate
review process:	high	10.11. re-assess conservation listing status in each jurisdiction, and nationally		high
review process:	high	10.12. review this recovery plan, iteratively throughout its life, and formally in 5 years		moderate-high

Appendix C. Indicative budget

Action numbers refer to those described in section 5. * indicates that action could be included within agency's normal operations. # contingent on demonstration of presence or persistence of Brush-tailed Rabbit-rat subpopulation. Note that the largest single items (3.8 and 7.6: total \$840k) are mostly funded under the current NESP North Australian Hub.

Jurisdiction	Priority						sub-total
	high		Moderate		low		
	Action	cost	Action	cost	Action	cost	
WA	2.2 survey	\$120k, for each of yrs 1 & 3	2.1 communications	\$10k			
	2.3 management (fire)	*	2.7. research	*			
	2.4 management (cats)	*	2.8. research (ecology)	\$100k			
	2.5 management (islands)	#					
	2.6 monitoring	\$200k, for each of yrs 1,3,5					
	2.9 review	\$50k					
	subtotal	\$890k		\$110k			\$1000k
	N.T.	1.1 Tiwi communications	\$10k	1.2 Tiwi cat survey	\$30k	1.3 Tiwi survey	\$50k
1.6 Tiwi monitoring		\$100k, for each of yrs 1,3,5	1.4 Tiwi management (fire)	*	3.2 Cobourg survey	\$50k	
3.5 Cobourg management (cats)		*	1.5 Tiwi management (weeds)	*	3.6 Cobourg management (stock)	*	
3.7 Cobourg monitoring		\$30k for each yr	1.7 Tiwi research	\$50k	7.2 Kakadu survey	\$100k	
3.8 Cobourg cat research		\$300k in yr 1, \$30k for all other yrs	1.8 Tiwi review	\$20k	8.1 Centre communications	\$5k	
3.9 Cobourg review		\$20k	3.1 Cobourg communications	\$10k	8.5 Centre	#	
4.1 Groote communications		\$10k	3.3 Cobourg management (fire)	*	5.2 Inglis survey	\$100k	

Jurisdiction	Priority						sub-total
	<i>high</i>		<i>Moderate</i>		<i>low</i>		
	Action	cost	Action	cost	Action	cost	
	4.5 Groote management (cats)	\$50k for each yr	3.4 Cobourg management (weeds)	*	5.6. Review changes in fire and Conilurus abundance	\$30k	
	4.6 Groote monitoring	\$50k, for each of yrs 1,3,5	4.2 Groote survey	\$100k			
	5.1 Inglis communications	\$20k	4.3 Groote management (fire)	*			
	5.3 Inglis management (cats)	\$30k	4.4 Groote management (weeds)	*			
	5.7 Inglis review	\$20k	4.7 Groote research	\$100k in yr 1, \$50k in yrs 2,3			
	7.1 Kakadu communications	\$10k	4.8 Groote review	\$20k			
	7.6 Kakadu research (cats)	\$300k in yr 1, \$30k for all other yrs	5.4 Inglis management (fire)	*			
	7.7 Kakadu review	\$20k	5.5 Inglis monitoring	\$50k in yrs 1,3,5			
			7.3 Kakadu management (fire)	*			
			7.4 Kakadu management (weeds)	*			
			7.5 Kakadu monitoring	\$30k for all yrs			
			8.2 Centre survey	\$100k			
			8.3 & 8.4 Centre management (cats, fire)	#			

Jurisdiction	Priority						sub-total
	high		Moderate		low		
	Action	cost	Action	cost	Action	cost	
	subtotal	\$1830k		\$1150k		\$335k	\$3315k
Qld	6.1 communications	\$20k	6.3 survey (other islands)	\$200k	6.4 quarantine	#	
	6.2 survey	\$120k			6.5 monitoring	#	
	6.7 review	\$30k			6.6. habitat & threats assessment	#	
	subtotal	\$170k		\$200k			\$370k
over-arching activities	9.6 review	\$20k	9.1 communications	\$20k	9.3 management (fire)	*	
	10.1 communications	\$20k for all yrs	9.2 survey	\$80k for all yrs	9.5 research habitat model	\$50k	
	10.3 captive breeding	\$80k yr 1, \$20k all other yrs	10.7 genetics	\$80k	10.3 survey	\$20k	
	10.4 integrate monitoring	\$30k for all yrs	10.2 trial camera-trapping	\$50k for yrs 2 and 3			
	10.5 research cats	included in 3.8 and 7.6 above	10.8 disease	\$50k for yrs 4 and 5			
	10.10 cat options	\$50k	10.9 livestock	\$50k yr 2			
	10.11 review status	\$10k	10.10 critical habitat ID	\$20k yrs 3 and 4			
	10.12 audit plan	\$30k					
	subtotal	\$520k		\$790k		\$70k	\$1380k
TOTAL (over 5 years)		\$3410k		\$2250k		\$405k	\$6065k