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A reassessment of Dusky Hopping Mouse *Notomyus fuscus* distribution in proximity to the Dog Fence in northern South Australia

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Landholder summary

The dusky hopping mouse is a small native rodent which inhabits sandy areas in the South Australian pastoral zone. Numbers have significantly declined over the past 200 years probably due in part to the introduction of feral cats and foxes. Rabbits and domestic stock are also thought to reduce plant cover lowering food resources for the dusky hopping mice which feeds mainly on seed and plant material. The Department for Environment and Natural Resources has been monitoring key populations of the dusky hopping mouse since 1993 and found their numbers fluctuate depending on seasonal conditions. After large rainfall events, hopping mice can breed rapidly, building up in numbers and dispersing out into surrounding sandy areas. During these good seasons dusky hopping mouse can be relatively easy to find, leading many people to believe they are a common species rather than one of our most threatened mammals. However, during dry times they are only found in a few core areas in the Strzelecki desert region north of the Dog Fence. During these dry times populations are very small and vulnerable to extinction through low food resources and predation from cats and foxes. High grazing pressure from rabbits or stock during dry times may further reduce food and plant cover making them more susceptible to local extinction. Dusky hopping mice have disappeared from many of these key areas so the remaining refugia areas are vital for securing the long term conservation of this species.

The introduction of calicivirus in 1995 drastically reduced rabbit numbers in many areas of the pastoral zone and is thought to have improved life for this native rodent through reduced predator numbers and increased plant cover. The recent excellent rainfall conditions in 2010 and 2011 have also helped the species to breed up and disperse across large areas of the pastoral zone. This study was conducted to determine how far dusky hopping mice had spread, how abundant they had become and the types of habitat used. By understanding what makes these key areas special we can hopefully determine if any management actions are needed to prevent extinction and return this species to its former distribution.

Fourteen pastoral stations situated primarily south of the Dog Fence were visited during 2011 and 2012 to look for sign of dusky hopping mice. We used a number of techniques including spotlighting, trapping and searching for hopping mice tracks and burrows. In 2011, hopping mice were recorded on the western, southern and southeastern side of Lake Frome as far south as Wirrealpa, Curnamona, Kalabity and Boolcoomata Stations, and near Cockburn. To the northwest of Lake Frome, sign extended from Moolawatana to Muloorina Stations including Mundowdna. Hopping mice were found in sandy areas such as creek lines, sand dunes and sandy rises on gibber plains. Hopping mice sign was most abundant in northern areas close to the Dog Fence and less in the south. More sign was recorded in areas of continuous dune systems and less in patches of isolated dunes. Despite the good conditions, rabbit numbers were quite low. In 2011, trapping at Wooltana recorded the highest density of dusky hopping mice per hectare (10) since trapping records began in South Australia in 1993. In 2012, the species remained widely distributed yet sign was more patchily distributed than in 2011 with a 44% decline in presence on trackplots. In areas where hopping mice were still recorded there was also a decline in the abundance of sign and dramatically fewer hopping mice were captured on trapping grids. Sign had become less evident in the southern parts of Mulyungarie, Kalabity Erundina and Wirrealpa Stations and remained most evident closer to Lake Frome and the southern edge of the Strzelecki Desert. Greatest abundance was recorded north of the Dog Fence on Quinyambie Station where lower cat, fox, emu and kangaroo activity was recorded. South of the Dog Fence, hopping mice had become more restricted to sand dunes and rises and less commonly encountered on plains and creek lines.

A number of management actions can be implemented to benefit the species. Maintaining habitat suitability for the species and increasing the number of key refugia areas will reduce the risk of extinction. This can be achieved by:

- maintaining good vegetation cover, particularly of grasses. This will help both stabilize the sand dunes where they live and provide hopping mice with food. This is particularly important during droughts when hopping mice populations are low. Stable sand dunes are needed to enable hopping mice to build their permanent burrow systems.
- reducing rabbit abundance through ripping warrens or deliberately releasing the rabbit calicivirus at key times (usually during autumn before young rabbits are present). This will reduce competition for food and lower predator numbers.
- encouraging kangaroo shooters to shoot any cats or foxes encountered during kangaroo harvesting. This will contribute to lowering predator numbers.
- finally, reporting any sightings of hopping mice tracks or forwarding any dead specimens to Reece Pedler (phone 86711083), particularly as conditions become dry. This will help us keep track of the status of the hopping mice, determine which management practices are working and inform future decision making.

We would like to thank all the pastoralists who assisted with this study through providing specimens, allowing property access, sharing their knowledge and assisting with surveys.

Executive Summary

A survey to determine the distribution of the dusky hopping mouse *Notomys fuscus* was conducted in 2011 and 2012. Resampling provided an opportunity to examine the habitats used during a population expansion phase following exceptional rainfall and a subsequent contraction phase. The survey area was located in northern eastern South Australia in the vicinity of the Dog Fence and used spotlighting, track-based monitoring and trapping to determine the distribution and relative abundance of a range of species including *N. fuscus*. Sampling was also conducted to a limited extent north of the Dog Fence on Quinyambie Station.

Prior to the 2011 survey, dusky hopping mice were recorded from the sandy deserts in the north east of South Australia (Strzelecki and Tirari Deserts) with only scattered records from arid areas south of the Dog Fence. In 2011, our survey found hopping mice sign on the western, southern and southeastern side of Lake Frome extending to Wirrealpa, Curnamona, Kalabity and Boolcoomata Stations and near Cockburn in the south. Sign extended to a southerly latitude of around 32^o S. To the northwest of Lake Frome, sign extended from Moolawatana to Muloorina Stations.

The survey in 2012 found that the expansion of the species was not sustained. The species was still broadly distributed south of Lake Frome but the number of individuals captured and the amount of sign encountered had diminished dramatically. To the northwest of Lake Frome, hopping mouse sign was no longer found on Mundowdna Station. Sign remained more abundant close to the Dog Fence and diminished further to the south and west. A range of landforms continued to be used including sand dunes, sand rises, plains and creek lines however sign had become less evident on creek lines and plains.

The use of trapping and track-based monitoring provided an opportunity to collect information on introduced and native species associated with the occurrence of *N. fuscus*. The occurrence of fox and feral cat had increased and dingo and rabbit occurrence remained stable based on track-based monitoring data. Stock, kangaroo and emu occurrence had increased and the house mouse population had declined dramatically compared to 2011 levels.

Stark differences in the occurrence of species were found at plots sampled north and south of the Dog Fence. More *N. fuscus*, dingo and cattle sign and far less emu, kangaroo, fox and cat sign was recorded north compared to south of the Dog Fence

The study indicated that the conditions associated with high dingo occurrence north of the Dog Fence and the distribution of sand dunes or sand rises were beneficial to the persistence of *N. fuscus*. The study was unable to determine the relative effects of introduced predator (red fox and feral cat) and herbivore (kangaroo and stock) impact on the distribution of *Notomys.*

Recommendations

1. Further resampling in the study area during drier conditions would help clarify:

    - the characteristics of residual populations north and south of the Dog Fence
    - the landscape features and conditions at key refugia sites
    - the distribution and occupancy of predator and introduced herbivore species associated with the *N. fuscus* population.
    - and validate the habitat models derived during the study.

2. Resampling each plot on two-three occasions within a year would provide a more accurate assessment of the area of occupancy and strength of association between detection and habitat covariables.

3. Being able to determine the relative effect of rabbit, kangaroo and stock grazing pressure on *N.fuscus* occupancy compared to predation pressure from cats, foxes and dingoes would allow management to become more targeted. The use of exclosures to selectively manipulate grazing pressure from rabbits, large native herbivores and stock would be required as part of the experimental approach.

4. The monitoring of additional areas immediately north and south of the Dog Fence would improve our understanding of the composition and predominance of the predator community associated with hopping mice activity.

Introduction

This document reports on a survey of dusky hopping mouse *Notomys fuscus* occurrence and distribution in a study region extending from the Barrier Hwy in the southeast to Lake Eyre South in the northwest of South Australia. Sites were surveyed in 2011 and again in 2012. *N. fuscus* was formerly widespread and early records show the species once occurred in the southern parts of the Northern Territory, southwest Queensland to Ooldea on the Nullarbour Plain in South Australia and as far west as Rawlina in Western Australia. In the last 50 years or more, the range of the species has declined and populations became restricted mainly to the Strzelecki Desert region of arid South Australia.

Four extant species of *Notomys* occur in arid Australia and all are around 35 g in weight. Along with dusky hopping mouse, the fawn hopping mouse *N. cervinus* was once known from the study area. The spinifex hopping mouse *N. alexis* occurs to the north and west and Mitchell's hopping mouse *N. mitchelli* occurs to the south and west inhabiting mallee country. Three other large hopping mice, each around 100 g in weight once occurred in the study area. The remains of the broad-cheeked hopping mouse *N. robustus*, long-tailed hopping mouse *N. longicaudatus* and short-tailed hopping mouse *N. amplus* have been recorded from owl pellets found in caves along the Flinders Ranges. None of these species have been recorded alive for over 100 years (Watts and Aslin 1981).

N. fuscus and *N. cervinus* can be found in close proximity but *N. fuscus* is found mainly on sandy substrates including dunes with sand hill canegrass *Zygochloa paradoxa* whereas the *N. cervinus* is mainly restricted to claypans and gibber plains. *Notomys fuscus* lives communally in complex warren systems. Warrens are often associated with sand hummocks or rabbit warrens and contain a number of vertical shafts (popholes) which they use to escape predators. Both species underwent a contraction in range following the establishment of pastoralism and expansion of rabbits, cats and foxes. By the 1970s *N. fuscus* had become restricted to localities in south-western Queensland and parts of northern South Australia. Extensive surveys in the 1990s recorded *N. fuscus* populations consistently only from within the Strzelecki Regional Reserve and in south-western Queensland near Betoota (Moseby *et al*. 1999; Moseby *et al.* 2006).

Notomys fuscus is similar to *N. alexis* in appearance and general biology and unlike *N. cervinus* which has a slower rate of reproduction (Watts and Aslin 1981). *N. alexis* is known to show large fluctuations in population numbers in the wild and 'boom-bust' cycles have been reported in some populations of *N. fuscus* but not others (Moseby *et al*. 2006). Saunders and Giles (1975) suggested that an irruption of a rodent species in Australia generally requires a period of drought followed immediately by a period of exceptional rainfall. Parasites, pathogens, competitors and competitors are reduced during the dry times and allowing populations to grow rapidly on the flourish of food following rainfall. The causes of rodent population collapse have been attributed to predation (Smith and Quin, 1996; Moseby *et al*. 2009), overcrowding (Breed 1979) and a nutrient deficit in food resources (Morton and Baynes 1985). The study area and the state of South Australia in general had a decade of dry, below average rainfall years prior to 2010. This was followed by the third wettest year on record occurred in 2010 and the fifth wettest in 2011 (Bureau of Meteorology).

Concerns about the conservation status of the dusky hopping mouse *N. fuscus* have led to its listing as a species of *Conservation Priority* in the South Australian Arid Lands NRM

Region and as *Vulnerable* under the national *EPBC Act 1999*. The species is also listed as *Vulnerable* in Schedule 9 of the *SA National Parks & Wildlife Act 1972 – Schedule 7* and *9,* amended September 2000.

In 2006, a study using track-based monitoring suggested that the range of *Notomys* spp. had expanded with sign recorded at a large number of sites between Muloorina and Mungeranie Stations on the Birdsville Track (Southgate, 2006). Subsequent trapping confirmed the identity of *N. fuscus* (Bellchambers 2007) in this region and on Kalamurina Station (R. Paltridge, pers. com.). The species was also rediscovered in the Sturt Desert National Park in western New South Wales. Anecdotal reports during 2007 and 2008 indicated hopping mouse numbers had become abundant across the southern parts of the Strzelecki Dunefields and the species was confirmed as *N. fuscus* (Waudby and How 2008; R. Pedler, unpublished data). These locations were typically 'outside' (north of) the Dog Fence and on Quaternary aeolian sand deposits. Reports of *N. fuscus* occupying habitat south of the Dog Fence and east of the Flinders Ranges began to emerge in 2010 following a period of exceptional rainfall extending through much of Australia.

Understanding the relative importance of threatening processes responsible for expansion or decline of native mammals has received considerable attention in Australia in recent times because of the dismal extinction record. Morton (1990) argued that native omnivores and herbivores would have originally favoured the more productive parts of the arid landscape such as riverine channels, paleodrainaege lines and runon areas for the same reasons as introduced herbivores like rabbits *Oryctolagus cuniculus*, camels *Camelus dromadarius* and stock. He proposed that the degradation of these productive areas by waves of introduced herbivores has been a significant driver in the decline of native medium sized mammals in arid Australia. In contrast, historic and empirical studies have provided abundant evidence that introduced mammalian predators contributed significantly to the decline and extinction of a vast array of native fauna (Burbidge and MacKenzie 1989; Dickman 1996; Smith and Quin 1996). A growing literature has begun to reveal the complex interaction among predator species and role of the dingo *Canus lupus* as an apex predator. Evidence is emerging on the ability of the dingo to limit the abundance of subordinate predators such as the red fox *Vulpes vulpes* and the feral cat *Felis catus* (Glen and Dickman 2005, Letnic *et al*. 2009b) and influence the composition of the herbivore and plant community through direct predation on species such as the red kangaroo *Macropus rufus*, emu and livestock (Caughley 1980; Pople *et al*. 2000; Read and Cunningham 2010). The Dog Fence stands as a testament to the fact that a dingo-size predator can have substantial impact on selective prey species, particularly sheep.

The study reports on the range expansion of *N. fuscus* south of the Dog Fence and documents the habitat and landscape features used by the species and the introduced and native species associated with its occurrence. Trapping, spotlighting and tracking were used to determine the distribution and occurrence of *Notomys* and associated species. A survey was conducted near the peak of *Notomys* activity and another a year later during a contraction phase. Factors that enabled expansion of the species following a set of good seasons are discussed. The effect of the Dog Fence and its influence on predator and herbivore species are described.

Methods

The survey used a combination of tracking, trapping and spotlighting to identify and verify the occurrence of *N. fuscus*. The survey was conducted during 5-18 April in 2011 and 29 April-4 May and 21-23 May in 2012 and extended from Mulyungarie Station near Olary in the southeast to Muloorina northwest of Marree. Existing roads and station tracks were used to reach the location of survey plots and a GPS was used to record the position of each plot in UTMs (datum: WGS84).

Average annual rainfall was least in the northwest of the study area (Marree: 162 mm) and greater in the southeast (Boolcoomatta: 193 mm). Complete rainfall records from three localities in the study area indicate that annual rainfall in 2010 and 2011 was around double or more the annual average rainfall in the preceding 10 years (Average annual rainfall for Marree, Erudina and Moolawattna: 112 mm, 160 mm and 143 mm, respectively for 2000-2009; and 265 mm, 315 mm and 400 mm, respectively for 2010 and 2011). During 2010 and 2011, more rain fell in the eastern side of the study area. Average to above average rainfall fell in the study area during 2012.

Trapping of animals was conducted at three locations: Mulyungarie, Wooltana and Mundowdna Stations (**Appendix 1**). Each grid was approximately 100 m x 400 m and contained 90 Elliott traps baited with peanut butter and oats and each trap was set 20 m apart. There were three central trap lines of 20 Elliotts and a line of 15 Elliotts on either side. A set of pitfall traps was established on the grid at five locations spaced along Elliott trap lines. Each set of pitfall traps consisted of one wide pit (200 mm diameter x 600 mm deep) and one narrow pit (150 mm diameter pit x 600 mm deep) set 10 m apart and dug in flush with the ground surface. Fly wire was placed between the pitfall traps in each set with a 3 m tail on either side. Elliott and pit fall traps were sprinkled with Coopex insecticide to prevent ant attack on captured animals. Peanut butter and oat bait was also placed in pitfall traps to reduce house mice attacking other species. Elliott and pitfall traps were set for two consecutive days at each site.

Spotlight counts were conducted at several localities during the study, including each trap grid. Each count involved the driver and passenger recording animals seen in the vehicle headlights and sometimes with a handheld spotlight (**Table1**). A 5 km transect was sampled with animals recorded on the outward and return legs (10 km in total) with the vehicle travelling at about 10 km/hr. A 6.7km spotlight transect (vehicle headlights only) was established immediately north and south of the dingo fence on Mulyungarie and Quinyambie stations to compare the abundance of *N. fuscus* on either side of the dingo fence in 2012.

Track-based monitoring using the occurrence of animal track imprints was the main method used to document the distribution of *N. fuscus* and a range of other native and introduced species. Although it is not feasible to distinguish among extant *Notomys* using only track and gait characteristics, this sign can be used to distinguish them from other genera. Presence on a plot was recorded if at least three consecutive gait imprints were observed. The presence of pop holes and runways was used as confirmatory sign. A track-based monitoring protocol similar to that outlined in Moseby *et al*. (2009) was used. A visual search of a 100m x 200m plot for a period of 25-30 minutes was conducted to determine the occurrence of species including feral cats, foxes, dingoes, cattle, camels, goats, rabbits, red and grey kangaroos, mulgara, small dasyurids (dunnarts), mice and sleepy lizards. The identity of species was assigned on the basis of gait pattern and foot imprint size.

Table 1 Spotlight transect locations conducted in 2011 and 2012. *Indicates transects that were only conducted in 2012. Bold font indicates both vehicle headlights and a handheld spotlight were used.

Transect	Location	Distance
Mulyungarie Grid	**From trap grid 5 km to the east and return**	**10km**
Wooltana Grid	**From trap grid 5 km east to Mulga Bore and return**	**10km**
Mundowdna Grid	**From Homestead to Claypan dam and return**	**31km**
Quinyambie 1*	6.7 km north of the Dog Fence to the Dog Fence gate between Mulyungarie and Quinyambie on east side.	6.7km
Mulyungarie 1*	Dog Fence gate between Mulyungarie and Quinyambie south for 6.7 km to Corona Dam towards Lake Charles Bore.	6.7km
Mulyungarie 2*	6.7 km south of Dog Fence gate to Lake Charles Bore	33.3km
Wooltana 1	**Mulga bore to Caldina New Bore, 5 km up and return**	**10km**

The age (days) of the most recent track imprint or activity for each species was estimated based on track clarity and antecedent wind or rain conditions. Data for tracks aged two nights or less are presented. Plots were located at least 30 m from an access track. Data of older sign collected on a plot or adjacent to a plot along the access track are not presented.

The detection of animal imprints is sensitive to a number of factors including the intensity of light, sun angle, continuity or extent of the trackable surfaces within the plot and the condition of the substrate along the search path used. The conditions that potentially affected the detection of animal imprints were recorded at each plot. Each attribute was scored between 1 and 3, with 1 indicating good response and 3 a poor response. An ordinal detection score (ODS) was derived for each plot by adding the score for the five attributes. This produced a minimum score of 4 (very good) and 13 (very poor). Observer skill is also an important variable affecting detection. The same primary observers RS and KM conducted the majority of plot monitoring in both 2011 and 2012. Observer RP assisted in 2012 monitoring plots with KM before surveying plots independently on Mundowdna Station. Abundance of sign was scored with 1 indicating localised sign only, 2 indicating sign was distributed over half the plot and 3 sign was distributed throughout the plot.

The plots were spaced more than 4 km apart and categorised as sand dune, sand rise, plain or creek line. Sand dunes and rises were typically formed with aeolian sediments, plains with clays, siltstones, shale or carbonates and creek lines bisected plains or hilly areas with undifferentiated alluvial/fluvial sediments. The composition of dominant ground and shrub vegetation was also recorded at each plot and the percentage vegetation cover of each layer was estimated visually.

The distance (km) of plots from the Dog Fence and from the edge of the Qe map unit on a digitised 1:250 k geological map (DENWR: geology_ply.shp) was determined using a GIS. The Qe geological map unit was the predominant unit used to describe the dune fields in the Strzelecki Desert. A negative distance value was assigned to plots located outside the Qe map unit. Similarly, a negative distance was assigned to plots located inside (south of) the Dog Fence.

The change in occurrence of the introduced predator and herbivore community and vegetation cover was compared at 60 plots sampled in both 2011 and 2012. The plots were located primarily south of the Dog Fence. Species occurrence and habitat attributes were also compared at 14 plots surveyed north of the Dog Fence (on Quinyambie Stn) and 14 plots south of the Dog Fence (on the northern end of Mulyungarie) in 2012. Plots were located several km from the fence and sampled on consecutive days.

Generalised linear modelling provided within the program PRESENCE (MacKenzie *et al*. 2006) was used to firstly consider the change in *Notomys* occurrence between 2011 and 2012 compared to the effect of detectability as reflected by the ods score. Secondly, modelling was also used to examine the relative strength of variables describing the proximity to Dog Fence and Qe edge, landform type. Two landform variables were considered; landf_r ranked sand dune better than rise, better than creek line and plain worst and landf2 identied either sand dune and rise or creekline and plain. Thirdly, the occurrence of herbivore and predator species and composite covariables that reflected predator richness (summed occurrence of cat, fox an dingo) and herbivore richness (summed occurrence of cattle, sheep, kangaroo and emu) were considered. Finally, the combined effect of the strongest variables was considered.

Data from each plot sampled in 2011 and 2012 was included and each year was treated as a repeat survey. Models were ranked using AIC with the best model indicating strongest association between the probability of occupancy and detection and habitat parameters. In ranking models, there is strong evidence of support for all the top ranked models if the delta values are within 2 AIC units of the best ranking model. If the delta values are between 2 and 7, then there is considerable support for that model as well as the top ranked model. Model over parameterisation can occur if the number of parameters estimated is greater than or equal to the number of unique histories i.e. a model based on $2^2 = 4$ possible encounter histories limiting the parameters to four at most.

Results

Trapping and spotlighting

Elliotts and pitfall traps

In 2011, a total of 71 *N. fuscus* individuals were captured at the three trapping grids (**Table 2**). Trap success ranged from 1 % to 21 % with the highest dusky hopping mouse captures recorded at the Wooltana grid followed by Mulyungarie Station and only low abundance recorded at the Mundownda grid. Pregnant females and/or subadult hopping mice were captured at all three trap grids. The introduced house mouse (*Mus musculus)* was the most abundant small mammal captured with 278 individuals caught. *Mus* dominated Elliott trap captures (57%) particularly at Mulyungarie (73%). Juvenile and/or pregnant *Mus* were recorded at each site and the site with the highest hopping mice captures corresponded with the lowest house mouse capture rate. The sandy inland mouse (*Pseudomys hermannsburgensis)* was present in low numbers at each trapping grid. One stripe-faced dunnart (*Sminthopsis macroura*) was captured in a pitfall trap on the Mundowdna grid and a short-tailed mouse (*Leggadina forresti*) was captured in an Elliott trap on the Mulyungarie grid.

Trap success was significantly lower in 2012. Only one *N. fuscus* was captured at the Mulyungarie trapping grid but tracks were relatively common on the Wooltana grid. Only two *Mus musculus* were captured (one at Wooltana and one at Mundowdna) and the only other mammal species captured was one *Pseudomys hermannsburgensis* on the Mundownda grid.

Spotlighting

In 2011, more than 2.8 hopping mice were recorded per kilometre along transects at Wooltana, 1-1.5 on Mulyungarie and none on Mundowdna Station (**Table 2**). In general, both slow and fast speed spotlight transects indicated a decline in *Notomys* abundance toward the southern, southwest and northwest of the study area. The same trend was not apparent for house mice or rabbits.

In 2012, no hopping mice were observed on spotlight transects despite over 100 km of transect being sampled (**Table 3**). Small rodent/dasyurid observations were also much lower with only one individual observed in over 100 km of spotlight transects. Rabbit counts were similar among years.

Spotlight transects surveyed just south (Mulyungarie 1) and north of the dingo fence (Quinyambie 1) indicated that rabbit abundance was higher north of the dingo fence and kangaroo abundance was lower. No *Notomys* were observed on either side of the fence.

Track-based monitoring

Notomys distribution, occurrence and activity

In 2011, 78 plots were sampled and 97 plots were sampled in 2012. Of these, 60 were sampled in both 2011 and 2012. Six plots were sampled outside the Dog Fence in 2011 and 18 were sampled in 2012, primarily on Quinyambie Station (**Table 4**). Tracking conditions were good during both years except rain occurred during two nights of sampling in 2011 and one night in 2012. Relatively few plots had high ordinal detection scores (ODS) indicating unfavourable detection conditions. Chance of *Notomys* detection was 0.62 (n=40) for an ODS<6 and 0.63 (n=41) for an ODS6-7 but detection reduced to 0.21 when the ODS>7 (n=14). A number of opportunistic records of *Notomys* were made on tracks and from road kill specimens, particularly in 2011 (**Fig. 1**).

Within the study area in 2011, *Notomys* sign extended southward from Lake Frome to latitude 32^{o} S or close to the Barrier Hwy. Sign was found on Wirrealpa, Curnamona, Kalabity Boolcoomata Stations. To the northwest of Lake Frome, sign extended from Moolawatana to Muloorina including Mundowdna Station (**Fig 1**). *Notomys* sign was less evident and more patchily distributed in 2012. However, south of Lake Frome, sign was still found on parts of Mulyungarie, Kalabity, Boolcoomata and Wirrealpa Stations producing a similar extent of occurrence as found in 2011. To the northwest of Lake Frome, sign was still evident on Moolawatana Stn but not on Mundowdna indicating the extent of occurrence had declined. *Notomys* sign was recorded at almost all plots sampled outside the Dog Fence in both years (**Table 4**). Inside the Dog Fence rate of occurrence was 0.69 in 2011 and 0.47 in 2012. Abundant *Notomys* sign (activity=3) was found at 21% of plots sampled within the Dog Fence in 2011 compared with 4% in 2012.

Other rodent and dasyurid species

In 2011, small rodent or dasyurid sign was recorded at 65% of plots. It was not feasible to distinguish among species and much of the sign was probably attributable to house mouse *Mus musculus*. Fresh tracks consistent with those of long-haired rat *Rattus villosissimus* were recorded at five plot locations (5%) (mainly in creeklines) and two dry specimens were collected on Muloorina Sation near Goyder Channel and Mundowdna Station. Crest-tailed mulgara (or ampurta) *Dasycercus cristicauda* sign was recorded on Muloorina Station near Goyder Channel between Lake Eyre North and Lake Eyre South and at 4% of plots.

In 2012, small rodent or dasyurid sign had declined to only 30% of plots and sign of *R. villosissimus* was recorded from only one plot on Quinyambie. No *Dasycercus cristicauda* sign was recorded but no plots were sampled on Muloorina Station in 2012.

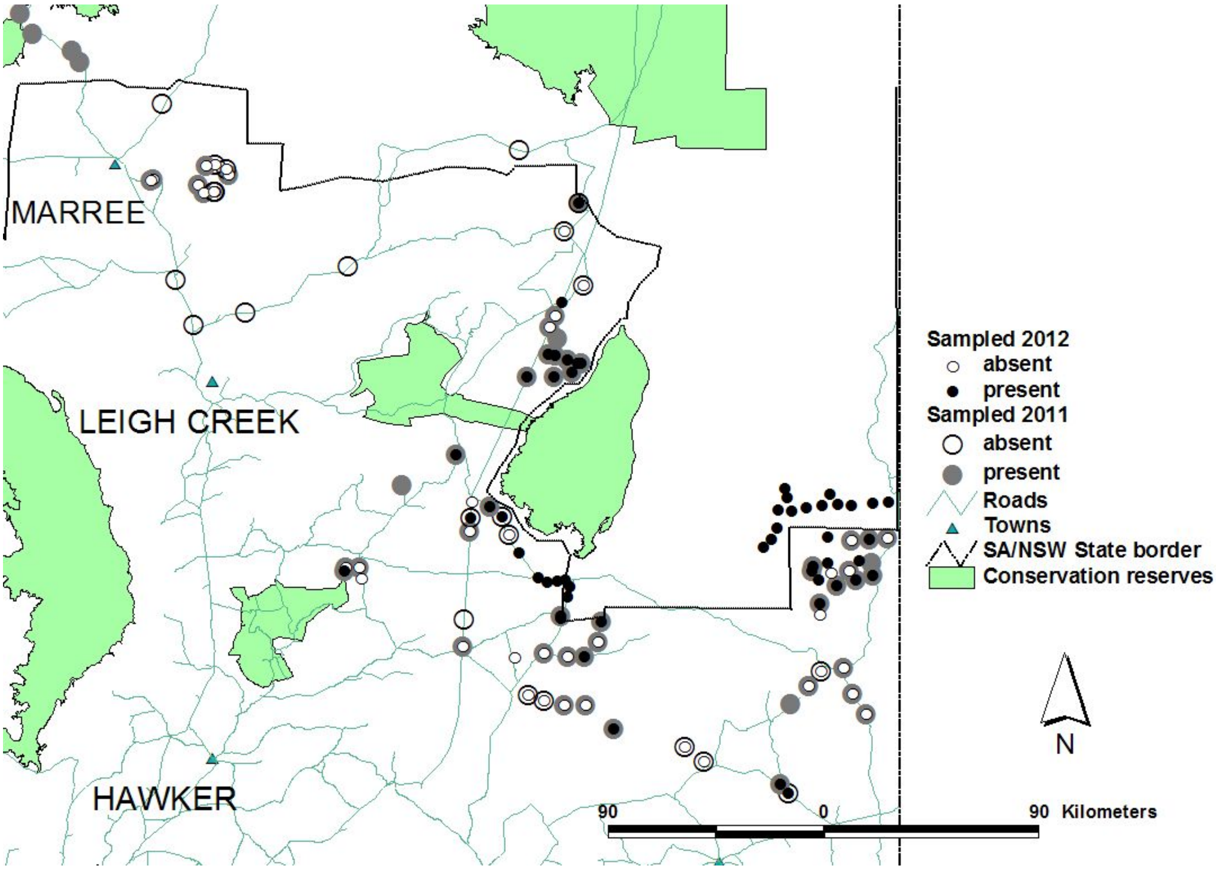

Figure 1 The change in occurrence of *N. fuscus* track sign on plots sampled in 2011 and 2012. Dog Fence shown as a black line.

Table 2 Individuals captured in Elliott and pitfall traps at each trap grid. Trap success is indicated in brackets. Total trap nights per grid for Elliott traps = 180 and pitfalls = 20

Trap grid	*Notomys fuscus* 2011	*Notomys fuscus* 2012	*Mus musculus* 2011	*Mus musculus* 2012	*Pseudomys hermans* 2011	*Pseudomys hermans*. 2012
Mulyungarie	28 (14%)	1 (0.5%)	146 (73%)	0	3 (1.5%)	0
Wooltana	41 (21%)	0	34 (17%)	1 (0.5%)	1 (0.5%)	0
Mundowdna	2 (1%)	0	128 (64%)	1 (0.5%)	5 (2.5%)	1 (0.5%)

Table 3 Spotlight transects conducted during the survey. Results are expressed as the number of animals seen per km with the total animals seen in brackets. Mice refers to small rodents or dasyurids. *= permanent spotlight transects starting at the trap grid and going 5km out and 5km back and the same as those identified in Southgate and Moseby (2011).

Property	Transect distance	2011 *N. fuscus*	Mice	Rabbits	2012 *N. fuscus*	Mice	Rabbits
Mulyungarie Stn*	10km	1.5 (15)	0.4 (4)	0.3 (3)	0	0	0.3 (3)
Wooltana Stn*	10km	2.8 (28)	0	0	0	0	0
Mundowdna Stn*	31km	0	1.5 (30)	0.4 (8)	0	0	0
Quinyambie 1	6.7km				0	0	3.88 (26)
Mulyungarie 1	6.7km				0	0	1.04 (7)
Mulyungarie 2	33.3km				0	0	0.09 (3)
Kalabity	10km				0	0	0
Wooltana 1	10km				0	0.1 (1)	6.4 (64)

Table 4 Plots sampled in 2011 and 2012 within and outside the Dog Fence and the average ordinal detection score

Plots *Notomys* present	2011 Plots sampled	ODS range	Avg. ODS	2012 Plots sampled	ODS range	Avg. ODS
Outside Dog Fence	6	4-7	5.0	18	4-9	5.8
Inside Dog Fence	72	4-10	5.9	79	4-10	6.1

Habitat attributes at 60 resampled plots

Notomys sign was detected on 75% of 60 plots sampled in 2011 and declined to 42% in 2012, a significant decrease of 44%. The number of plots with abundant *Notomys* activity (activity score=3) declined by 68% (**Table 5**).

In 2011, *Notomys* sign was recorded from a range of habitats including sand dunes, sand plains and sandy creek lines and aeolian deposits among the foothills of the Flinders Ranges. Within stony gibber habitat, hopping mice sign was usually restricted to narrow sandy creeks or drainage lines that bisected the gibber plains or small patches of sand or isolated sandy rises/dunes within otherwise hard stony substrate. Spotlighting also recorded *Notomys* sightings in the vicinity of creek lines and sandy patches within areas of harder substrate.

In 2012, sign was still distributed broadly among the four landform categories although it was less frequently encountered on plains and creek lines (**Table 5**). Active plots were actually closer to Qe boundary in 2011 than in 2012 but closer to the Dog Fence in 2012 than 2011 suggesting a slight contraction northwards.

Ground cover and shrub cover declined at active and non-active plots in the period between 2011 and 2012 (**Table 5**). Slightly less ground and shrub cover was present at plots with *Notomys* sign in 2011 compared to plots without sign. In 2012, there was slightly more ground cover but less shrub cover at plots with sign. However, these data should be treated cautiously because of the qualitative nature.

Table 5 Proportional occurrence of *Notomys* and a comparison of landform and vegetation attributes at plots with *Notomys* sign present and absent at plots sampled in both 2011 and 2012. Statistical significance: * p<0.05, ** p<0.01

	2011	2012	Increase/ decrease	Chi sq.
Notomys occurrence	0.75	0.42	-44%	13.7 **
Sand dune (n=19)	0.89	0.58	-35%	4.5 *
Sand rise (n=10)	0.9	0.70	-22%	1.2 ns
Plain (n=19)	0.63	0.26	-58%	5.2 *
Creek line (n=11)	0.63	0.18	-71%	4.7 *
Distance (km) from Qe boundary	-14.3	-16.0	12%	
Distance (km) from Dog Fence	-22.4	-19.8	-12%	
Notomy present				
Plots (*Notomys* present)	45	25		
Ground cover	31%	25%	-20%	
Shrub cover	6.9%	4.4%	-36%	
Plots (*Notomys* absent)	15	35		
Ground cover	34%	21%	-37%	
Shrub cover	9.5%	7.9%	-17%	

Predator and herbivore activity at 60 resampled plots

Each of the predator species was broadly distributed in the study area. The dingo was the least commonly recorded predator species. It was detected on 8% of plots in both 2011 and 2012, (**Table 6**). Dingo occurrence was slightly greater at plots where *Notomys* were present compared to where they were absent during both years (**Table 7**).

The red fox was detected on 15% of plots in 2011 and was the most commonly detected predator species in that year. In 2012, it was detected on 27% of plots, an increase of 33%. Fox occurrence was lower where *Notomys* were present during both years.

Feral cats were detected on 13% of plots in 2011 and at 32% of plots in 2012, increasing significantly by 135%. This species was less frequently encountered where *Notomys* were present in 2011 but occurrence was greater on active plots in 2012.

Rabbits were broadly distributed in the study area and detected on 75% of plots in 2011 but this declined to 58% in 2012, a decrease of 22%. Rabbit occurrence was similar at plots with *Notomys* present in 2011 and 2012. Sign of cattle and sheep was scarce in 2011 (3% and 2%, respectively) but increased by several-fold in 2012 (27% and 5%, respectively). Cattle and sheep sign was less commonly encountered where *Notomys* were present in 2012.

Red and grey kangaroo and emu sign also increased significantly between years. In 2011, red and grey kangaroo was detected on 25% and 5% of plots, respectively and this increased to 53% and 17% in 2012. Sign of both kangaroo species was generally more common where *Notomys* was detected compared to where it was absent. Detection of emu sign increased from 30% to 55% between 2011 and 2012, representing an increase of 83%. In 2012, it was less commonly encountered where *Notomys* were present.

Table 6 Proportional occurrence of *Notomys,* predators and herbivores at 60 plots sampled in 2011 and resampled in 2012. Statistical significance: * p<0.05, ** p<0.01

	2011	2012	Increase/decrease in relation to 2011	Chi sq
Notomys	0.75	0.42	-44%	
Dingo	0.08	0.08	0%	0 ns
Red fox	0.2	0.27	33%	0.75 ns
Feral cat	0.13	0.31	135%	5.8 *
Rabbit	0.75	0.58	-22%	1.0 ns
Cattle	0.07	0.27	700%	12.8 **
Sheep	0.03	0.05	200%	1.0 ns
Red kangaroo	0.33	0.53	113%	10.1 **
Grey kangaroo	0.05	0.17	233%	4.3 *
Emu	0.37	0.55	83%	7.7 **
Rodent/dasyurid	0.65	0.30		

Table 7 Proportional occurrence of predators and herbivores associated with *Notomys* presence and absence at 60 plots sampled in 2011 and again in 2012.

	Notomys present	*Notomys* absent	Increase/decrease in relation to *Notomys* present
Plots sampled 2011	45	15	
Dingo	0.09	0.07	25%
Red fox	0.16	0.33	-143%
Feral cat	0.13	0.13	0%
Rabbit	0.73	0.80	-9%
Cattle	0.04	0.0	200%
Sheep	0.0	0.07	-100%
Red kangaroo	0.27	0.20	25%
Grey kangaroo	0.02	0.13	-500%
Emu	0.31	0.27	143%
Plots sampled 2012	25	35	
Dingo	0.12	0.06	52%
Red fox	0.2	0.31	-57%
Feral cat	0.44	0.23	48%
Rabbit	0.68	0.51	24%
Cattle	0.20	0.31	-57%
Sheep	0.0	0.09	300%
Red kangaroo	0.56	0.51	8%
Grey kangaroo	0.20	0.14	29%
Emu	0.44	0.63	-43%

Comparison of species and habitat attributes at plots within and outside the Dog Fence

Notomys sign was detected significantly more frequently at plots outside the Dog Fence (100%, n=14) compared to inside (71%, n=14). Abundant sign (activity=3) was also far more frequently encountered at plots outside the Dog Fence (86%) compared to plots inside (7%) (**Table 8**).

Predator sign on plots differed significantly between sites inside and outside the Dog Fence. Dingo sign was the most frequently encountered predator outside (43%) compared to inside the Dog Fence (14%). Feral cat sign was recorded on only one of the plots outside the dingo fence (7%) compared with eight plots inside (57%). Foxes were also considerably less abundant outside (7%) the Dog Fence compared to inside (49%). Similarly, the occurrences of some herbivores was considerably different outside the Dog Fence compared to inside. Cattle sign was more frequently encountered outside (43%) compared to inside (14%) but this difference was not significant. In contrast, no sign of grey kangaroo or emu occurred on plots north of the Dog Fence and only 7% had sign of red kangaroo. Within the Dog Fence, red kangaroo, grey kangaroo and emu sign was encountered significantly more frequently (79%, 21% and 57%, respectively). The occurrence of rabbits was the same (79%) on both sides of the Dog Fence and no sign of sheep was encountered at plots sampled on either side.

The plots sampled had a similar average distance from the Dog Fence on either side (north 9.8 km and south 11.1 km) but the average distance from Qe boundary (edge of suitable sandy habitat) was considerably greater for plots to the north (34.3 km) compared to the south (14.9 km). Grass and forb cover was slightly less inside (11% and 13%) the Dog Fence compared to outside but there was marginally more shrub cover (5% compared to 4%). The average ODS was the same for plots sampled on either side (**Table 8**).

Modelling of *Notomys* occupancy in relation to detection, landscape and habitat variables

The number of parameters included within candidate models was restricted to four or less because of the limited number (2) of surveys. The model psi(.),p(surv_spec) was stronger than psi(.),p(.) indicating the detection of *N. fuscus* was survey specific and clearly different between 2011 and 2012. Inclusion of the ods variable (a composite descriptor of trackability conditions at a plot) was a stronger individual variable than survey specificity and indicated that consideration of tracking conditions is a critical factor in the derivation of *Notomys* occupancy using track sign. Model strength increased if both ods and survey specificity covariables were combined (Table 9).

Models including the variable landf2 along with either ods or survey specificity variable were stronger than those with d_aeolian or landf_r suggesting that availability of sand dunes and sandy rises were more important to *Notomys* occupancy than distance from a dune field system (i.e. Qe boundary) or a ranking of landform suitability (sand dune>sand rise>creek line>plain).

Table 8 Proportional occurrence of *Notomys*, predators and herbivores and a comparison of location, vegetation ordinal detection score (ODS) attributes at 14 plots sampled inside (south of) and outside (north of) the Dog Fence in 2012. Statistical significance: * p<0.05, ** p<0.01

	Inside	Outside	Difference relative to inside Dog Fence	Chi sq
N. fuscus	0.71	1.0	-41%	4.7 *
Dingo	0.14	0.43	-200%	4 *
Red fox	0.49	0.07	83%	4.8 *
Feral cat	0.57	0.07	87%	8.0 **
Rabbit	0.79	0.79	0%	-
Cattle	0.14	0.43	-200%	2.8 ns
Red kangaroo	0.79	0.07	91%	14.6 **
Grey kangaroo	0.21	0	100%	3.4 ns
Emu	0.57	0	100%	11.2 **
Distance from Qe (km)	14.8	34.3		
Distance from Dog Fence (km)	-11.1	9.8		
Grass cover	11%	13%		
Forb cover	13%	14%		
Shrub cover	5%	4%		
ODS	6	6		

Models including the variable d_dogf (distance from Dog Fence) or dog (occurrence of dog) produced the strongest models when combined with variables ods, landf2 or herb_c.

The composite herbivore richness variable (herb_c) performed bette r than the composite richness predator variable, and the variable for fox occurrence was stronger than cat occurrence. Collectively, these results suggest that the effect of the Dog Fence and the occurrence of dingoes/dogs were significant to the occurrence of *Notomys.* Dingo sign was positively associated with *Notomys* occupancy and fox, cat and the composite herbivore covariables were negatively associated.

Table 8 The ranking of occupancy models for *Notomys* using AIC criteria.

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	-*LogLike
psi(d_dogf),p(ods)	217.67	0.00	0.2163	1.0000	4	209.67
psi(.),p(ods, dog)	217.75	0.08	0.2078	1.0000	4	209.67
psi(landf2),p(dog)	218.02	0.35	0.1816	0.8395	4	210.02
psi(d_dogf),p(dog)	220.10	2.43	0.0642	0.2967	4	212.10
psi(.),p(surv_spec,ods)	221.12	3.45	0.0615	0.1782	4	213.12
psi(d_dogf),p(surv_spec)	221.44	3.77	0.0524	0.1518	4	213.44
psi(landf2),p(ods)	222.26	4.59	0.0348	0.1008	4	214.26
psi(landf2),p(herb_c)	222.82	5.15	0.0263	0.0762	4	214.82
psi(landf2),p(surv_spec)	222.90	5.23	0.0253	0.0732	4	214.90
psi(d_dogf),p(fox)	224.21	6.54	0.0131	0.0380	4	216.21
psi(d_aeolian),p(ods)	224.31	6.64	0.0125	0.0362	4	216.31
psi(landf2),p(fox)	224.61	6.94	0.0107	0.0311	4	216.61
psi(landf_r),p(ods)	225.15	7.48	0.0082	0.0238	4	217.15
psi(landfs),p(cat)	226.72	9.05	0.0037	0.0108	4	218.72
psi(.),p(ods)	227.61	9.94	0.0024	0.0069	3	221.61
psi(landf_r),p(surv_spec)	227.63	9.96	0.0024	0.0069	4	219.63
psi(d_dogf),p(.)	227.76	10.09	0.0022	0.0064	3	221.76
psi(landf2),p(.)	227.96	10.29	0.0020	0.0058	3	221.96
psi(landf2),p(cattle)	229.24	11.57	0.0011	0.0031	4	221.24
psi(d_aeolian),p(surv_spec)	229.28	11.61	0.0010	0.0030	4	221.28
psi(landfs),p(pred_c)	229.33	11.66	0.0010	0.0029	4	221.33
psi(landfs,d_dogf),p(.)	229.95	12.28	0.0007	0.0022	4	221.95
psi(.),p(surv_spec)	230.25	12.58	0.0006	0.0019	3	224.25
psi(.),p(.)	234.08	16.41	0.0001	0.0003	2	230.08

Discussion

Distribution, abundance and habitat of *N. fuscus*

Trapping, spotlighting and track-based monitoring in 2011 indicated that *Notomys* was very common in parts of the study area (south of the dingo fence), particularly closer to Lake Frome and the southern edge of the Strzelecki Desert. *Notomys fuscus* was the only species of hopping mouse recorded during the study, either as captures, live observations or specimens provided by landholders. Similarly *N. fuscus* was also the only species of hopping mouse captured during recent surveys by DENR staff in the Gammon Ranges National Park (de Preu, pers. comm.) and by environmental consultants near the Beverly Uranium Mine (Sue Carter, pers. comm.). Hence, it is reasonable to assume that all hopping mouse track sign encountered by us and similarly, all the hopping mice observed by spotlight can be attributed to *N. fuscus*.

Our survey in 2011 extended the known current distribution of *N. fuscus* southward almost to the Barrier Hwy and westward to the Flinders Ranges. This represents a substantial expansion in range for the species from its known distribution in the late 1990s at which time the species could only be consistently captured at a few colonies and all of these were north of the Dog Fence. We found the species at some locations over 70 km south and west of the Dog Fence. *Notomys* sign was not recorded on Farina Station and recent surveys on adjacent Witchelina Station have also failed to record the species (G. Medlin, pers. comm.). It is possible that the large areas of unsuitable rocky habitat between isolated patches of sandy habitat have limited the expansion of the species into this region.

The density of *N. fuscus* at the Wooltana and Mulyungarie trapping grids in 2011 was 10 and 7 individuals per ha, respectively but much lower further west on the Mundownda grid. The density of *N. fuscus* at the Wooltana grid is the highest ever recorded on a trapping grid for this species. In comparison, the highest density recorded on trapping grids at Montecollina and SW Queensland between 1993 and 2000 was 8 and 2 individuals per ha, respectively (Moseby *et al*. 2006). Similarly, Letnic *et al*. (2009) had an overall 6-fold lower trap success and a 10-fold lower spotlight count of *Notomys* than recorded by us.

Caution is required when comparing the density of *Notomys* and other species between trap grids and with previous studies. House mice probably impacted significantly on the rate of capture of *Notomys* and other native species reported in our study. *Mus* showed a willingness to enter Elliott traps and were extremely abundant in 2011. This may have reduced trap success of native species during the first survey. The greatest number of *Notomys* was captured in Elliotts and pitfall traps at Wooltana Station where *Mus* were least abundant. Elsewhere it has also been shown that high trap success using Elliott traps can be achieved for *N. alexis* (eg. 24%) and *P. hermannsburgensis* (eg. 29%) when *Mus* numbers are low (4%) (Southgate and Masters 1996).

Trapping, spotlighting and track-based monitoring indicated that *Notomys* was far less common in 2012 compared to 2011 although it was still broadly distributed. Sign had become less evident in the southern parts of Mulyungarie, Kalabity Erundina and Wirrealpa Stations and was still most evident closer to Lake Frome and the southern edge of the Strzelecki Desert. Abundant *Notomys* sign was recorded north of the Dog Fence particularly on Quinyambie Station. The almost complete absence of *N. fuscus, Pseudomys hermannsburgensis* and *Mus musculus* on the trapping grids and with other survey techniques suggested the decline in rodent abundance was broadly based, had occurred rapidly and was not restricted to *Notomys*.

Habitats associated with the occurrence of *N. fuscus*

The study demonstrated that *N. fuscus* was capable of occupying a much broader range of landforms than previously characterized by Watts and Aslin (1981) and Owens *et al*. (2006). The species was previously reported as restricted to sand dunes and ridges. We found them occupying a wide range of landform types (rocky ranges, gibber plains, sand dunes, sand plains) but nearly always in association with at least small sandy areas. Sandy habitat is needed for *N. fuscus* to build the burrow systems it requires to live communally and breed. Isolated sand dunes or rises were inhabited despite being separated by several kilometers of hard substrate indicating *N. fuscus* are capable of dispersing over considerable distances and colonizing small patches of suitable habitat.

N. fuscus continued to use creek lines, plains, sand rises and sand dunes in 2012 but proportionally greater decline occurred on creek line and plain landform types. A variable identifying both sand dunes and rises (landf2) associated more strongly with *Notomys* occupancy than proximity to the boundary of the Quaternary aeolian sand deposits (identified in broad-scale geological mapping) suggesting that the dispersion of both these landforms is a key feature limiting the distribution of *N. fuscus*.

Seasonal conditions at the time of our survey in 2011 were described by many landholders as similar to the exceptional rainfall years in the mid 1950s and mid 1970s. Vegetative cover was high throughout the study area including the three trap sites, and many perennial and short-lived plant species showed recent sign of fruiting and seeding. Prolific seeders such as *Dacyloctenium radulans* were common in all habitats supporting a range of species including little button quail *Turnix velox* and large flocks of budgies *Melopsittacus undulatus*. Pregnant and/or subadult *N. fuscus* were recorded at all three trapping grids suggesting that the population was still breeding and food resources had not yet become limiting. Vegetation monitoring in 2012 indicated both ground and shrub cover had declined slightly compared to 2011. However, prolific seeders were no longer evident and button quail and budgies were far less common. Grass species such as *Paracteneum* favoured by some granivores persisted at some plots but were generally scarce.

Change in occurrence of introduced and native species

Saunders and Giles (1975) argued that a rodent irruption required not only a flush of food stimulated by rain but also a dry period prior to rain. Under these conditions the abundance of parasites, pathogens, competitors and predators were reduced and allowed the rodent population to quickly boom in response to flourishing food resources. The numbers of predators and large competitors often lag behind because of their slower rates of reproduction. The conditions in the region during the study exhibited many of these characteristics. A drought of almost a decade preceded the exceptional rainfall in 2010 and 2011. Stock numbers were low and the high price/low availability of sheep and cattle largely prevented immediate and broadscale restocking within the region. From 10% in 2011, fresh sign of cattle and sheep had increased to 32% in 2012. The occurrence of the larger native herbivores was also greater in 2012 compared to 2011 with sign of emu, red kangaroo and grey kangaroo more than doubling in frequency. Within the study region, Pople *et al*. (2000) also found that rainfall pattern was broadly reflected in red kangaoo and emu numbers with little time lag and Olsen and Braysher (2000) concluded that rainfall, by influencing productivity, was the most important influence on kangaroo populations.

Rabbits did not follow this trend. They were relatively widespread in the study area but not abundant in 2011 and occurrence declined further in 2012. Rabbit occurrence in the study area was lower than recorded around Lake Eyre in 2006 (Southgate, unpublished) and lower than the number of rabbits per km of spotlight transect recorded at Montecollina Bore prior to and three years following the release of the calicvirus (Moseby *et al*. 2006). Landholders reported periodic but non-uniform recurrence of the calicivirus across the study area.

Sign of most predators increased during the study and their predominance changed. Read and Bowen (2001) documented a similar response for predators following significant rainfall in 1989. Fox sign was predominant in 2011 but feral cat occurrence increased significantly in 2012 and it became the most frequently encountered predator species south of the Dog Fence. Dingo sign was comparatively low in the study area south of the dog fence because of ongoing control efforts and the influence of the Dog Fence. However landholders reported that dingo numbers were the highest they had been for decades. Fresh tracks were recorded at 8% of plots in both 2011 and 2012. Occurrence (14%) was greater within the subset of paired plots located closer to the Dog Fence.

The effect of the Dog Fence on the occurrence of key predator and herbivore species was particularly stark. No sign of emu or grey kangaroo recorded north of the Dog Fence and red kangaroo was one third of the occurrence compared to south of the fence. These trends support the findings of Pople *et al*. (2000) and Letnic and Koch (2009) and the assertion of Caughley *et al*. (1980) that dingo predation can reduce kangaroo and emu density outside the Dog Fence. Cattle sign was more frequently encountered to the north of the fence. The same amount of rabbit sign was encountered on either side of the fence but limited spotlight counts indicated rabbits were more abundant north of the fence. The dingo was the predominant predator species north of the fence and fox and cat occurrence was less than a quarter of that recorded on the paired sites to the south. These results support the findings of other studies where lower fox occurrence or survival has been found in areas where dingoes are more active (Letnic and Koch 2009; Kennedy *et al*. 2012; Moseby *et al*. 2012)

The increase, irruption and decline of *N. fuscus*

Our study has documented the dramatic response of the *N. fuscus* population to exceptional rainfall following drought and highlights the species' spatial variability of occurrence in relation to landform type and a landscape-scale management feature (i.e. Dog Fence). The study was too coarse-grained to provide a clear explanation for the rapid decline of the species and other rodents. Several mechanisms that cause a rodent population to decline rapidly in Australia have been proposed including a nutrient deficit and changing food quality (Morton and Baynes 1985), overcrowding (Breed 1979) and a build up of predators, particularly cats (Smith and Quin 1996; Moseby *et al*. 2006) and impacts from grazing (Morton 1990; Read and Cunningham 2009). The effect of the Dog Fence and dingo occurrence appeared to mitigate the decline of *N. fuscus*. Whether this resulted from less predation pressure from foxes and cats or competition for key resources by large herbivores is unclear. Modelling suggested that composite herbivore richness at a plot was a stronger negative indicator of *N. fuscus* presence than those for individual predators or composite predator richness. Furthermore, the weakest response among individual predators was for the feral cat despite the frequency of occurrence of this predator increasing most during the study.

While the irruption of *N. fuscus* in the study area fits well with the 'drought-plague' model it does not adequately explain why a similar irruption did not occur following exception rainfall in 1974 (P. Absolm and J. McIntee, pers comm.). Nor does it explain why a number of other rodent and small dasyurid species had begun to expand their range prior to 2010. A southward expansion in the range of the spinifex hopping mouse *N. alexis,* the plains rat *P. australis* and the kultarr *Antechinomys laniger* has been documented to the west of the study area (Moseby *et al*. 2009; R. Pedler, unpublished). Similarly, the expansion of *N. fuscus* and the crest-tailed mulgara *Dasycercus cristicauda* was documented around Lake Eyre North in 2006 (Southgate, unpublished) during a drought period. The most likely 'game-changer' has been the release of the rabbit calcivirus in 1995. The subsequent decline in rabbit populations has most probably lowered predator abundance and reduced grazing pressure sufficiently to allow vegetation and associated invertebrate communities to recover and the expansion of a suite of native species is beginning to reflect subtle but broad-scale changes in the landscape brought about by the calicivirus. This conclusion provides some support for the hypothesis proposed by Morton (1990) suggesting that invading herbivores can cause habitat degradation and disrupt food resources thus negatively affecting native mammals in arid Australia.

Biodiversity Strategy Actions

Four, five year actions were outlined in the SAAL Board biodiversity strategies for the dusky hopping mice. This present study has contributed to these actions in the following ways;

- ACTION: Determine area of occupancy and relationship between habitat and distribution and abundance of the dusky hopping-mouse in the Strzelecki Desert.

The extent of occurrence during good seasons has now been quantified with regards to the southern limit of the species. This serves as a baseline for future surveys after significant rainfall events and will allow changes in distribution to be determined over the long term. This comparison is needed to determine if the species listing of Vulnerable is appropriate or whether the population is stable or increasing. The area of occupancy can be more accurately assessed with repeated sampling of existing plots and the survey of additional plots at locations where information is missing.

The range of habitats utilized by the species during these good seasons has also been documented. Resampling of survey locations during drier conditions identified the importance of a scattered sand dunes and rises away from the expansive dune systems in the Strzelecki Desert. Further monitoring during drier times will strengthen this understanding of the size of these landforms necessary to sustain a hopping mouse population.

- ACTION: Identify and, where possible, quantify the disruption, and sources of disruption, of key ecological processes supporting individual populations of the dusky hopping-mouse in the Strzelecki Desert.

A relationship was found between hopping mice occurrence and a number of covariables including landform characteristics and the conditions associated with high dingo occurrence north of the Dog Fence. Hopping mouse detection was also found to be sensitive to variables affecting tracking conditions. The distribution of sand rises and sand hills was more important to their occurrence than distance from the edge of the aeolian sand sheet deposits. Lower fox, cat, kangaroo, emu and sheep activity was associated with high dingo and hopping mouse occurrence. Rabbit activity during the study was low where dingo activity was both high and low.

- ACTION: Identify potential habitats within the Strzelecki Desert for the Dusky Hopping-mouse.

Dusky hopping mice were found in a range of sandy habitats and were able to live and breed in very small patches of isolated sandy substrate. These included sandy creeklines, sand sheets on gibber plains and isolated dunes adjacent to rocky ranges. However, the highest abundance and activity of hopping mice was more frequently found in areas of continuous sand dune habitat close to or north of the Dog Fence where dingo occurrence was higher.

- ACTION: Rank populations of the Dusky Hopping-mouse within IBRA subregions for viability, based on size, threats and landscape context.

Populations were not ranked but the highest density of dusky hopping mice south of the Dog Fence were recorded on Wooltana and Mulyungerie Station, suggesting they may support important populations of the species.

Recommendations

1. Further resampling in the study area during drier conditions would help clarify:

   - the characteristics of residual populations north and south of the Dog Fence
   - the landscape features and conditions at key refugia sites
   - the distribution and occupancy of predator and introduced herbivore species associated with the *N. fuscus* population.
   - and validate the habitat models derived during the study.

2. Resampling each plot on two-three occasions within a year would provide a more accurate assessment of the area of occupancy and strength of association between detection and habitat covariables.

3. Being able to determine the relative effect of rabbit, kangaroo and stock grazing pressure on hopping mice occupancy compared to predation pressure from cats, foxes and dingoes would allow management to become more targeted. Results from other exclosure studies have found significant increases in native rodents when exotic herbivores and predators were removed (Moseby et al 2009). However, separating out the relative effects of each potential impact group is difficult. The use of exclosures to selectively manipulate grazing pressure from rabbits, large native herbivores and stock would be required as part of the experimental approach.

4. The monitoring of additional areas immediately north and south of the Dog Fence would improve our understanding of the composition and predominance of the predator community associated with hopping mice activity.

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References

Bellchambers, K. 2007. *Assessing the southern and western limits of the Dusky Hopping Mouse , Notomys fuscus*. Unpublished report prepared for The South Australian Arid Lands NRM board- Ardeotis Biological Consultants.

Breed, W.G. 1979. The reproductive rate of hopping mice, *Notomys alexsis*, and its ecological significance. *Australian Journal of Zoology* **27**, 177-194.

Caughley, G., Grigg, G. C., Caughley, J., and Hill, G. J. E. 1980. Does dingo predation control the densities of kangaroos and emus? *Australian Wildlife Research* **7**, 1–12.

Kennedy, M., Phillips, B.L., Legge, S., Murphy, S.A. and Faulkner, R.A. 2012. Do dingoes suppress the activity of feral cats in Australia. *Austral Ecology* **37**, 134-139.

Letnic M, Crowther M.S. and Koch, F. 2009. Does a top-predator provide an endangered rodent with refuge from an invasive mesopredator? *Animal Conservation* **12**, 302–312.

Letnic, M. and Koch, F. 2010. Are dingoes a trophic regulator in arid Australia? A comparison of mammal communities on either side of the dingo fence. *Austral Ecology* **35**, 375–175.

MacKenzie, D. I., Nichols, J. D., Royle, J.D., Pollock, K.H., Bailey, L.L. and Hines, J.E. 2006. *Occupancy estimation and modeling. Inferring patterns and dynamics of species occurrence*. Elsevier: Academic Press.

Morton, S.R., 1990. The impact of European settlement on the vertebrate animals of arid Australia: a conceptual model. *Proceedings from the Ecological Society of Australia* **16**, 201-213.

Morton, S.R. and Baynes, A. (1985). Small mammal assemblages in arid Australia: a reappraisal. *Australian Mammalogy* **8**, 159-169.

Moseby, K.E., Neilly, H., Read, J.L. and Crisp, H.A. 2012. Interactions between a top order predator and exotic mesopredators. *International Journal of Ecology* Article ID 250352, doi:10.1155/2012/250352.

Moseby, K.E., Hill, B.M. and Read, J.L. 2009. Arid Recovery- A comparison of reptile and small mammal populations inside and outside a large rabbit, cat and fox-proof exclosure in arid South Australia. *Austral Ecology* **34,** 156-169

Moseby, K., Nano, T. and Southgate, R., 2009. *Tales in the sand: A guide to identifying Australian arid zone fauna using spoor and other signs*. Ecological Horizons, South Australia

Moseby K.E., Brandle R., and Adams M., 1999. Distribution, habitat and conservation status of the rare dusky hopping-mouse, *Notomys fuscus* (Rodentia: Muridae). *Wildlife Research* **26**, 479- 494.

Moseby K.E., Owens H., Brandle R., Bice J.K., and Gates J., 2006. Variation in population dynamics and movement patterns between two geographically isolated populations of the dusky hopping mouse (*Notomys fuscus*). *Wildlife Research* **33**, 223-232.

Olsen, P. and Braysher, M. 2000. *Situation Analysis Report: Update on Current State of Scientific Knowledge on Kangaroos in the Environment, Including Ecological and Economic Impact and Effect of Culling*. Report to the Kangaroo Management Advisory Committee.

Owens, H.M., Moseby, K.M. and Brandle, R. 2006. Dusky Hopping-mouse. In *The mammals of Australia.* Ed. S. Van Dyck and R. Strahan. NewHolland Publishers. pp 602-604.

Pople, A.R., Grigg, G.C., Cairns, S.C., Beard, L.A. and Alexander, P. 2000. Trends in the numbers of Red Kangaroos and Emus on either side of the South Australian Dingo fence: evidence for predator regulation? *Wildlife Research* **27**, 269–276.

Read, J.L. and Bowen, Z. 2001. Population dynamics, diet and aspects of the biology of feral cats and foxes in arid South Australia. *Wildlife Research* **28,** 195-203.

Read, J.L. and Cunningham, R. 2010. Relative impacts of cattle grazing and feral animals on an Australian arid zone reptile and small mammal assemblage. *Austral Ecology* **35**, 314-324.

Saunders, G.R. and Giles, J.R. 1975. A relationship between plagues of the house mouse *Mus musculus,* (Rodentia: Muridae) and prolonged periods of dry weather in south-eastern Australia. *Australian Wildlife Research* **4**, 241-247

Smith AP, Quin DG, 1996. Patterns and causes of extinction and decline in Australian conilurine rodents. *Biological Conservation* **77**, 243–267.

Southgate, R. and Masters, P. 1996. Fluctuations of rodent populations in response to rainfall and fire in a central Australian hummock grassland dominated by *Plechtrachne schinzii*. *Wildlife Research* **23**, 289-303.

Southgate, R., 2006. *Investigation of Dasycercus distribution on canegrass sand dunes in the Lake Eyre region*. Report to the Department of Environment and Heritage (SA) - Envisage Environmental Services.

Waudby H.P. and How, T. 2008. An additional record of the dusky hopping mouse *Notomys fuscus* in South Australia. *Australian Mammalogy* **30**: 47–49.

Watts, C.H.S. and Aslin, H.J. 1981. *The rodents of Australia* Angus & Robertson, Australia.

Appendix 1 Location and habitat features of each trapping grid.

Grid Location	Northing	Easting	Habitat
Mulyungarie Station	54J 469211	6551138	Callitrus glaucophylla pale orange dune adjacent to Eucalyptus coolabah creekline. Abundant grasses and understorey of *Sida*, *Abutilon*, *Salsola kali* and *Enneapogon*
Wooltana Station	54J 375736	6638345	Linear orange dune vegetated with sandhill canegrass *Zygochloa paradoxa, Sida*, Rhagodia and *Crotolaria eremea*. Dunes separated by 500m-1km of grassy clay swale.
Mundowdna Station	54J 245572	6706734	Pale dune located within 1 km of permanent spring and salt pans. Vegetated with *Z. paradoxa* and *Crotolaria* as well as overstorey of *Acacia ligulata*.

Appendix 2 The location details of plots sampled during 2011 and 2012 survey and opportunistic records

Plot no.	Location	Sampled 2011	2012	11_12	Dog fence	Latitude	Longitude	Zone	Easting	Northing	Notomys occurrence 2011	2012	Notomys activity 2011	2012
cm01	Curnamona	1	1	2	1	-31.67362	139.66745	54	373685	6494968	0	0	0	0
cm02	Curnamona	1	1	2	1	-31.65588	139.60478	54	367718	6496861	0	0	0	0
cm03	Curnamona	1	1	2	1	-31.49715	139.66741	54	373443	6514530	1	0	1	0
cm04	Curnamona	1	1	2	1	-31.51192	139.75599	54	381874	6512992	1	0	2	0
cm05	Curnamona	1	1	2	1	-31.51149	139.81915	54	387871	6513106	1	1	0	1
cm06	Curnamona	1	1	2	1	-31.45398	139.87033	54	392666	6519532	1	0	1	0
cm07	Curnamona	1	1	2	1	-31.37935	139.88277	54	393764	6527816	1	1	2	1
cm51	Curnamona	0	1	1	1	-31.36909	139.73131	54	379347	6528797	-	1	-	1
cnb	Wooltana	0	1	1	1	-30.41293	139.79156	54	383930	6634838	-	1	-	2
er01	Frome downs	1	1	2	0	-31.36045	139.72818	54	379039	6529752	1	1	2	1
er51	Erudina	0	1	1	1	-31.51289	139.55446	54	362737	6512650	-	0	-	0
fr51	Frome downs	0	1	1	0	-31.22438	139.74507	54	380473	6544852	-	1	-	2
fr52	Frome downs	0	1	1	0	-31.25019	139.76169	54	382089	6542009	-	1	-	2
fr53	Frome downs	0	1	1	0	-31.28585	139.7537	54	381372	6538048	-	1	-	1
gl01	Martins Well	1	1	2	1	-31.47341	139.36008	54	344213	6516766	1	0	3	0
gl03	Wertaloona	1	1	2	1	-31.04287	139.38696	54	346069	6564529	1	0	2	0
gl04	Wertaloona	1	1	2	1	-30.98953	139.39031	54	346303	6570447	0	1	0	1
gl05	Wertaloona	0	1	1	1	-30.93197	139.39391	54	346554	6576832	-	0	-	0
kalab01	Kalabity	0	1	1	1						-	0	-	0
kl01	Kalabity	1	1	2	1	-31.9028	140.26617	54	430612	6470103	0	0	0	0
kl02	Kalabity	1	1	2	1	-31.84697	140.19498	54	423834	6476244	0	0	0	0
kl03	Kalabity	1	1	2	1	-31.78128	139.92837	54	398537	6483308	1	1	1	3
kl04	Kalabity	1	1	2	1	-31.69072	139.82147	54	388306	6493241	1	0	1	0
kl05	Kalabity	1	1	2	1	-31.69311	139.74139	54	380719	6492892	1	0	1	0
mn01	Murnpeowie	1	1	2	1	-29.8112	139.79863	54	383908	6701530	1	1	3	2
mo03	Wooltana	1	1	2	1	-30.44641	139.77262	54	382151	6631107	1	1	1	2
mo04	Wooltana	1	1	2	1	-30.46361	139.70508	54	375687	6629129	1	1	1	2
mo05	Wooltana	1	1	2	1	-30.46323	139.60122	54	365715	6629052	1	1	1	2
mu02	Mundowdna	1	1	2	1	-29.72431	138.19912	54	229063	6708477	1	1	3	1
mu03	Mundowdna	1	1	2	1	-29.7435	138.36931	54	245580	6706738	1	0	3	0
mu04	Mundowdna	1	1	2	1	-29.77217	138.38902	54	247560	6703602	1	0	3	0
mu05	Mundowdna	1	1	2	1	-29.76768	138.4299	54	251502	6704189	0	0	0	0
mu06	Mundowdna	1	1	2	1	-29.76768	138.42938	54	251452	6704188	0	0	0	0
mu07	Mundowdna	1	1	2	1	-29.70734	138.48229	54	256423	6710990	1	0	3	0
mu08	Mundowdna	1	1	2	1	-29.68456	138.47412	54	255577	6713498	0	0	0	0
mu09	Mundowdna	1	1	2	1	-29.66799	138.42996	54	251262	6715241	0	0	0	0
mu10	Mundowdna	1	1	2	1	-29.67312	138.39785	54	248166	6714602	1	0	3	0
mu20	Mundowdna	1	1	2	1	-29.72593	138.19009	54	228194	6708277	1	0	3	0
mu21	Mundowdna	0	1	1	1	-29.71485	138.2653	54	235442	6709676	-	0	-	0
my01	Mulyungarie	1	1	2	1	-31.18791	140.81018	54	481914	6549557	1	0	1	0
my03	Mulyungarie	1	1	2	1	-31.22272	140.83738	54	484512	6545704	1	1	2	2
my04	Mulyungarie	1	1	2	1	-31.2439	140.76399	54	477527	6543344	1	1	2	1
my05	Mulyungarie	1	1	2	1	-31.18935	140.67272	54	468817	6549367	1	1	1	1
my06	Mulyungarie	1	1	2	1	-31.31087	140.70354	54	471790	6535907	1	1	1	3
my07	Mulyungarie	1	1	2	1	-31.20497	140.90182	54	480071	6509242	1	1	2	1
my08	Mulyungarie	1	1	2	1	-31.55163	140.79002	54	490648	6547678	1	0	1	0
my09	Mulyungarie	1	1	2	1	-31.06487	140.95611	54	495813	6563208	1	0	1	0
my10	Mulyungarie	1	1	2	1	-31.07127	140.88693	54	489213	6562494	1	1	1	1
my11	Mulyungarie	1	1	2	1	-31.07635	140.82187	54	483008	6561923	1	0	1	0
my12	Mulyungarie	1	1	2	1	-31.17335	140.67682	54	469204	6551142	1	1	1	2
my13	Mulyungarie	1	1	2	1	-31.64964	140.82426	54	483338	6498385	1	0	2	0
my14	Mulyungarie	1	1	2	1	-31.72736	140.87559	54	488215	6489777	1	0	1	0
my15	Boolcoomata	1	1	2	1	-32.02279	140.58502	54	460812	6456963	0	1	0	1
my16	Boolcoomata	1	1	2	1	-31.98722	140.55561	54	458019	6460895	1	1	3	1
my17	Mulyungarie	1	1	2	1	-31.56389	140.70471	54	471977	6507864	0	0	0	0
my18	Mulyungarie	1	1	2	1	-31.62099	140.65793	54	467557	6501523	1	0	2	0
my52	Mulyungarie	0	1	1	1	-31.1584	140.73083	54	474346	6552812	-	1	-	3
my53	Mulyungarie	0	1	1	1	-31.22223	140.69893	54	471325	6545730	-	1	-	1
my54	Mulyungarie	0	1	1	1	-31.35262	140.69997	54	471463	6531279	-	0	-	0
my80	Quinyambie	0	1	1	1	-30.93132	140.96175	54	496345	6578009	-	1	-	3
my81	Quinyambie	0	1	1	0	-30.93509	140.90187	54	490626	6577587	-	1	-	3
my82	Quinyambie	0	1	1	0	-30.93991	140.76881	54	477915	6577035	-	1	-	3
my83	Quinyambie	0	1	1	0	-30.95478	140.6499	54	466562	6575357	-	1	-	3
my84	Quinyambie	0	1	1	0	-31.02732	140.54034	54	456131	6567279	-	1	-	3
my85	Quinyambie	0	1	1	0	-31.07208	140.52193	54	454394	6562311	-	1	-	3

my86	Quinyambie	0	1	1	0	-31.1009	140.49045	54	451406	6559104	-	1	-	3
my87	Quinyambie	0	1	1	0	-30.880113	140.57294	54	459179	6583604	-	1	-	3
my88	Mulyungarie	0	1	1	1	-31.06308	140.73375	54	474599	6563377	-	1	-	2
my89	Mulyungarie	0	1	1	0	-31.15304	138.85808	54	485779	6553428	-	1	-	2
my90	Mulyungarie	0	1	1	1	-31.19591	140.8508				-	0	-	0

cont.

		Sampled			Dog						Notomys occurrence		Notomys activity	
Plot no.	Location	2011	2012	11_12	fence	Latitude	Longitude	Zone	Easting	Northing	2011	2012	2011	2012
qy01	Quinyambie	0	1	1	0	-30.94316	140.82239	54	483034	6576684	-	1	-	2
qy02	Quinyambie	0	1	1	0	-30.94442	140.71204	54	472494	6576522	-	1	-	3
qy03	Quinyambie	0	1	1	0	-30.96626	140.59764	54	461574	6574068	-	1	-	3
qy04	Quinyambie	0	1	1	0	-30.96169	140.54621	54	456661	6574556	-	1	-	3
qy05	Quinyambie	0	1	1	0	-30.91627	140.58096	54	459961	6579602	-	1	-	2
qy06	Quinyambie	0	1	1	0	-30.9032	140.74026	54	475179	6581097	-	1	-	3
wi01	Wirrealpa	1	1	2	1	-31.17697	138.97394	54	306919	6549017	1	0	3	0
wi02	Wirrealpa	1	1	2	1	-31.1754	138.92128	54	301897	6549098	1	0	3	0
wi03	Wirrealpa	1	1	2	1	-31.18935	138.91896	54	301704	6547548	1	1	2	1
wo01	Wooltana	1	1	2	1	-30.38065	139.7066	54	375728	6638325	1	1	1	2
wo02	Wooltana	0	1	1	1	-30.39757	139.75585	54	380481	6636502	-	1	-	2
wo05	Wooltana	0	1	1	1	-30.37958	139.68487	54	373639	6638419	-	1	-	2
wo07	Moolawatna	1	1	2	1	-29.91771	139.7432	54	378680	6689669	0	0	0	0
wo10	Wooltana	1	1	2	1	-30.41198	139.80587	54	385304	6634957	1	1	3	2
wo12	Wooltana	1	1	2	1	-30.23325	139.70831	54	375707	6654662	1	0	3	0
wo13	Wooltana	1	1	2	1	-30.27714	139.68785	54	373794	6649776	1	0	2	0
wo14	Wooltana	1	1	2	1	-30.11851	139.81489	54	385831	6667490	0	0	0	0
wo99	Wooltana	0	1	1	1	-30.18226	139.73218	54	377940	6660339	-	1	-	2
wr01	Wertaloona	1	1	2	1	-30.9846	139.51082	54	357804	6571154	0	1	0	1
wr02	Wertaloona	1	1	2	1	-31.05291	139.53469	54	360183	6563612	0	0	0	0
wr03	Wertaloona	1	1	2	1	-30.95033	139.46125	54	353017	6574888	1	1	1	1
wr04	Wertaloona	1	1	2	1	-30.75194	139.33622	54	340745	6596706	1	1	1	2
wr51	Wertaloona	0	1	1	1	-31.12009	139.57127	54	363770	6556211	-	1	-	1
wr52	Wertaloona	0	1	1	1	-31.21478	139.64542	54	370969	6545804	-	1	-	1
wr53	Wertaloona	0	1	1	1	-31.23209	139.68055	54	374338	6543926	-	1	-	2
wr54	Wertaloona	0	1	1	1	-31.22594	139.71604	54	377711	6544647	-	1	-	1
wr55	Wertaloona	0	1	1	1	-31.21991	138.9823	54	307803	6544271	-	0	-	0
fa01	Farina	1	0	1	1	-30.26843	138.34966	54	245027	6648496	0	-	0	-
fa02	Farina	1	0	1	1	-30.09922	138.28233	54	238099	6667104	0	-	0	-
gl02	Martins Well	1	0	1	1	-31.37005	139.36658	54	344660	6528233	0	-	0	-
ma01	Muloorina	1	0	1	0	-29.28107	137.92292	54	783983	6757329	1	-	2	-
ma02	Muloorina	1	0	1	0	-29.24237	137.89637	54	781509	6761684	1	-	3	-
ma03	Muloorina	1	0	1	0	-29.09939	137.6986	54	762643	6777994	1	-	3	-
ma04	Muloorina	1	0	1	0	-29.17489	137.7467	54	767131	6769514	1	-	3	-
ma05	Muloorina	1	0	1	1	-29.44074	138.2333	54	231621	6739996	0	-	0	-
ml01	Mt Lyndhurst	1	0	1	1	-30.04902	138.93167	54	300590	6673981	0	-	0	-
ml02	Mt Lyndhurst	1	0	1	1	-30.22058	138.54654	54	263859	6654226	0	-	0	-
mo02	Moolawatna	1	0	1	1	-30.39752	139.75571	54	380468	6636508	1	-	1	-
mu01	Mundowdna	1	0	1	1	-29.8891	138.2249	54	231994	6690262	0	-	0	-
mv01	Mulga View	1	0	1	1	-30.86882	139.13252	54	321460	6583443	1	-	3	-
my02	Mulyungarie	1	0	1	1	-31.16049	140.89483	54	489976	6552607	1	-	3	-
wo06	Wooltana	1	0	1	1	-30.37958	139.68487	54	373639	6638419	1	-	1	-
wo11	Wooltana	1	0	1	1	-30.3201	139.71717	54	376668	6645047	1	-	2	-
wu02	Murnpeowie	1	0	1	0	-29.61273	139.57199	54	361733	6723274	0	-	0	-
ym01	Yarramba	1	0	1	1	-31.69015	140.59406	54	461528	6493836	1	-	1	-
Opportunistic records														
DHM01	specimen	1	0	1	1	-31.61267	140.67065	54	468761	6502448	1	-		
DHM02	specimen	1	0	1	1	-31.85762	139.46276	54	354567	6474316	1	-		
S01	spotlight obs	1	0	1	1	-31.76351	140.88487	54	489097	6485771	1	-		
S02	spotlight obs	1	0	1	1	-31.67883	140.84128	54	484956	6495151	1	-		
S03	spotlight obs	1	0	1	1	-31.90075	140.25493	54	429547	6470324	1	-		
S04	spotlight obs	1	0	1	1	-31.89292	140.23344	54	427510	6471177	1	-		
S05	spotlight obs	1	0	1	1	-31.88628	140.23227	54	427393	6471912	1	-		
S06	spotlight obs	1	0	1	1	-31.89061	140.23274	54	427441	6471432	1	-		
S07	spotlight obs	1	0	1	1	-31.89687	140.23767	54	427913	6470742	1	-		
S08	spotlight obs	1	0	1	1	-31.90181	140.26102	54	430124	6470210	1	-		
S09	spotlight obs	1	0	1	1	-31.87448	139.46191	54	354514	6472446	1	-		
S10	spotlight obs	1	0	1	1	-31.86721	139.50627	54	358699	6473311	1	-		
S11	spotlight obs	1	0	1	1	-31.86455	139.47495	54	355732	6473564	1	-		
T01	tracks	1	0	1	1	-31.16163	138.94485	54	304115	6550667	1	-		
T02	tracks	1	0	1	1	-31.17147	138.92359	54	302109	6549538	1	-		

T03	tracks	1	0	1	1	-31.18254	138.91643	54	301450	6548298	1	-
T05	tracks	1	0	1	1	-30.71661	139.44991	54	351574	6600778	1	-
O15	tracks	1	0	1	1	-29.85774	139.815	54	385543	6696389	1	-