Wild Otways Initiative
Project 4: Conserving threatened small mammals in the Otway Ranges, Bells Beach (Ironbark Basin) and Great Ocean Road hinterland.

Recovery management guidelines for the threatened New Holland Mouse (Pookila/Koornam), *Pseudomys novaehollandiae* in the Otways

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Front cover: New Holland mouse LHS, House mouse RHS Image, New Holland mouse (Images: Doug Beckers).

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Executive Summary

The New Holland mouse (Pookila, Koornam) *Pseudomys novaehollandiae* is a small, burrowing native rodent found in small, disjunct populations predominantly along coastal south-eastern Australia: Queensland, New South Wales, Victoria and Tasmania. The species occurs in closed and open heathland, woodland and forest with a dense understorey, and on vegetated sand dunes and has a preference for floristically rich vegetation. The species is listed as **Vulnerable** (*Environment Protection and Biodiversity Conservation Act 1999*) due its restricted distribution, low numbers of mature individuals and the likelihood of continued decline. Recently it has been nominated for reclassification to **Endangered** due to the magnitude of nationwide reduction in captures and national reduction in population size (> 50%), over the last 10 years.

Threats to the New Holland mouse that have been identified include: habitat destruction and fragmentation; declining quality of habitat due to impacts of *Phytophthora cinnamomi*, overabundant coast tea tree monocultures, overgrazing; reduced genetic diversity and resilience due to population fragmentation and genetic isolation; inappropriate fire regimes – too frequent, too large, too severe, or poorly timed fires; drought - reducing habitat quality and food availability; climate change – increasing frequency and intensity of drought, fire, and extreme heat events; invasive species – predation by cats and foxes and possibly invasive rats.

As a consequence of the recent significant declines the *National Pookila Recovery Team*, was established (July 2021) and *The National Recovery Plan for the Pookila* is being drafted 2022-23.

The major objectives of the plan are to;

- Conduct reintroductions to the historically occupied range.
- Manage genetic health across populations through captive breeding and translocations.
- Identify key habitat requirements.
- Understand and effectively manage a) fire regimes across the range, develop location-specific fire management plans; b) current and projected impacts of climate change; c) the impacts of *Phytophthora cinnamomi*, d) the impacts of invasive species.
- Design and implement monitoring programmes using best practice methods.
- Engage Traditional Custodians in the management and recovery of the Pookila.
- Increase community awareness of Pookila and increase engagement with recovery efforts.

In Victoria the New Holland mouse has been lost from at least six localities out of 12 in the past 30 years and exhibited a decline in area of occupancy of approximately 45%. The species was assessed as **endangered** in Victoria (*Flora and Fauna Guarantee Act 1988*) in 2021 due to its continuing decline in extent of occurrence, area of occupancy, number of locations and mature individuals. New Holland mouse has been one of Zoos Victoria's focal species and in response to the species' rapid decline and genetic risks, a captive breeding program was established (2022) with animals obtained from remnant Victorian populations. Captive bred animals from these founders will be released to suitable habitats with the first release planned to establish an insurance population at Cranbourne Botanic Gardens.

In the Otways the New Holland Mouse has a very restricted distribution predominantly in Heathy woodlands and Lowland Forests of the eastern Otways, east and west of the Anglesea River. Long-term research since 1981 has investigated the distribution, habitat preferences, population ecology

reproduction and captive breeding of the species. Trial reintroductions were undertaken (2002 -03), and these were the last individuals of the species recorded in the Otways. Populations of the species were predominantly small, localised and extant for 1–6 years. High-density populations occurred after above-average rainfall and declined precipitously during drought. Wildfire resulted in the extirpation of some populations, while others survived in unburnt refuges. Post-fire vegetation (3–7 years) contemporaneous with above average rainfall delivered productive habitat resulting in a population irruption.

Following the absence of monitoring (2003 - 2013) the status of New Holland mouse was unclear and required reassessment. Surveys between 2013-16 (Wilson and Garkaklis), and 2021-23 (Wilson *et al.* WOI Project 4) involving > 400 camera trapping sites and >120 live trapping sites have failed to record New Holland mouse across the Otways landscape. The species persistence is considered now to be highly doubtful, and its future likely is contingent on captive breeding and reintroductions, as outlined in the '*National Recovery Plan for the Pookila (New Holland Mouse)*'.

The following guidelines for the recovery of New Holland Mouse in the Otways are developed in support of the draft '*National Recovery Plan for the Pookila (New Holland Mouse)'* and contribute to its objectives and actions to ensure the species' long-term viability.

1. Conduct reintroductions to the historically occupied range and other areas of suitable habitat

Reintroductions in the Otways would be significant and would contribute to an emergency response strategy to future catastrophic events (e.g., wildfire) by spreading the risk of population losses across the national distribution but particularly in Victoria. They would be important to manage genetic health of species across populations through the captive breeding program. The remnant Victorian genetic diversity forms the species southern ESU (Evolutionarily Significant Unit), and as such is managed independently to populations in the northern ESU (NSW+Qld)(Burns *et al*. 2023). Reintroductions will provide significant opportunities for cultural on country management by Traditional Owners Wadawurrung Aboriginal Corporation (WTOAC) and the Eastern Maar Aboriginal Corporation (EMAC).

The threats that led to the species' loss from the Otways must be addressed in any reintroduction effort. Factors such as habitat degradation (e.g. due to Phytophthora and poor fire regimes), drought and predation must be considered. One potential pathway for reintroduction is through the establishment of one or more cat and fox-free fenced areas that could service multiple threatened species. Cost-benefit analyses that consider the value of fenced areas in the Otways should include other threatened species that either overlap in NHM habitat preferences (e.g. Southern Brown bandicoot, White-footed dunnart) or where preferred habitat occurs in the same landscape (e.g. heathy woodland located upslope (NHM) and wet swampy heath downslope (Swamp antechinus, Long Nosed Potoroo). Options and methods for reintroductions will be informed by current (Cranbourne, Wilson's Promontory) and previous trials (Anglesea, Mulligans Flat NSW). Cost benefit analyses of options would be required.

2. Identify suitable habitat and key sites for reintroductions

An initial priority would be to identify and assess suitable habitat and key sites for reintroductions, and to protect these areas from future degradation. This would include desk and on ground assessments informed by the detailed habitat model in the eastern Otways (Wilson *et al.* 2015) and a Victorian wide Habitat SDM (Liu *et al.* 2013, Burns *et al. 2020*) which has extended the predicted

habitat further west in the Otways. Identified areas would be priority locations for Phytophthora management and carefully designed fire management (see 3 below).

Detailed vegetation and habitat suitability assessments (e.g., vegetation floristics and structure, and soils) would be necessary at identified key sites. Significant data and analyses from sites where the species was extant will provide a strong base for comparison (Kentish 1982, 1983; Lock and Wilson 1999, 2017; Wilson 1990, 1991, 1994; Wilson *et al.* 1990; Wilson and Laidlaw 2003, Slattery 1998, Lock 1998, 2005; Williamson 2015).

3. Manage habitat for reintroduction sites, current and emerging disturbances, and threats

Any reintroductions will require intensive management of populations, habitats and threatening processes.

Impacts of fire and fire management

Previous research in NSW found that NHM increases in abundance in habitat regenerating after fire to reach a maximum between 2 and 8 years. In the eastern Otways the 1983 Ash Wednesday wildfire resulted in the extirpation of some populations, while others survived in unburnt refuges. Analyses of populations revealed that time since fire (TSF) vegetation (3–7 years) contemporaneous with above average rainfall delivered productive habitat resulting in a population irruption. These responses to fire are related to preferences exhibited by the species for specific vegetation structure and floristics, and likely food availability. The rate of recovery of vegetation, not time *per se*, is likely the most important factor (Burns and Phillips 2020). Rainfall and drought also have significant impacts on the population dynamics of the species. There is thus a need to assess fire regime suitability for NHM across the Otways and develop location-specific fire management plans (frequency, intensity, spatial dynamics) in preparation for reintroductions.

Significant analyses of vegetation floristics and structure from sites where the species was previously extant provide a strong base for comparison to current habitats together with long term vegetation changes (1995-2000-2015) (Lock and Wilson 1999, 2017; Wilson 1990, 1991, 1994; Wilson *et al.* 1990; Wilson and Laidlaw 2003, Williamson 2015).

Cultural burning is currently undertaken in the eastern Otways in collaborative partnership between Parks Victoria and WTOAC. Extension of this work to implement burning for NHM would continue to build on-ground capacity, monitoring training, data capture and reporting.

Impacts of Phytophthora cinnamomi and management

Phytophthora dieback was first observed in the Otway Ranges in 1972 and has now been observed extensively particularly in heathy open forest, heath, and heathy woodland. Long-term studies found significant declines in plant species richness and numbers of susceptible species, and an increase in cover of resistant sedges and grasses in post-disease areas and declines in total mammal captures and captures of individual species (Agile Antechinus, Bush rat, Swamp rat, White-footed Dunnart) in post-disease areas. The grasstree *X. australis* was a highly significant structural element providing important nesting sites for Agile Antechinus, White-footed Dunnart and Eastern Pygmy Possum.

The impacts on New Holland Mouse populations and habitat have not been directly investigated, however, the loss of susceptible plant species vegetation structure and food resources (invertebrates, fungi) are expected to place the species at significant risk. The impact of *P. cinnamomi* in NHM habitat should be assessed. Comparisons of current and historic vegetation data sets (e.g., Forest Road,

Flaxbourne Road - 1995-2000-2015) and infected and uninfected vegetation in identified priority reintroduction sites would be necessary to determine if simplification of habitat would risk success of reintroductions.

There is a need to develop management strategies for *P. cinnamomi* in Pookila*,* New Holland mouse habitat, including application of phosphite. Traditional Owners (EMAC, WTOAC) are currently undertaking training for on-ground phosphite treatments, and their involvement will ensure significant field time, strong transfer of knowledge, skills and improved capacity building.

4. M*anage predation by foxes and cats*

Predation impacts have not been demonstrated for NHM but population-level risks are assumed to be substantial. Risks from cats and foxes may be magnified where fire or grazing has reduced ground cover. Feral cats may be vectors of disease impacting Pookila (e.g. toxoplasmosis). Cats are more likely to prey on small rodents than are foxes (Stobo-Wilson *et al.* 2021). While fox control is in place in the Otways cat control is limited. Fox and cat control will be required for reintroductions.

5. Manage genetic health of species across populations through captive breeding programmes and translocations

The reintroduction of captively bred New Holland mouse in the Otways would support a key strategy to undertake genetic rescue among the Victoria populations. Remnant populations are often small and isolated, making them vulnerable to genetic drift and inbreeding- processes that can lead to the expression of deleterious alleles (genetic load) and reductions in overall population fitness (inbreeding depression). Translocation has a potential role in overcoming some of the issues associated with reduced genetic diversity. The current Zoos Victoria project aims to improve the viability of small populations and is a recovery and risk-spreading objective. Reintroduction provides an opportunity to extend the extent of occurrence and improve resilience of this endangered species within its indigenous range.

6. Increase community awareness of and appreciation for the Pookila and engagement with recovery efforts

There is a need to prepare material, make presentations, engage local groups (ANGAIR, Friends of eastern Otways, Geelong Field Naturalists). Work with traditional owners to align with their management plans and goals for Country and enhance current habitat and manage threats to the species alongside community groups and volunteers.

1. Introduction

The Wild Otway's Initiative (WOI) Project 4 aims are to improve the condition of the six *Environment Protection and Biodiversity Conservation* Act 1999 (EPBC) mammal species in the Otway Ranges and hinterland. These focal species are the Broad-toothed rat, New Holland mouse, Smoky mouse, Swamp antechinus, Southern brown bandicoot and Long-nosed potoroo. Field surveys of potential refuge habitat for these species is also a key deliverable of this project. A major output is to publish project outcomes that detail management prescriptions and guidelines for managers (e.g., Barwon-Otway District Forest Fire Management Victoria, DEECA Regional Biodiversity management, Parks Victoria (Pests & Disease Management and PV Fire), local government environmental and bushfire management and Corangamite Catchment Management Authority) to support endangered native small mammal recovery in the Otways and manage the threat of species extinction so that key populations are resilient and secure in the longer-term.

Here we provide draft management guidelines for the threatened rodent the Pookila/New Holland mouse (*Pseudomys novaehollandiae*) based on new knowledge gained though implementation of WOI projects (2020 -2023). This draft will be presented to land managers for incorporation into the development of specific, pragmatic management interventions that are considered during annual planning and land management activities.

2. Description and distribution

The New Holland mouse is a small, burrowing native rodent. It is similar in size and appearance to the introduced House mouse (*Mus musculus*), but can be distinguished by its larger round ears, larger eyes, the absence of a notch on the upper incisors and the absence of a distinctive 'mousy' odour (Seebeck *et al.* 2003a; Threatened Species Scientific Committee 2010; TSSC 2021, Burns et al *in press*). The species has pale grey-brown dorsal fur, with light grey underfur and pale feet. The tail is dusky brown on top, white below and is 15% longer than the body length. The head-body length is approximately 80 mm, tail length of 90 mm and hind foot 21 mm (Menkhorst and Knight 2001).

Figure 1. ***Captive bred Pookila at Deakin University (1998), (Image: M. Lock)***

The New Holland mouse is found in small, disjunct populations predominantly along coastal south-eastern Australia across four states: Queensland, New South Wales, Victoria and Tasmania, (Seebeck et al. 1996; TSSC 2010) although its range extends inland to 100 km in north-east NSW (TSSC 2010, 2021).

3. Biology and Ecology

Reproduction in *P. novaehollandiae* is seasonal with a distinct breeding period restricted to spring and early summer, followed by a period of complete cessation in reproduction (Kemper 1976b, 1980; Wilson 1991; Lock 2005). However, extension of the breeding season of several months has been recorded in New South Wales following above-average rainfall (Kemper 1980; Fox *et al.* 1993). To date, there have been no published records of extended breeding seasons for *P. novaehollandiae* populations in Victoria or Tasmania.

Pookila, New holland mouse is found in closed and open heathland, woodland and forest with a dense understorey, and on vegetated sand dunes (Braithwaite and Gullan 1978; Fox and Fox 1978, 1984; Wilson 1991, 1994; 1996a, 1996b; Lock and Wilson 1999, 2017; Wilson *et al.* 2005, 2018). *P. novaehollandiae* has a preference for floristically rich vegetation with a substantial understorey cover, but with less cover at lower strata levels (Fox and Fox 1984; Wilson 1991; Seebeck *et al.* 1996; Wilson and Laidlaw 2003; Lock and Wilson 1999, 2017). The species occurs on dunes, undulating sand plains, sandy/gravely break of slope soil deposits in granite landscapes and a range of sandy soils ranging - sandy clay, loam, yellow duplex, sand and friable peaty sand, granite derived gravely sands. Predictive modelling of habitat has found relationships of occurrence with topography and proximity to the coast and are likely to be related to the presence of soils of a remnant lateritic plateau that is suitable for constructing burrows, and a negative relationship with aspect represent sites that are warm to cool. (Wilson *et al* 2015).

Figure 2. ***Habitat at a) Coles Bay, Tasmania (Image M. Visoiu) b) Anglesea, Victoria (Image: B. Wilson).***

The Pookila, New Holland Mouse is a social animal, living predominantly in underground burrows shared with other individuals (Kemper 1980; Lazenby *et al.* 2008). The extensive burrows are considered to contribute to soil turnover and infiltration.

The species is nocturnal and spends considerable time foraging above-ground for food. The species has a generation length of one to two years and females reach sexual maturity at 13 weeks of age (Kemper 1980; Lock and Wilson 2007). Gestation is around 32–39 days and litter size ranges from 1–6 young. Breeding usually occurs late winter to early spring or autumn in the north and late spring to early summer in the south (Kemper 1976; 1980; Pye 1991; Wilson 1991; Wilson and Lock 2017). The timing of breeding is related to abundance and quality of food which in turn is related to rainfall patterns and fire succession (Kemper 1976; 1980; Fox et al. 1993; Wilson and Lock 2017, Wilson et al 2018).

The New Holland Mouse has been described as a food generalist and a habitat specialist (Braithwaite and Gullan 1978) due to its omnivorous diet yet restriction to very specific habitat types. The species' diet consists principally of seeds (particularly of legumes) but insects and other invertebrates, leaves, flowers, and fungi are also eaten (Cockburn 1980; Wilson and Bradtke 1999).

The species makes significant contributions to ecosystem processes including soil turnover and infiltration arising from extensive burrowing. Due to its omnivorous diet it contributes to herbivory and facilitates movements of propagules (e.g. seeds, pollen, fungi).

Research has found that the species increases in abundance in habitat regenerating after disturbance, particularly after fire, and reaches maximum abundance ~2–8 years after fire (Braithwaite and Gullan 1978; Fox and Fox 1978, 1984; Kemper 1990; Wilson et al. 1990; Lock and Wilson 1999, 2017). Peaks in abundance have also been observed three to four years after fire, or eight to nine years following sand mining (Fox and McKay 1981; Fox 1982; Wilson 1991). The rate of recovery of vegetation, not time *per se*, has been proposed as the most important factor (Monamy and Fox 2000; Fox and

Monamy 2007). Recent analyses of New Holland mouse populations and time since fire across Victoria has also found weak relationships with occupancy and abundance (Burns and Phillips 2020). The species was unlikely to occupy habitat > 50 years' time since fire and abundance peaked at 8- 16 years however there was substantial uncertainty as to the size of that effect. It is likely that individual fire events, rainfall pre- and post-burn, and burn severities, patterns, and patch sizes, combine to impact New Holland mouse in the days and decades following a fire (Wilson *et al.* 2018; Burns and Phillips 2020). Remnant populations have certainly been recorded in older vegetation at Wilsons Promontory National Park, Providence Ponds Flora and Fauna Reserve and Anglesea but they are considered refuges and not preferred, and populations are low.

There is evidence that population abundance is strongly influenced by rainfall (Lock and Wilson 2017; Wilson *et al*. 2018). In studies in the eastern Otways, the species was significantly influenced by rainfall, exhibiting a population irruption (15–20 individuals ha ^{1}) following six years of above-average rainfall and a precipitous decline to site extinction during subsequent drought. The decline was predominantly related to loss of adults before and during breeding seasons, together with an apparent decrease in juvenile survival. Population abundance was positively correlated with a rainfall lag of 0–9 months. The response of the species to high rainfall is considered to be mediated through increased productivity and that rainfall decline resulted in resource depletion and population decline.

4. Conservation status and Threats

4.1 Current status of taxon:

Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth): Vulnerable
From 11th August 2010.

The species has now been nominated for reclassification to **Endangered** (EPBCA) due to the magnitude of nationwide reduction in capture per unit (up to 99%) and average national reduction in population size (> 50%), over the last 10 years years (Threatened Species Nomination *Pseudomys novaehollandiae* 2019). Following the east coast Black Summer fires (2019-20) additional population losses have occurred with estimates that approximately 45% of Pookila habitat was burned, and that the species suffered a 75% decrease in abundance in severely burned areas (Legge *et al.* 2021). The Extent of Occurrence (EOO) for the species is estimated at 257 000 km2 and the Area of Occupancy (AOO) for the species is estimated at 350 km2 (TSSC 2021). The estimated AOO does not include areas of the species range that burned at high intensity during the 2019/2020 bushfire season. The reclassification assessment under the Threatened Species Scientific Committee is currently underway (2022 -23).

- *Nature Conservation Act 2014* (Australian Capital Territory): Vulnerable
- *Nature Conservation Regulations 2020* (Queensland): Vulnerable
- *Flora and Fauna Guarantee Act 1988* (Victoria): 2022 Endangered
- *Threatened Species Protection Act 1995* (Tasmania): Endangered
- *Biodiversity Conservation Act 2016* (NSW): Not listed
- *IUCN Red List of Threatened Species* (Global; 2016): Vulnerable

In 2010 the New Holland Mouse was listed under the EPBCA based on two criteria:

Criterion 2: Its geographic distribution is precarious for the survival of the species and is very restricted, restricted or limited

Criterion 3: The estimated total number of mature individuals is limited to a particular degree; and either (a) evidence suggests that the number will continue to decline at a particular rate; or (b) the number is likely to continue to decline and its geographic distribution is precarious for its survival

Threats to the New Holland mouse have been identified (Woinarski *et al.,* 2014, TSSC 2010) including:

- Habitat destruction and fragmentation– caused by factors including land clearing for agriculture, roads and housing,
- Declining quality of habitat due to impacts of *Phytophthora cinnamomi*, tea tree encroachment, weed species, and overgrazing / selective grazing by invasive herbivores such as deer and rabbits and overabundant native grazers.
- Population fragmentation – genetic isolation of populations leading to reduced genetic diversity, increased risk of inbreeding and reduced resilience.
- Inappropriate fire regimes – too frequent, too large, too severe, or poorly timed fires may lead to direct loss of individuals and/or sudden or gradual loss of habitat. Similarly, prolonged exclusion or poorly timed application of fire may encourage tea tree encroachment and loss of favourable food and habitat species.
- Drought – extended periods of low rainfall reducing food availability.
- Climate change – increasing frequency and intensity of drought, fire, and extreme heat events.
- Invasive species – predation by cats and foxes and possibly invasive rats, potential competition with house mice.
- Disease – *Toxoplasmosis gondii* spread by cats, potential blood parasites from invasive rodents.

Overall, the threats are likely to be synergistic. For example, a disturbance event such as a fire may allow for easier hunting opportunities for introduced predators and increased spread of *Phytophthora cinammomi*.

New Holland Mouse has undergone significant decline in Victoria and Tasmania in the time since it was listed under the EPBC Act in 2010 (TSSC 2010). The species is considered to be endangered in Victoria as it has been lost from six localities in the past 30 years and has exhibited a decline in area of occupancy of approximately 45%. In Tasmania, the species exhibited a contraction from 16 to two sites and > 99% reduction in capture per unit effort. Recently the species has been recorded at 5 sites on Flinders Island, which now is the single representative population. While more than 95% of the New Holland Mouse's range occurs from the mid- and north coasts of NSW, to north of Toowoomba, Queensland little is known regarding the status of populations, but they are likely to be highly fragmented at a local scale.

4.2 Victoria

In Victoria, remote camera surveys between 2015 and 2018, detected the species in just five out of 12 previously occupied parks and reserves (Burns 2020) and systematic retrapping (2013-2018) at sites in the Eastern Otway ranges (Wilson and Garkaklis 2013, 2014, 2015; Wilson *et al.* 2018, 2020) failed to detect the New Holland Mouse from 42 survey sites, 17 of which the species had been recorded at previously (1970 – 2002).

New Holland mouse was assessed under the *Flora and Fauna Guarantee Act 1988* Threatened Species Assessment (2021). Based on IUCN Criteria the species is eligible as **endangered** in Victoria. The Extent of Occurrence (EoO) across the taxon's range is estimated to be 3,107 km², and the Area of Occupancy (AoO) 204 km², based on accepted, post-1970 records from the Victorian Biodiversity Atlas. The taxon is estimated to be severely fragmented and is estimated to have 3 locations. It has a continuing decline in extent of occurrence, area of Occupancy, number of locations and mature individuals.

Considering the limited dispersal ability of the taxon, the barriers to dispersal, or lack of habitat separating them, the individuals can be considered to be severely fragmented. Most subpopulations are now fragmented by historic clearing, rendering them vulnerable to the effects of inbreeding and unable to recolonise following stochastic events.

The number of mature individuals is estimated to continue to decline, and the number of mature individuals in each subpopulation is between 51 and 250. Monitoring indicates that populations in Providence Ponds and Wilsons Promontory have declined recently and may continue to in future.

Victorian populations of the Pookila have relatively low heterozygosity and are at risk of inbreeding, with no natural gene flow possible between locations (Burns *et al.* in prep. Emily Roycroft pers comm 2022). Populations across New South Wales represent greater heterozygosity and are distinct from those in Victoria, although animals in Broadwater National Park appear to have undergone a genetic bottleneck (Burns *et al.* in prep.). Genetic mixing within Victorian populations has been recommended and is being pursued (Zoos Victoria), while no immediate action is required in New South Wales (Burns *et al.* in prep.).

5. Conservation Actions

5.1 2010

In 2010 the Threatened Species Scientific Advisory Committee recommended direction to implement priority actions and mitigate against key threats (**Appendix 1**).

5.2 2021

As a consequence of the recent significant declines the *National Pookila Recovery Team*, was established (July 2021) with representatives from all states where the species currently or recently has been recorded. The committee is currently chaired by Dr. P. Burns (Zoos Victoria) with Coordinators: M. Broadway, Dr S. Carrizo (Zoo and Aquarium Association). *The National Recovery Plan for the Pookila* is being drafted 2022-23. The National Pookila Recovery Team has the responsibility of advising, coordinating and directing the implementation of recovery actions outlined in this recovery plan.

The plan considers the conservation management of the species across its national range and identifies the actions to be taken to ensure the species' long-term viability in nature, and the responsible agencies that will undertake those actions. It has a vision to halt the species decline and to expand it into historically occupied sites through assisted colonisations and recovery of extant populations. The plan aims to improve understanding of the species' habitat requirements, threatening processes and management priorities. It also aims to engage Traditional Custodians in the recovery process, and knowledge and skills sharing and the public and communities, so the species is appreciated and actively supported by conservation initiatives.

The main threats to the Pookila include those listed above. However, more research is required to understand the severity of and interactions among threats, and how these threats vary across the species' range.

The major objectives of the plan are to;

- Conduct reintroductions to the historically occupied range
- Manage genetic health of species across populations through captive breeding programmes and translocations
- Identify key habitat requirements; manage habitat for those requirements and for current and emerging threats including:
  a) Identify and manage for key habitat requirements;
  b) Understand fire regimes in various contexts across range, develop location-specific fire management plans;
  c) Identify current and projected impacts of climate change; develop current and future management plans to mitigate those impacts;
  d) Understand and manage for the impacts of *Phytophthora cinnamomi*.

- Understand and effectively manage for the impacts of invasive species
- Design and implement ongoing monitoring programmes using best-practice methods and allowing collaboration and information sharing across jurisdictions
- Engage Traditional Custodians in the management and recovery of the Pookila
- Increase community awareness of and appreciation for the Pookila and engagement with recovery efforts

5.3 2022

In 2022 the New Holland Mouse was identified as one of the 21 priority mammal species found across a range of Australian environments under the Threatened Species Action Plan (2022 -32).

Priority actions identified included:

- Identify and protect known New Holland Mouse habitat, as well as areas of open heathland, open woodlands with heath and vegetated sand dunes where the species may occur.
- Feral cat and fox control.
- Determine appropriate severity, scale and interval of fires, then implement fire management to create a mosaic of habitat at different successional stages.
- Ensure that currently or recently occupied habitat is protected from disturbance by development or other land use change.
- Limit the spread of *Phytophthora* (eg. through implementing hygiene practices).
- Maintain existing and establish new captive breeding subpopulations, consider translocations into southern parts of range where populations have been disappearing.
- Raise community awareness in communities near New Holland Mouse habitat, to reduce mortality from 'mistaken identity' with house mice.

6. Genetic diversity of the Pookila

High level sequencing of NHM samples from across its Australian distribution have recently been undertaken at Australian National University (Burns *et al* in prep, Roycroft *et al* 2022-23). The results show that NSW/QLD populations are closely related and have deep divergence in their phylogeny compared to Victorian populations. This is supported by the fact that there is a large geographical gap between the known records in Victoria and NSW. Another significant result was the finding that the Broadwater National Park, NSW population is genetically separate from other NSW populations.

In Victoria the Wilsons Promontory population has unique genetics from the remainder of the Victorian populations, and sampling suggests individuals are more closely related than siblings and cannot be paired in captivity.

Two key strategies arising from the work are: Genetic rescue is required among the Victoria populations; the northern and southern clades of the species should be treated as separate units.

6.1 Victoria

Following research on the distribution and decline of New Holland Mouse (Wilson 1982-1991) the species was listed as endangered under the Flora and Fauna Guarantee Act 1988 (1991). A State Recovery Team was established in 1995 (NRE (State, Regions), Parks Victoria, Royal Botanic Gardens (RBG), ZPG Board, Gippsland Water, FNCV, MSGV, Deakin University) and an FFGA Action Statement-(Recovery Plan) published in 1996. The Recovery Team held regular meetings; developed funding submissions (e.g. ARC) with Deakin University (Wilson *et al. 2001*), initiated establishment of a captive breeding colony at Deakin University and a reintroduction proposal for Anglesea. The team was disbanded under new approaches to endangered species recovery that devolved all monitoring and research to regions (ABC Actions 2004) and include an assessment of the requirements of, and potential for, translocating animals from other sites to Anglesea, in the possible absence of a captive breeding program.

New Holland mouse has been one of Zoos Victoria's focal species since 2009 and is a key part of *Zoos Victoria's Wildlife Conservation Master Plans (*2014-19), (2019-24).

In response to the species' rapid decline and genetic risks, a captive breeding program for the Pookila was established at Melbourne Zoo and Moonlit Sanctuary in Autumn 2022. Twenty-two mice (11 pairs) were obtained from Gippsland Lakes Coastal Park, west of Loch Sport, Yanakie Isthmus, Wilsons Promontory National Park, The Lakes National Park, Providence Ponds Flora and Fauna Reserve and Dutson Downs. Pairing of animals was based on their genetics and behaviour, as well as some same location pairs. The program had its first breeding season in December 2022. Captive bred animals from these founders will be released to suitable habitats.

The first release will establish an insurance population of Victorian Pookila (New Holland Mouse) at Cranbourne Botanic Gardens, where a population of the species was recorded previously until about 1976 (Braithwaite and Gullan 1978). Cranbourne now has a cat proof fence and very low levels of foxes. The program would involve a semi wild reintroduction involving the release of a certain number of animals, supplemental feeding and the installation of artificial burrows. The initial release is planned for Autumn 2023, pending breeding outcomes, with ongoing population monitoring and management into the future.

7. Distribution and status of New Holland Mouse in the Otways

7.1 Distribution

The records of New Holland Mouse in the Otways are restricted to the eastern Otways (Figure 3). The species was first located in west of the Alcoa mine area (Kentish 1982, 1983) and subsequently following the 1983 "Ash Wednesday" wildfire to the east of the mine area along Forest Road and Flaxbourne Road (Wilson *et al.* 1990; Wilson 1991). The species was located along Harrison Track in and further populations in the Forest reserve the 1990s (Wilson 1991, Lock 1995, 2005). There are limited records available for the species in the Otways (114) (Wilson *et al.* 2021 a) spanning 1981 - 1995 (Figure 3). However, we know the species persisted naturally in the eastern Otway area until 1999, and subsequently with a reintroduction attempt to 2003. Unfortunately, some primary trapping records e.g., 1996-2001 (Lock 2005) have been lost. The known records do indicate an extremely limited distribution (Figure 3) predominantly in Heathy woodlands (86) and Riparian scrubs, Heathy woodlands (22) to the east and west of the Anglesea River and Lowland Forests (5) on the eastern plateau of the Anglesea Heath along Forest Road. (Figures 4, 5, 6).

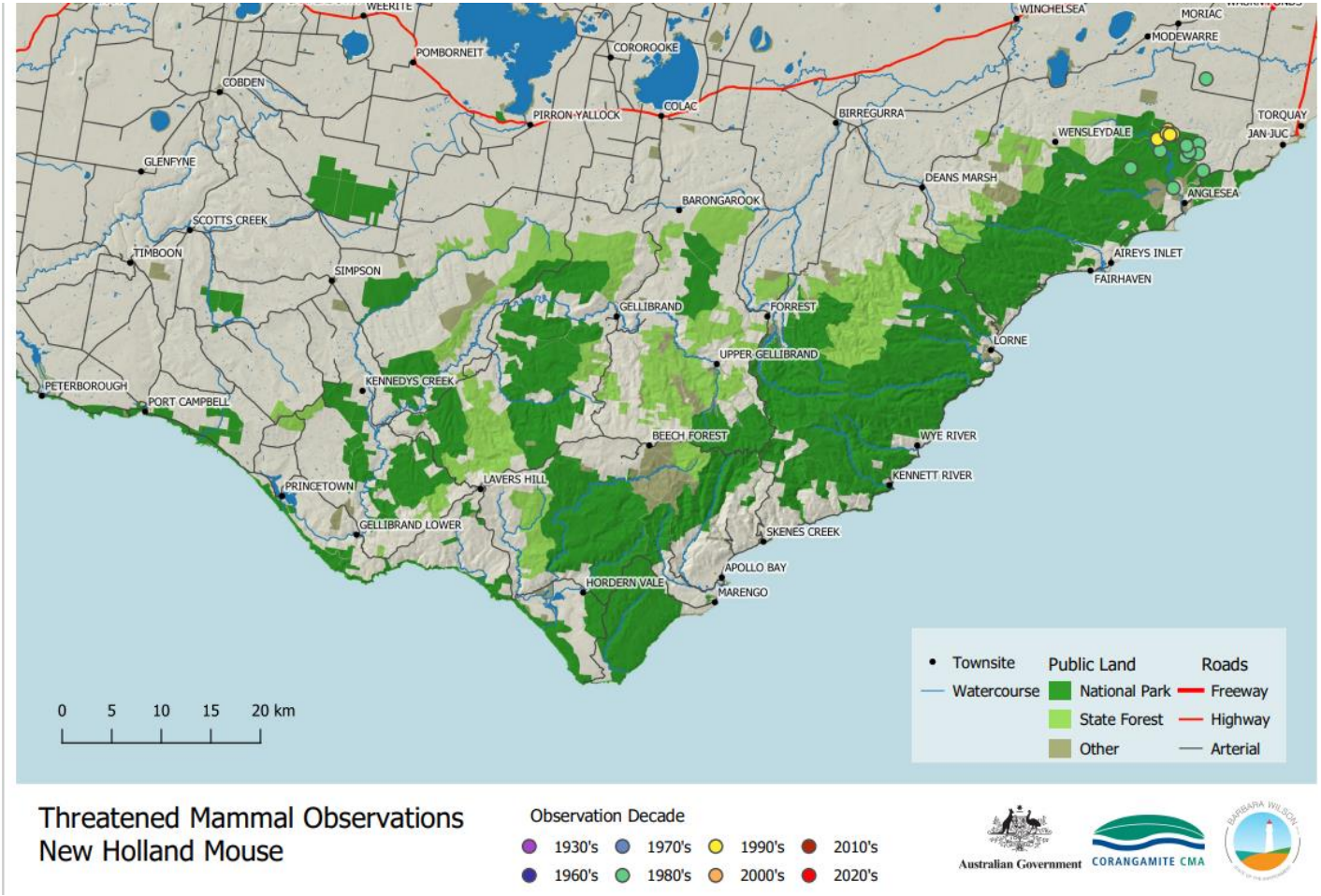


Figure 3. ***Records of NHM occurrence across the Otway Ranges 1957 – 2021 (Wilson et al 2021a).***

Figure 4. ***Distribution of observation records of new Holland Mouse in EVCs across the Otways (Wilson et al. 2021b)***

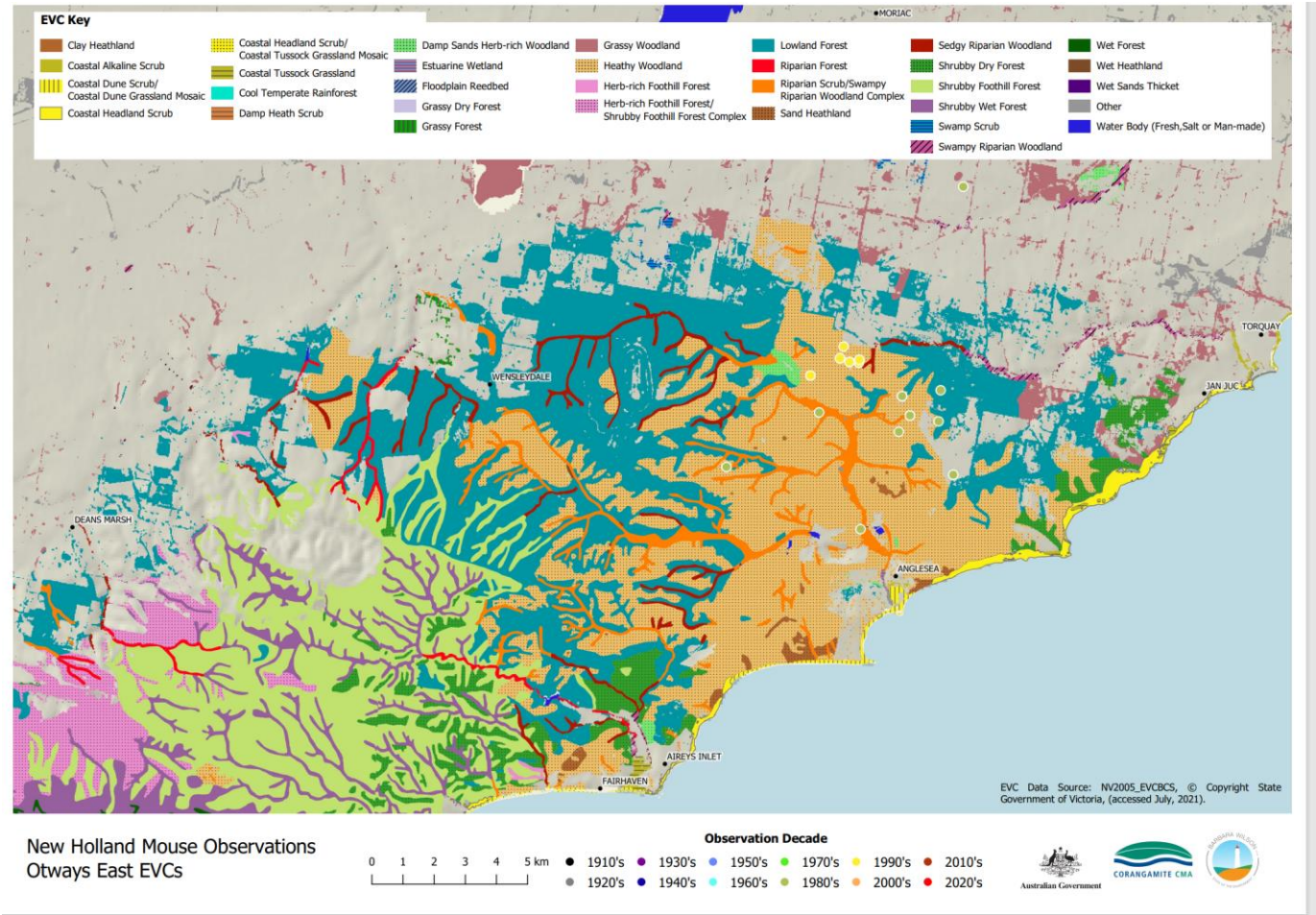


Figure 5. ***Distribution of observation records of New Holland Mouse in EVCs across the Otway east (Wilson et al. 2021b)***

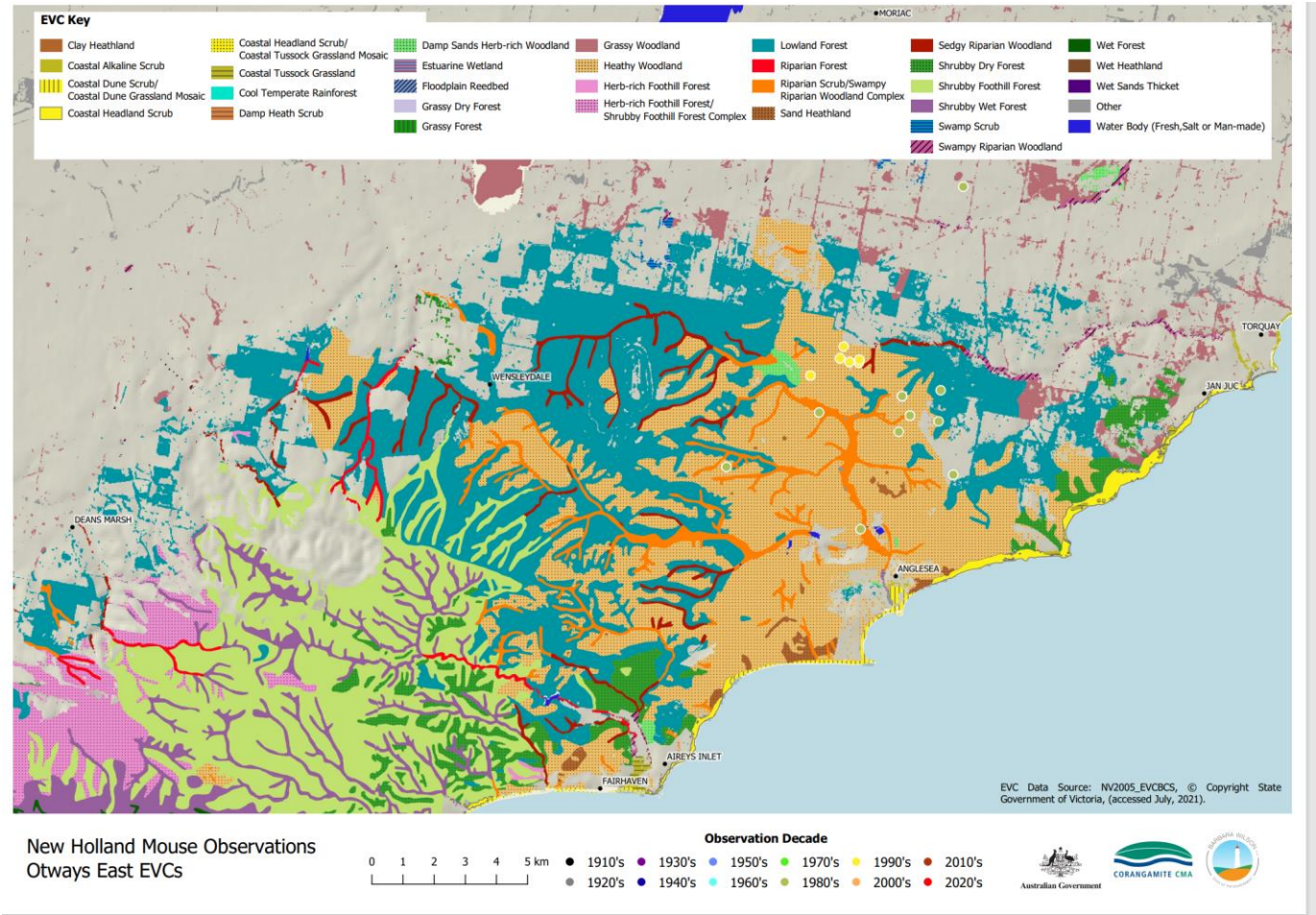


Figure 6. ***Distribution of observation records of New Holland Mouse in EVCs across the Otway east (Wilson et al. 2021b)***

Figure 7. ***Habitat of NHM in EVCs across the Otways 1a) Heathy woodland Coalmine Road Sept. 1983; 1b 1986; Flaxbourne road 20121 b) Forest road 2013***

7.2 Historical research and information

Long-term research investigating the reproduction, population ecology and captive breeding of the New Holland mouse has been conducted in the eastern Otways since 1981 (see **1. Introduction**, Table 1); (Kentish 1982, 1983; Wilson *et al.* 1990; Wilson 1991, 1994, 1996*a*; Lock and Wilson 1999, 2017; Lock 2005). Trial reintroductions were undertaken (2002 -2003) to develop techniques and protocols involving soft release from enclosed pens (Tidey 2003; Gibson *et al.* 2004). Studies on the species ceased after the trials.

Table 1: General description of long-term studies for Pookila, New Holland Mouse.

Table 1. General description of long-term study sites for *P. novaehollandiae*
Ecological vegetation divisions are from Cheal (2010); vegetation structure is from Specht (1981)

Location	Distance inland (km)	Altitude (m)	Topography	Soils	Ecological vegetation divisions and vegetation structure	Dominant species
Coalmine 16	2	75	Hillside well drained	Sandy, loam	Heathland, Low woodland.	*E. baxteri*, *E. radiata* (7 m), *L. juniperinum*, *L. myrsinoides*, *A. myrtifolia*, *A. suaveolens*, *B. marginata*, *P. obtusangulum*
Coalmine 17	2	50	Lower hillside, depression	Sandy, loam	Heathland, Low woodland, scrub.	*E. radiata* (7 m), *L. juniperinum*, *L. myrsinoides*, *E. impressa*, *A. suaveolens*, *B. marginata*
Forest	5	100	Flat to undulating	Sandy gravel, loam, clayey quartz	Heathland, Low open-forest, scrub.	*E. obliqua*, *E. willissii* (7–11 m), *E. impressa*, *A. pycnantha*, *A. myrtifolia*, *L. juniperinum*, *L. myrsinoides*, *G. radula*, *L. semitieres*
Pipeline	4	70	Undulating	Clayey silt to fine sand	Heathland, Woodland, scrub.	*E. obliqua*, *E. willissii* (7 m), *X. australis*, *P. esculentum*, *G. radula*, *L. juniperinum*, *L. myrsinoides*, *L.semitieres*, *E. impressa*, *B. marginata*, *D. glaberrima*
Harrison	6	0	Hillside	Loamy coarse sand	Heathland, Low woodland, scrub.	*E. obliqua*, *E. willissii* (7 m), *L. myrsinoides*, *E impressa*, *H. fastigiata*, *D. serricea*, *C. restionacea*
Flaxbourne A	6	100	Flat	Loamy, sand	Heathland, Low open-forest 20–25 m.	*E. obliqua*, *A. myrtifolia*, *A. serrulata*, *B. marginata*, *G. ecostatum*, *L. virgatus*, *L. filiforme*, *G. radula*, *L. continentale*
Flaxbourne B	6	100	Flat	Loamy, sand	Heathland, Low open-forest 20–25 m.	*E. obliqua*, *E. aromaphloia*, *A. pycnantha*, *L. filiforme*, *L. continentale*, *B. marginata*, *H. riparia*
Flaxbourne C	6	100	Flat	Loamy, sand	Old pine plantation.	Felled *P. radiata*, *E. aromaphloia*, *L. scoparium*, *L. continentale*, *L. filiforme*, *G. radula*, *A. myrtifolia*, *A. serrulata*, *H. stricta*, *P. obtusangulum*
Flaxbourne D	6	100	Flat	Loamy, sand	Old pine plantation.	Felled *P. radiata*, *E. aromaphloia*, *L. scoparium*, *L. continentale*, *L. filiforme*, *G. radula*, *A. myrtifolia*, *A. serrulata*, *H. stricta*, *P. obtusangulum*

The research found that populations were extant for 1–6 years and were predominantly small, localised and extinction prone (see Figures 7, 8) (Lock and Wilson 2017; Wilson *et al.* 2018). High-density populations occurred after above-average rainfall but declined precipitously during drought (Figure 8). Wildfire resulted in the extirpation of some populations, while others survived in unburnt refuges. The results revealed that post-fire vegetation (3–7 years) contemporaneous with above average rainfall delivered productive habitat resulting in both a population irruption, and recovery after wildfire (Lock and Wilson 2017; Wilson *et al.* 2018).

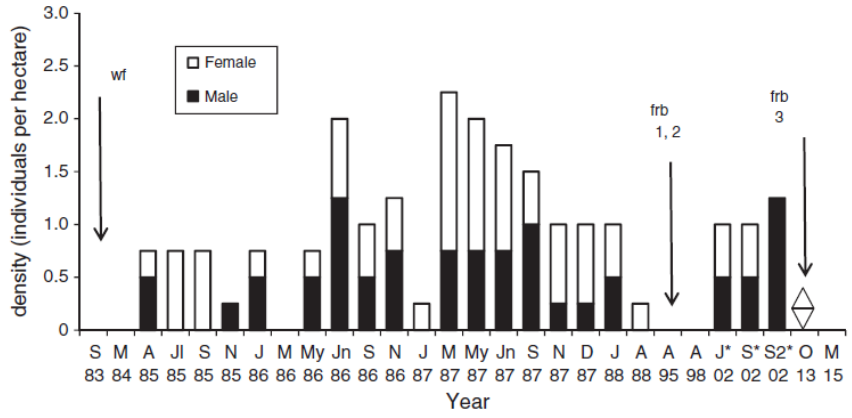
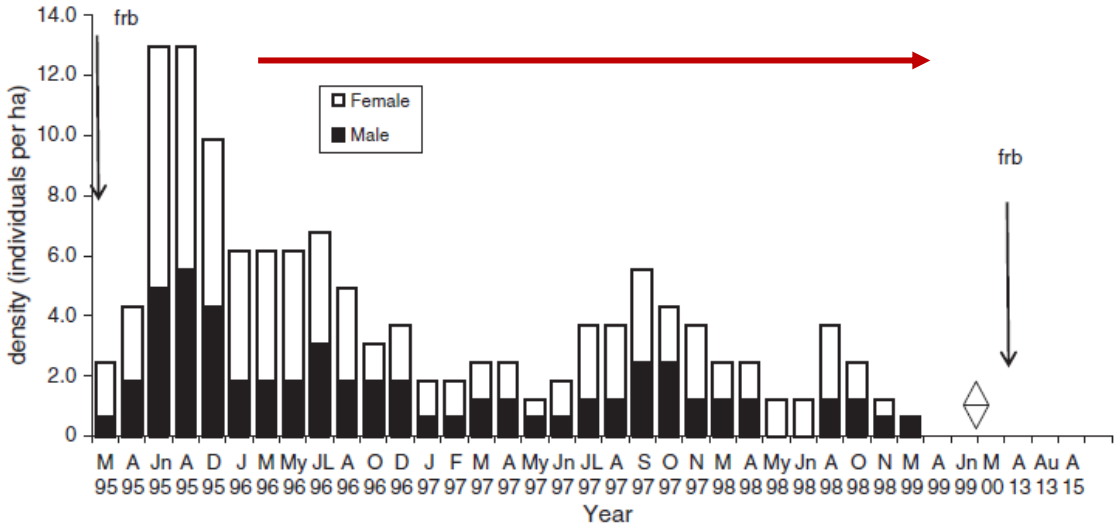
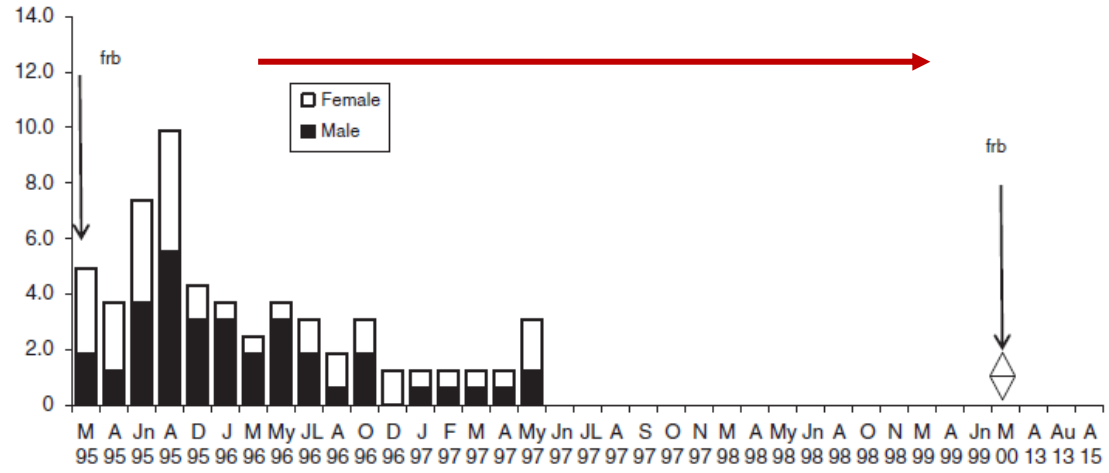


Figure 8. ***Population density of P.novaehollandiae on Forest Road grid 1983 -2015; wf wildfire; frb, fuel reduction burn * reintroduction; ◊ not trapped 2003 -12***



Population density of *P. novaehollandiae* on Flaxbourne Grid A between 1995 and 2015. frb, fuel reduction burn (1988, 2001); ◊, not trapped 2001–12.



Population density of *P. novaehollandiae* on Flaxbourne Grid B between 1995 and 2015. frb, fuel reduction burn (1988, 2001). ◊, not trapped 2001–12.

Figure 9. ***Population density of P.novaehollandiae on Flaxbourne Road. Red arrow represent period of Millenium drought***

All long-term New Holland mouse sites were burnt in the 1983 "Ash Wednesday wildfire". Fuel-reduction burns were conducted subsequently on the Forest site (1993, 1998, 2011), at the Pipeline site (2001) and at the Flaxbourne grids (1988, 2002, 2013). A wildfire burnt the Harrison site in 2009.

There was little burning of heathland vegetation in the eastern Otways between 1970 and 2005 apart from the 1983 wildfire (Department of Environment and Primary Industries 2013). The total area burnt between 1987 and 2008 (21 years) was 2266 ha (mean = 107.9 ha per annum), and between 2009 and 2012 (3 years) was 3095 ha (mean = 1031.67 ha per annum) (Department of Environment and Primary Industries 2013), a 900% increase in the area burnt annually.

The long-term average annual rainfall in the eastern Otways 1950 – 2016 was 664mm (Figure 9). Rainfall in 1982 (403 mm), the year before the 1983 wildfire, was the lowest recorded over a 36-year period (1968–2004) (Bureau of Meteorology 2015). Rainfall from one to eight months after the wildfire was higher than the monthly average (>80 mm), and in the first three years (1983–85) was greater than the annual mean resulting in significant regeneration of vegetation and small mammal fauna (Wark *et al.* 1987, 1996, 1997, 1999; Wilson 1990, 1991, 1994; 1996a, 1996b; Wilson *et al.* 1990). Above-average rainfall was recorded (1990–93), while record levels of annual deficit and accumulative declines occurred during the 'millennium drought' (1996–2010) (Figure 8) (CSIRO and Bureau of Meteorology 2015). Between 2010 and 2013 annual rainfall was average; however, in 2014 and 2015 it was extremely low.

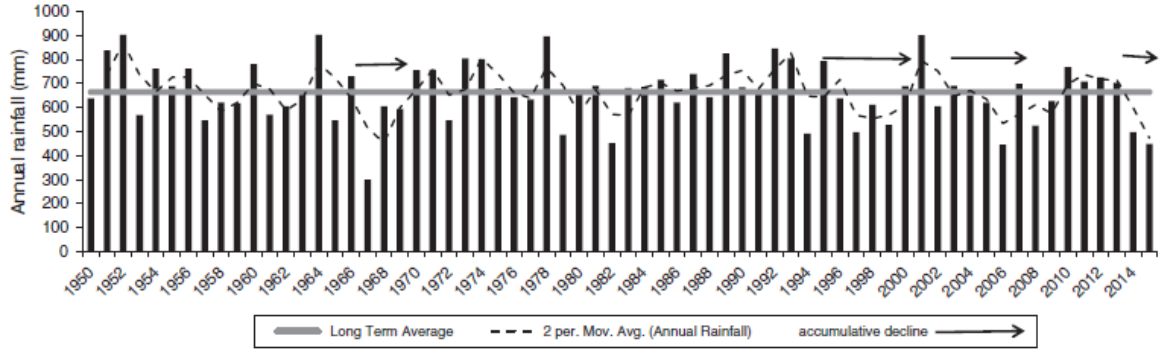


Figure 10. ***Annual rainfall, moving average and long-term rainfall in the eastern Otways 1950 -2016.***

Optimal habitat for the recovery and management of New Holland mouse in the eastern Otways has been identified through habitat modelling (Figure 10) (Wilson *et al.* 2015). The strongest model identified strong relationships between the presence of New Holland Mouse with topography, proximity to the coast and aspect. The relationship with topography and proximity to the coast are likely to be related to the presence of soils of a remnant lateritic plateau that is suitable for constructing burrows, and the relationship with aspect to represent sites that are warm to cool. Although the proportion of potentially suitable habitat predicted in the entire area was low (3252 ha) it was similar to the area estimated as possible New Holland Mouse habitat (4000 ha) by Wilson (1996), however the distribution of the habitat predicted by the model was very different. Previously the main area considered to be suitable was that located southwest of known population locations. The model predicted additional areas to the north-west and east, on land that was not previously considered as suitable habitat. The New Holland mouse habitat was in small patches. This modelling predicted additional habitat in areas that were not previously considered as suitable for New Holland mouse (Wilson *et al.* 2015). This habitat represents refuge habitat for the species. The study provides fundamental information to protect key habitat; to undertake systematic surveys for new populations and to implement appropriate fire regimes and reintroductions.

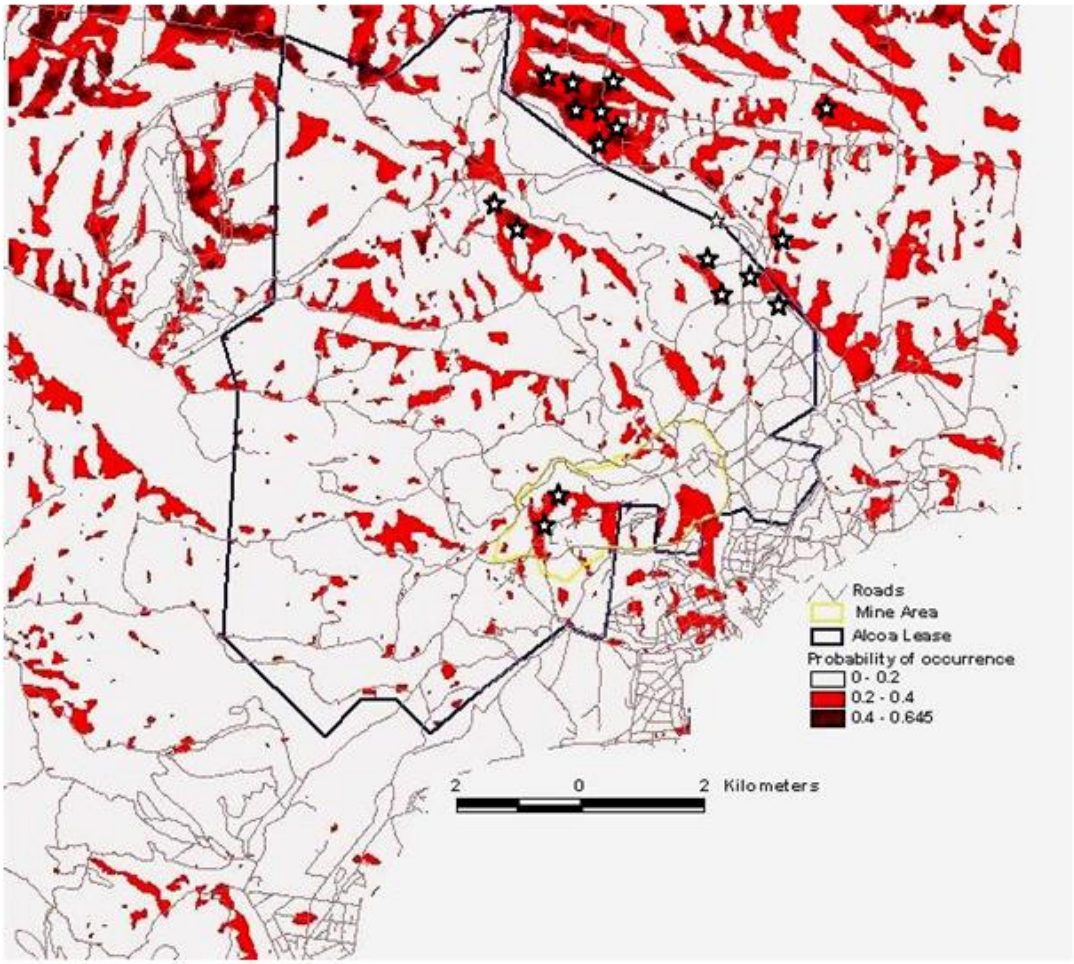


Figure 11. ***Habitat model for P.novaehollandiae in the eastern Otways showing the probability of occurrence (Wilson et al. 2015).*** ☆ ***site presence of New Holland mouse***

As no monitoring or research was conducted on New Holland mouse in the eastern Otways for 10 years (2003 - 2013) the status of the species was unclear and required reassessment. A project supported by Parks Victoria investigated the species' current distribution and status compared with previous records however the species was not recorded during this time (Wilson and Garkaklis 2014, 2015, 2016).

Subsequently this work was extended to assessing the species across the Otways landscape under the WOI Project 4: "Conserving threatened small mammals in the Otway Ranges, Bells Beach (Ironbark Basin) and Great Ocean Road hinterland". Overall, the surveys under both these programs (2013 – 2023) involving > 400 camera trapping sites and >120 live trapping sites has failed to record New Holland mouse in the Otways. The species persistence is considered now to be highly unlikely, and its future likely is contingent on captive breeding and reintroductions as outlined as major objectives of the '*National Recovery Plan for the Pookila (New Holland Mouse)*'. Any reintroductions would require intensive management of populations, habitats and threatening processes.

5. Management guidelines and actions to support recovery of New Holland mouse (Koornam) in the Otways Ranges

8. Otway Ranges Pookila (New Holand Mouse) Recovery Actions

The following guidelines for the recovery of New Holland Mouse in the Otways are developed in support of the draft '*National Recovery Plan for the Pookila (New Holland Mouse)* and contribute to its objectives and actions to ensure the species' long-term viability.

8.1 Conduct reintroductions to the historically occupied range and other areas of suitable habitat

An assessment of 'Rewilding' threatened species in the Otway Ranges identified New Holland mouse as a species suitable for reintroductions (Park *et al.* 2021). The assessment considered the current conservation status) in the Otways, the IUCN and/or EPBC listing and the decision criteria in the Procedure Statement for the Translocation of Threatened Native Fauna in Victoria (DELWP, 2019).

New Holland mouse was recently extant in the eastern Otways (2003) and the habitat that was occupied is likely to provide a significant role as part of the national recovery plan for reintroductions. It is possible that other areas of suitable habitat across the Otways may also be appropriate for reintroductions.

Reintroductions in the Otways would be significant as they would contribute to an emergency response strategy to future catastrophic events (e.g., wildfire) by spreading the risk of population losses across the national distribution but particularly in Victoria. The increasing scale, intensity, and frequency of fires under a changing climate (CSIRO and Bureau of Meteorology 2020) pose a risk to the Pookila and its habitat as was experienced during the east coast Black Summer fires (2019-2020) where the species suffered a 75% decrease in abundance in severely burned areas (Legge *et al.* 2021). Reintroductions would also be important as part of the recovery plan to manage genetic health of species across populations through captive breeding programmes and translocations (see below). Reintroductions of *Koornam* also are of significance as part of cultural on country management of TOs (Wadawurrung)

There are a number of options for reintroductions including predator free fenced areas, soft releases (nest boxes/refuge tunnels and supplementary feeding stations) and free reintroductions. Options, protocols and methods will be informed by current trials being undertaken by Zoos Victoria (Cranbourne Botanic Gardens) previous trials at Anglesea (Tidey 2003; Gibson *et al.* 2004) and trials at Mulligans Flat (Abicair *et al.* 2020; Smith *et al.* 2022). Cost benefit analyses of options would be required. The cost benefit of predator free fenced areas in the Otways should include other threatened species that have overlap in habitat preferences (e.g. Swamp antechinus, Southern Brown bandicoot, Long-nosed potoroo, White-footed dunnart). Of significance is the recording of Swamp antechinus and New Holland Mouse within 100 m of each other where the first record of NHM in the Otways was documented (Kentish 1982, 1983). The New Holland Mouse was recorded in heathy woodland located upslope and the Swamp antechinus downslope in wet swampy heath.

8.2 Identify suitable habitat and key sites for reintroductions

An initial priority would be to identify and assess suitable habitat and key sites for reintroductions across the Otways. This would include desk and on ground assessments informed by the detailed local habitat model in the eastern Otways (Wilson *et al.* 2015) and a Victorian wide Habitat SDM (Liu *et al.*

2013, Burns *et al. pers comm*). The latter has extended the area for assessment of Koornam habitat further west in the Otways and totals approximately 63,400 hectares.

In this process the Priority Protection areas identified under the WOI program (Walshe *et al.* 2021) should be assessed to identify the availability of suitable NHM habitat. Six of these areas were identified across the Otways for Protection of Commonwealth listed species including New Holland Mouse. Management within these areas to prevent the introduction of *Phytophthora cinnamomi* into critical habitat areas and reduce the impact of infection at priority sites utilising phosphite application is underway (see below)

Following these initial assessments, it would be necessary to undertake detailed vegetation and habitat suitability assessments (e.g., vegetation floristics and structure, and soils). Significant data and analyses from sites where the species was extant in the eastern Otways provide a strong base for comparison (Kentish 1982, 1983; Lock and Wilson 1999, 2017; Wilson 1990, 1991, 1994; Wilson *et al.* 1990; Wilson and Laidlaw 2003, Slattery 1998, Lock 1998, 2005; Williamson 2015).

8.3 Manage habitat for reintroduction sites, current and emerging disturbances, and threats

8.3.1 Impacts of fire and fire management

There is a need to understand the response of NHM to previous fire regimes across the Otway ranges and develop location-specific fire management plans in preparation for reintroductions.

In temperate south-eastern Australia, rodent population dynamics have been strongly associated with the structure and floristic composition of habitats and with fire regimes (Catling 1986; Fox 1996; Fox and Monamy 2007; Arthur *et. al.* 2012). Different species recolonise recovering burnt areas at different rates and recovery has been related to variables such as fire intensity and species' habitat requirements (Newsome et al. 1975; Catling and Newsome 1981; Fox and McKay 1981; Fox 1982, 1983, 1990; Catling 1991). The rate of recovery of vegetation, not time *per se*, has been proposed as the most important factor (Monamy and Fox 2000; Fox and Monamy 2007). Rainfall and drought also impact population dynamics in temperate communities.

Previous research found that NHM increases in abundance in habitat regenerating after fire to reach a maximum between 2 and 8 years (Braithwaite and Gullan 1978; Fox and Fox 1978, 1984; Kemper 1990; Wilson *et al.* 1990; Lock and Wilson 1999, 2017).

In the eastern Otways the 1983 Ash Wednesday wildfire resulted in the extirpation of some populations, while others survived in unburnt refuges (Wilson 1991, Wilson *et al.* 1990; Lock and Wilson 1999, 2017). Analyses of populations revealed that time since fire (TSF) vegetation (3–7 years) contemporaneous with above average rainfall delivered productive habitat resulting in a population irruption (Lock and Wilson 2017; Wilson *et al.* 2018). In the eastern Otways *P. novaehollandiae* response to fire is related to preferences exhibited by the species for specific vegetation structure and floristics (Wilson 1991; Wilson and Laidlaw 2003). If the rate of recovery of vegetation, not time *per se* is the most important factor for population recovery then TSF may not be similar across the region or for fire events, and recovery may more strongly be related to rate of recovery. Rainfall and drought also strongly impact population dynamics of NHM in the Otways. There is thus a need to assess fire regime suitability for NHM across the Otways.

Significant data and analyses from sites where the species was extant in the eastern Otways provide a strong base for comparison to current conditions (Kentish 1982, 1983; Lock and Wilson 1999, 2017;

Wilson 1990, 1991, 1994; Wilson *et al.* 1990; Wilson and Laidlaw 2003, Slattery 1998, Lock 1998, 2005; Williamson 2015). Long term vegetation changes in known NHM habitat are available from recorded data (Forest Road, Flaxbourne Roads 1995-2000-2015) in relationship to fire histories Otways (Lock and Wilson 1999, 2017; Wilson 1990, 1991, 1994; Wilson *et al.* 1990; Wilson and Laidlaw 2003, Slattery 1998, Lock 1998, 2005; Williamson 2015).

Cultural burning is currently undertaken in the eastern Otways in collaborative partnership between Parks Victoria and Wadawurrung. Extension of this work to implement burning for NHM would continue to build on-ground capacity, monitoring training, data capture, data archive, data presentation and reporting.

8.3.2 Impacts of Phytophthora cinnamomi and management

The plant pathogen *Phytophthora cinnamomi* causes severe declines in Australian native vegetation, including susceptible plant species and communities, fauna abundance and habitats and ecosystem function. The resultant "dieback" disease has been listed as a Key Threatening Process (EPBC Act 1999).

Diseased vegetation infected with *P. cinnamomi* was first observed in the Otway Ranges of southern Victoria in 1972 (Land Conservation Council 1985; Wilson 1990; Wilson et al. 1990, 1997). Dieback disease symptoms have been observed in heathy open forest, heathy woodland, Bald Hills heathland and riparian open forest (Wark et al. 1987; Wilson et al. 1990, 2000, 2003; Laidlaw 1997; Laidlaw and Wilson 1989; Annett 2008).

Long-term studies (26 years) of disease progression and impacts on vegetation floristics and structure have been undertaken in heathy woodland in the eastern Otways (Laidlaw and Wilson 2003; Wilson *et al* 2020). The pathogen significantly affected not only the floristic diversity, but also vegetation structure. There were significant declines in plant species richness and numbers of susceptible species; *X. australis* and increases in percentage cover of resistant sedges and grasses overall, and in cover of *Leptospermum continentale* (prickly tea-tree) in post-disease areas. Structural differences observed included a decline in cover, between 0- and 0.6-m height strata, in diseased vegetation.

Studies on the impacts of *P. cinnamomi* on small mammals found capture frequency was lower in post-disease areas and captures of individual species (*Antechinus agilis* (Agile Antechinus), *Rattus fuscipes*, (Bush rat)*, Rattus lutreolus* (Swamp rat) *Sminthopsis leucopus*) (White-footed Dunnart) were greatest in non-diseased vegetation and were less frequent in areas of diseased vegetation. Radio-tracking studies found that *X. australis* provided important nesting sites for three species; *Antechinus agilis Cercartetus nanus* (Eastern Pygmy Possum) and *Sminthopsis leucopus* (White Footed Dunnart) (Laidlaw and Wilson, 2006; Garkaklis et al., 2004).

The impacts specifically on NHM populations and habitat have not been investigated and are unclear. However, the species is likely be at significant risk due to loss of susceptible plant species e.g. *Xanthorrhoea australis,* vegetation structure and food resources (invertebrates, fungi) required by NHM. The impact of *Phytophthora cinnamomi* in NHM habitat should be assessed by comparison of current and historic vegetation data sets (e.g., Forest Road, Flaxbourne Road - 1995-2000-2015) and infected and uninfected vegetation in identified priority reintroduction sites.

Development of management strategies for *Phytophthora cinnamomi* in NHM habitat, including application of Phosphite need to be developed. In particular, Traditional Owner capacity building and training for on-ground phosphite treatments following on from the inroads made with the Wild

Otways Initiative. This will ensure EMAC and WTOAC have a strong transfer of knowledge, skills and improved capacity to manage threats to the NHM in the landscape whilst addressing specific threats and goals of the WTOAC Paleert Tjaara Dja (healthy country) plan.

8.4 Manage predation by foxes and cats

Predation impacts have not been demonstrated for Pookila but population-level risks are assumed to be substantial. Risks from foxes may be magnified where fire or grazing has reduced ground cover (Hradsky 2020, Hradsky et al 2017). Feral cats may be vectors of novel disease impacting Pookila (e.g. toxoplasmosis spread by feral cats; Lazenby *et al.* 2018; Burns 2020).

The relative impact on the Pookila of predation by feral cats and by foxes is not yet understood. Cats are more likely to prey on small rodents than are foxes (Stobo-Wilson *et al.* 2021). While fox control is in place in parts of the species' range, effective cat control is not yet possible, particularly in Victoria. There is potential that fox control may lead to increased cat density or activity (Risbey *et al.* 2000). Where possible, existing or future fox control programmes in occupied Pookila habitat will be paired with fox, cat, and Pookila monitoring programmes.

8.5 Manage genetic health of species across populations through captive breeding programmes and translocations

The reintroduction of captively bred New Holland mouse in the Otways would support a key strategy to undertake genetic rescue among the Victoria populations. The current Zoos Victoria project aims to improve the viability of small populations and is a recovery and risk-spreading objective. Reintroduction provides an opportunity to extend the extent of occurrence and improve resilience of this endangered species within its indigenous range.

As remnant populations are often small and isolated, this renders them vulnerable to the negative effects of genetic drift and inbreeding. These processes can lead to the expression of deleterious alleles (known as genetic load) and reductions in overall population fitness (known as inbreeding depression). Translocation has a potential role in overcoming some of the issues associated with reduced genetic diversity. Direct genetic intervention (e.g. genetic rescue) can improve gene flow, reducing the genetic load of small populations suffering from inbreeding depression and fitness declines as a consequence of close relatives mating and random genetic drift.

8.6 Increase community awareness of and appreciation for the Pookila and engagement with recovery efforts

There is a lack of knowledge in the community around native rodents including Pookila. There is a need to partner with Zoos Victoria to prepare engaging resources, make presentations, and engage local groups in the area. Organisations like ANGAIR, Friends of eastern Otways, and the Geelong Field Naturalists are well placed to assist with revegetation projects, information sessions and habitat surveys to promote the Koornam in the region.

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THREATENED SPECIES SCIENTIFIC COMMITTEE 2010

Conservation Advice *New Holland Mouse*

Priority Actions

Priority Actions include regional priority recovery and threat abatement actions to support the recovery of the New Holland Mouse.

Regional Planning Approach

- Consider appropriate landscape scale management strategies that take into account appropriate fire regimes, management of predator / prey relationships and the enhancement of landscape function through connectivity, water balance and other related ecological drivers.
- Regional planning to maintain connectivity

Habitat Loss, Disturbance and Modification

- Monitor known populations to identify key threats.
- Monitor the progress of recovery, including the effectiveness of management actions and the need to adapt them if necessary.
- Ensure that fire management is undertaken so that populations have access to appropriate age classes of vegetation and areas of suitable habitat.
- Identify populations of high conservation priority.
- Ensure there is no disturbance in areas where the New Holland Mouse occurs, excluding necessary actions to manage the conservation of the species.
- Investigate formal conservation arrangements, management agreements and covenants on private land, and for crown and private land investigate inclusion in reserve tenure if possible to halt the removal and fragmentation of suitable habitat.
- Control access routes to suitably constrain public access to known sites on public land.
- Suitably control and manage access on private land and other land tenure.
- Manage total grazing pressure in areas known to be utilised by the species
- Consider acquisition of private or leasehold land containing populations of the New Holland Mouse.
- Minimise adverse impacts from land use at known sites.

Animal Predation or Competition

- Implement actions outlined in the Threat Abatement Plan for Predation by Feral Cats and the Threat Abatement Plan for Predation by European red fox for the control and eradication of feral cats and red foxes in areas where the species occurs.

Invasive Weeds

- Identify and remove weeds which could become a threat to the New Holland Mouse, using appropriate methods.
- Manage sites to prevent introduction of invasive weeds, which could become a threat to the New Holland Mouse, using appropriate methods.
- Ensure chemicals or other mechanisms used to eradicate weeds do not have a significant adverse impact on the New Holland Mouse. Animal Predation or Competition
- Implement actions outlined in the Threat Abatement Plan for Predation by Feral Cats and the Threat Abatement Plan for Predation by European red fox for the control and eradication of feral cats and red foxes in areas where the species occurs.

Fire

- Identify appropriate intensity and interval of fire to create patches of habitat of different successions for the New Holland Mouse.
- Implement suitable fire management strategies for the habitat of the New Holland Mouse.
- Where appropriate provide maps of known occurrences to local and state Rural Fire Services and seek inclusion of mitigative measures in bush fire risk management plan(s), risk register and/or operation maps.

Diseases, Fungi and Parasites

- Develop and implement suitable hygiene protocols to protect known sites from further outbreaks of dieback caused by *Phytophthora cinnamomi*.
- Implement appropriate management actions to minimise the adverse impacts of existing *Phytophthora cinnamomi* infestations Conservation Information
- Raise awareness of the New Holland Mouse within the local community through fact sheets/information brochures / field days in conjunction with known industry or community interest groups.
- Engage with private landholders and land managers responsible for the land on which populations occur and encourage these key stakeholders to contribute to the implementation of conservation management actions.