Final Report: Mala Population Viability Analysis and Conservation Planning Workshop

An initiative of the Mala Recovery Team

Lees, C.M. & Bennison, K. (Eds) (2016)

Project collaborators

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The 2015 workshop drew on work done in 2004 and 2009 by the following collaborators: Nick Atchison, Onnie Byers, Dick Frankham, Gary Fry, Chris Hibbard, Richard Jakob-Hoff, Ken Johnson, Caroline Lees, Peter Nunn, Chris Pavey, Vincenzo Repaci, Jonathan Wilcken.

This workshop was an initiative of the Mala Recovery Team and was directed towards objectives identified in the Recovery Plan.

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Content

Executive Summary

The Mala (*Lagorchestes hirsutus*) is a little known but charismatic wallaby, rescued from imminent extinction in the 1980s when the last 22 animals were secured in predator-proof enclosures. The last mainland wild population perished in a wild fire in 1991. Mala numbers remain critically low, dispersed among six predator-free sites, isolated from each other and located in three different States and Territories.

From 3-5 November 2015, the Mala Recovery Team which comprises thirteen people from eight organisations, met to take a national view of Mala management and to identify and agree what it would take to move beyond saving the species from extinction and towards securing its long-term future. The workshop was funded by public donations and was facilitated by the IUCN SSC Conservation Breeding Specialist Group.

The ongoing presence of introduced predators makes it impossible to sustain Mala populations outside fences on mainland Australia. Though an essential conservation tool for the short to medium-term, existing enclosures are considered to have a number of disadvantages: relative intensity of management; tendency for periodic over-population; potential for some relaxation of wild selection pressures; ongoing susceptibility to inbreeding accumulation and gene diversity loss due to small population size. Participants envisaged a long-term future for the species in much larger areas, protected from introduced predators, with sufficient habitat heterogeneity to support genetically viable, demographically self-regulating Mala populations under minimal management.

Recommended priorities for 2016-2017:

Development of:
- mala enclosure carrying capacity indicators;
- appropriate fire regimes for enclosures;
- a plan for Mala movement to promote genetic health;
- base-line health screening for Mala;
- a procedure for assessing toxoplasma risk.

Establish:
- whether Bernier and Dorré Island populations can be included in the meta-population.

Standard Operating Procedures for:
- paddock husbandry and hygiene;
- management of fence breaches.

Develop a proposal for:
- a ‘federal oversight’ role for the recovery team.

In the interim, participants identified a need to improve the viability and resilience of populations at current sites by: 1) formalising and implementing meta-population-wide, best practice management with respect to disease risk, prescribed burning, wild fire prevention and mitigation, vertebrate pest control and maximising/optimising carrying capacity; and 2) instigating regular, strategic transfers between sites to improve gene diversity retention and slow inbreeding accumulation. The cultural importance of Mala to Traditional Owners was recognised. In particular, the persistence and continuity of Mala customs related to cultural harvest are at immediate risk and actions were identified to address this.

Population simulation models built in 2009 using the VORTEX program were reviewed and revised. Based on the information provided models indicate that populations constrained to $N \leq 70$ are vulnerable to decline even in absence of external threats. In general, healthy populations of $N \geq 250$ individuals bounced back from expected external threats (rabbits, wildfire, predator incursion) once removed. Those of $N<250$ could not be relied upon to do so. Further development of models in 2016 will finalise a strategy of inter-site exchanges to support meta-population-wide demographic and genetic viability.

Summary of Workshop Outcomes

50-YEAR VISION*:* *In the absence of introduced predator eradication, there is a secure and resilient Mala population that is genetically viable and has maintained wild behaviours. There is a well-established management system where several large enclosures are spread across the species' ecological and geographical range, allowing for a changing climate, and where Mala traditional knowledge and customs are sustained. Australians are aware of Mala and acknowledge their cultural and ecological values. On ground predator control has produced a situation in which wild release is conceivable.*

THIS VISION WILL BE REALISED WHEN:

At least 3 sites are secured which:

- **are geographically separated (to manage risk);**
- **are representative of former range;**
- **include a mosaic of habitat types (to promote natural population regulation);**
- **will each carry ≥ 1500 Mala;**
- **are accessible for management but require minimal management;**
- **have secure land tenure/long-term conservation covenants.**

Meta-population monitoring and management is in place to:

- **maintain expected 50-year extinction risk at zero;**
- **manage rate of inbreeding accumulation below detrimental levels (<1% per generation);**
- **minimise loss of remaining gene diversity.**

Ongoing support for Mala conservation is secure:

- **the species is present in at least two major zoos;**

IN PURSUIT OF THESE OUTCOMES OUR FIVE-YEAR GOALS ARE:

- To maintain best practice management at all sites:
  - prevent and contain wild-fires
  - use fire to manage for optimal habitat
  - exclude and control rabbits
  - minimise fence breaches and their impacts
- Understand and resolve carrying capacity issues and increase capacity where possible.
- Develop and implement a plan for management of gene diversity and inbreeding.
- Maintain cultural and ecological knowledge.
- Manage disease risk:
  - carry out baseline health assessments
  - implement best practice disease risk management
  - manage Toxoplasmosis

Introduction

A brief history of Mala conservation

Once widespread and common across the inland western half of Australia, the Mala or Rufous Hare-wallaby was important in the cultural and culinary life of Aboriginal people. Its abundance collapsed in the first half of the 1900s. This rapid decline is widely acknowledged to be the result of predation by foxes and cats, with likely contributing pressures such as rabbits, two severe droughts and the concurrent movement of Aboriginal people from their traditional lands to missions, settlements and cattle stations and a consequent reduction in their land management practices such as the use of fire.

By 1978 the mainland subspecies was known to occur only in the Tanami Desert, in two adjacent populations numbering a few tens of individuals in total. An initial five animals from these two populations were brought into captivity in 1980 by the Conservation Commission of the Northern Territory. Wild populations were monitored and after their successful breeding a further 17 animals were added to the captive population over time, with highly successful results.

In partnership with local traditional Aboriginal owners a trial release of 12 captive-bred animals commenced at a site near Lake Surprise in September 1984. A number persisted until a second release of 13 animals in August 1985, but by December no surviving Mala could be found. Predation, and dispersal during very dry conditions were probably responsible.

A bolder method was developed, in consultation with traditional Aboriginal owners, which saw the establishment of a one-square-kilometer predator-proof holding enclosure near Lander River. Between December 1986 and May 1987, 47 hare-wallabies from the Alice Springs captive colony were released into the “Mala Paddock” as it become known. They bred well and between 1990 and 1992, a total of 81 animals were released into the wild from the Mala Paddock. Some of these released Mala survived for up to 18 months and produced young but all eventually disappeared or were killed, largely due to predation by feral cats.

In 1987, one of the two remaining wild populations was wiped out by drying condition and foxes. Tragically in 1991, a wildfire swept through the only remaining wild Mala population, and despite much effort no survivors could be found. The only mainland Mala remaining alive at that time were those in captivity in Alice Springs and in the Mala Paddock at Lander River.

A telling indicator of the potential of introduced predators to wreak havoc in Mala populations occurred in 1997 when a fox gained entry to the Mala Paddock. Before it could be found and removed the fox was responsible for killing 70 Mala.

In 1998 30 Mala plus 11 pouch young were translocated from the Mala Paddock to Trimouille Island off the coast of Western Australia. This was done to establish an insurance population, and has been very successful with the population flourishing and persisting to this day. Two more populations were established in predator-proof enclosures at Dryandra

Woodlands in March 1998 (WA) and Peron Peninsula in November 1998 (WA) with animals from the Mala Paddock.

By 2000 a new 120ha Mala Enclosure had been established at a much more accessible site at Watarrka National Park. The remaining 93 animals were moved from the Lander River enclosure to this new feral-proof site during 2000 and 2001 and the Lander River (Mala Paddock) enclosure was decommissioned. In 2005 a further enclosure was built at Uluru National Park and 24 Mala were moved from Watarrka to this new enclosure. In November 2004 Scotia Sanctuary was established (NSW) and more recently at Lorna Glen (Matuwa) in 2011 (WA) with animals from Peron, Dryandra and Trimouille Island, at the same time the Peron facility was closed.

What remains of the mainland Mala subspecies is currently divided between six predator-proof locations: Trimouille Island (WA), Lorna Glen (WA), Scotia Sanctuary (NSW), Watarrka National Park (NT), Uluru-Kata Tjuta National Park (NT) and those displayed at the Alice Springs Desert Park (NT).

These sites are dispersed among three States and Territories, isolated from each other and managed in different ways. Given the risks present at these sites (wild fire, predator incursion, rabbits, carrying capacity limits, inbreeding depression, disease) it is unlikely that any one of the six remaining populations will persist over the long-term if in continued isolation.

The 2015 workshop

From 3-5 November 2015, the Mala Recovery Team which comprises thirteen people from eight organisations, met to take a national view of Mala management and to identify and agree what it would take to move beyond saving the species from immediate extinction and towards securing its long-term future. Explicitly, the aim of the workshop was to agree answers or estimates to the following questions:

- What does the mainland Mala meta-population look like now?
    - Where are the remaining Mala now?
    - In what numbers?
    - Of what genetic/demographic quality?
    - Under what kind of management?
    - With what potential for growth?
    - With what level of connectivity?
    - Subject to what kinds of risk?
- What should the mainland Mala meta-population look like?
    - Where would we like Mala to be?
    - In what numbers?
    - In what kinds of environments/ecosystems or species assemblages?
    - Of what genetic/demographic quality?
    - Under what kinds of management?
    - Subject to what magnitude of risk?
- How could we get from here to there?

The workshop was funded by public donations and contributions from Federal, State and Territory Governments and the Australian Wildlife Conservancy, and was facilitated by the IUCN SSC Conservation Breeding Specialist Group.

Workshop process

DAY 1: Welcome and introductions

Kerrie Bennison opened the workshop and thanked Chris Pavey and CSIRO for hosting the meeting. Participants introduced themselves, their history and current involvement with Mala, and flagged priority issues that they hoped would be resolved during the three-day workshop. Caroline Lees introduced IUCN SSC CBSG, its philosophy and proposed workshop process.

Presentations

A series of scene-setting presentations were provided to bring participants to a common understanding of the history and current status of the mainland Mala subspecies:

Jim Clayton (Parks Australia): The Mala Story – a quick tour of the decline, rescue and chequered history of Mala conservation action since the late 1970s, past & present distribution and threats.

Chris Pavey (CSIRO): Recovery Efforts - a discussion of the challenges and successes of Mala recovery planning to date.

Neil Thomas & Colleen Sims (WA Department of Parks and Wildlife) (WA sites), Leah Kemp (Australian Wildlife Conservancy), Amber Clarke (Parks and Wildlife Commission of the NT), Scott Pullyblank (Alice Springs Desert Park), Jim Clayton (Uluru): Current Populations – for each existing site, estimated number of Mala present, source and number of founder stock and year of arrival, observed population growth rates (where available), monitoring/management methods, relevant successes and challenges, and any future plans.

Caroline Lees (IUCN SSC CBSG): Population Viability Analysis Tools – introduction to the VORTEX programme, how it works and how it will be used to address key questions about the future of Mala.

Visioning

Following the scene-setting presentations, participants worked to develop a 50-year vision for the future of Mala in Australia. The process began with a brief presentation of the potential value of a vision statement in encouraging broader, aspirational thinking about what it means to save a species, which included some examples of completed vision statements from previous workshops. Participants brainstormed themes and ideas that they wished to include in the vision and a working group was formed to craft these into a draft statement, while others began work on model parameters. At the end of this session participants from the two groups returned to plenary to discuss their work. Following discussion and some modification the vision was agreed as a basis for further work.

Population Viability Analysis: VORTEX parameters

Computer modelling can be a valuable tool for quantitatively assessing risk of decline and extinction of wildlife populations, both free ranging and managed. Complex and interacting factors that influence population persistence and health can be explored, including natural and anthropogenic causes. Models can also be used to assess the relative impact of alternative management strategies, to help identify the most effective conservation actions for a population or species, and to identify research needs. This kind of analysis is commonly referred to as Population Viability Analysis (PVA). One of the goals of the 2016 workshop was to refine a population model for Mala, for use as a tool for exploring population viability under existing conditions, and to evaluate alternative approaches to meta-population management.

A sub-group of participants reviewed the VORTEX model parameters used in a 2009 population viability analysis (PVA) for Mala, which was itself an update of a PVA exercise carried out in 2004, both organised by Gary Fry and colleagues at Alice Springs Desert Park. Changes were made to starting population sizes and carrying capacities, and some site-specific changes were made to female reproductive rates in line with recent observations.

Ideal outcomes

The vision is an aspirational statement designed to elevate thinking and paint a picture of a desired future state for the species. Communicating this in operational terms requires some additional work in identifying operational measures which will allow progress towards the vision to be monitored objectively. Participants worked to identify a series of “Ideal Outcomes”, the achievement of which would signal that the 50-year vision had been realised.

Issue generation

Using the Vision and Ideal Outcomes as a guide, participants identified the full suite of obstacles, threats and issues relevant to moving from the current state of play to the desired future state. The “Rule of 5 Whys” was introduced and used to identify both the root cause of each issue identified and the way in which it acts on Mala populations. A map of the issues identified, their causes and impacts, was created on the wall using sticky notes.

DAY 2: Issue development

Two self-managed working groups were created: one dealing with issues related to management of the meta-population and a second with issues relevant to the management of individual sites.

Group 1. Meta-population management: Kerrie Bennison, Amber Clarke, Brydie Hill, Scott Pullybank, Neil Thomas.

Group 2. - Site management: Jim Clayton, Leah Kemp, Chris Pavey, Colleen Sims, Craig Woods.

Issues that belonged in neither category were dealt with by the wider group on Day 3.

Each working group discussed the subset of issues assigned to it, making sure that each member of the group had the same understanding of the issue. Issues were clumped or split as needed, to improve clarity. For each issue an “Issue Statement” was developed to explain clearly: 1) what the issue is; 2) why it poses a problem for the recovery or conservation of Mala and 3) why it occurs. Once this task had been completed participants returned to plenary to present and discuss their results.

Data assembly and assessment

The next task was to assemble and assess the information available with respect to each of the issues identified. Working groups resumed to consider for each issue in turn: what is known, what is assumed, and what needs to be known or better understood. This exercise helped to identify important information gaps and to ensure that each group was agreed on both the facts and on the assumptions underpinning current understanding of each issue.

Goals

Once data assembly was complete, each working group developed goals for each issue. Goals were aimed at answering the questions, “What and how much should we do about this issue? And by when? Goals were written in the form, “Our goal is to….” Wherever possible and appropriate groups included with each goal a measure or indicator that would allow progress with or completion of the goal to be assessed, and a time-line to indicate when the goal should be completed.

Participants agreed that in the short-term, activities would need to focus on optimising management of existing Mala populations in order to build a strong, productive base from which to move forward towards the broader vision. Most goals were therefore developed with a 5-year time-frame in mind.

Completed goals were brought to plenary and grouped so that they could be directly compared. Participants used sticky dots to prioritise them in terms of 1) overall importance to achieving the vision and 2) urgency.

Actions

Working groups reconvened to discuss the actions or next steps that could be taken towards achieving the agreed goals. For each action participants identified: 1) what needs to be done; 2) who should do it; 3) when it should be done by and 4) what measures or indicators could be used to assess completion.

DAY 3: Summarising, implementation planning and remaining issues

Summarising

Day 3 began with a brief presentation on the work done up to that point: a summary of the current situation; a vision for the future with clearly defined operational outcomes that would signal realisation of that vision; a list of perceived threats, obstacles and issues; and priority goals aimed at addressing them. Modifications to the PVA models were summarised, some preliminary model results were displayed.

This summary was followed by presentation and discussion of the actions developed by working groups at the end of DAY 2. One of the actions involved the development of a genetic management strategy for the meta-population, to slow gene diversity loss and inbreeding accumulation. Additional information was sought to inform follow-up scenario modelling towards this end.

Remaining issues

Some of the issues identified on Day 1 fell outside the remit of the two working groups: Climate Change, Governance and Funding.

Climate change

The situation with respect to likely climate change impacts remains highly uncertain for the arid zone. In the context of that uncertainty securing large, heterogeneous areas within and across the arid zone was agreed to be the best approach at present. The three (minimum) areas identified in the vision were considered to be consistent with this approach. An action was added to ensure that a process is set in place to ensure that three such sites are at least identified within the first 5 years of the programme.

Governance

This is covered under implementation.

Funding

It was reported that some funding has been set aside through Parks Australia, for priority actions arising from the workshop. Also, some funding has been secured to progress some of the pre-existing expansion plans. These sources are a good start but will not cover all of the work needed. This will be a focus of later Recovery Team discussions.

Implementation

Coordinated delivery of the recommended actions will require regular communication and cooperation between site managers. Periodic meetings (either face to face or virtual) were considered important in keeping the network moving forward together and maintaining momentum. Further, it was agreed that meeting with teams working on other arid zone species was valuable in maintaining a landscape view of arid zone ecology and conservation, in identifying synergies, reducing redundancy and making efficient use of available resources. Actions were developed to take forward this recommended framework, prioritising the need to maintain cohesion among Mala site managers. Kerrie Bennison, the Mala Recovery Team Chair has been fulfilling that role to date and will continue to do so for a few months, but will then be taking on a different role and will need to be replaced by another member of the group, to ensure smooth succession.

To help maintain communication and information in the immediate term it was agreed that a CBSG Implementation web-site would be established, through which participants would be able to share materials related to standard operating procedures for site management and other information relevant to the completion of priority actions.

A session was held to prioritise actions for the coming year before the meeting was officially closed.

Vision

For workshop participants, the ideal future scenario would see Mala free-living outside fences. However, as this is possible only in the absence of introduced predators, participants agreed that for short to medium-term planning the vision would be more valuable if premised on existence behind fences or on islands in the first instance. Current Mala enclosures are comparatively small and homogeneous, requiring active management of food and habitat and potentially of abundance. This heavy reliance on human intervention is itself a risk to long-term viability. Over the long-term participants envisaged enclosures encompassing much larger areas, with more heterogeneous habitat structures that would allow for greater natural regulation of numbers and greater potential for animals to move around in response to climate change. Risk management through replication and gene diversity management given the history of bottlenecks in the current population, were also important themes.

The cultural significance of Mala to Traditional Owners was emphasised. There is an urgent need to preserve the dwindling knowledge base that exists in those communities around Mala ecology, customs and traditions. It was also considered important to promote Mala to the wider Australian community.

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- are representative of former range;
- include a mosaic of habitat types (to promote natural population regulation);
- will each carry ≥ 1500 Mala;
- are accessible for management but require minimal intervention;
- have secure land tenure/long-term conservation covenants.

Meta-population monitoring and management is in place to:

- maintain expected 50-year extinction risk at zero;
- manage rate of inbreeding accumulation below detrimental levels (<1% per generation);
- minimise loss of remaining gene diversity;
- minimise risk of disease outbreak.

Ongoing support for Mala conservation is secure:

- the species is present in at least two major zoos;
- long-term funding is secured.

Threats, obstacles and issues

Participants worked to identify the threats, obstacles and issues relevant to achieving the agreed VISION. The full list of items identified, with assumed causal relationships, is shown in Figure 1. Working groups were formed to consider items in more detail, grouping where appropriate. Final grouped issues are shown in Table 1.

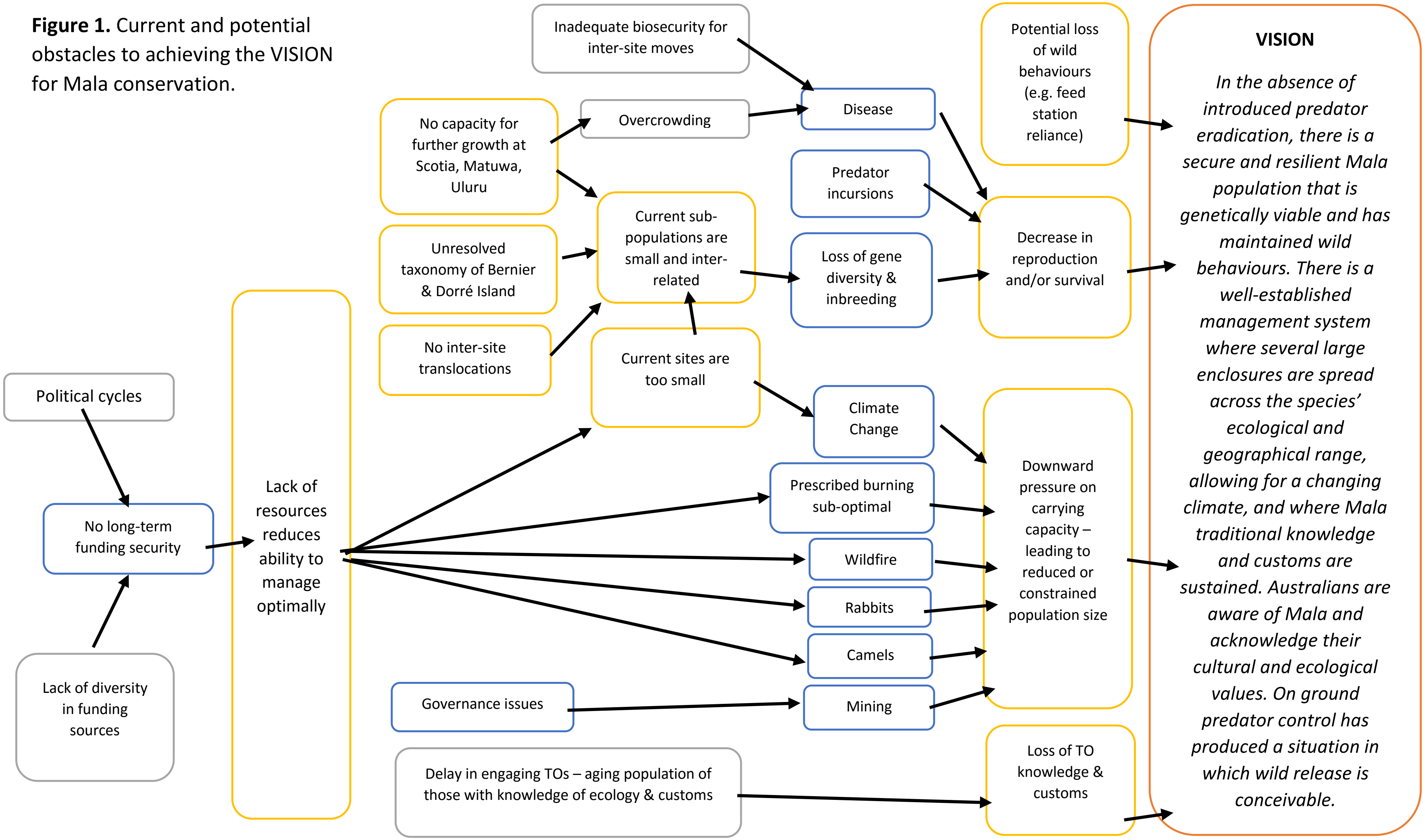
Most of the issues identified fell into one of two categories: 1) site-based management or 2) meta-population management and working groups were formed around these themes. Three items arose that did not sit comfortably in either category: Climate Change, Governance and Funding. These were deferred to plenary discussion on Day 3.

Following the discussion and characterisation of issues, groups worked to identify the facts, assumptions and information gaps relevant to each. The results are displayed in the following pages.

Table 1. List of threats, obstacles and issues worked on by participants.

Threats, Obstacles, Issues	Threats, Obstacles, Issues
Disease	Sub-optimal habitat within enclosures
Overcrowding	Rabbits in enclosures
Potential loss of wild behaviours	Inability to expand populations in existing enclosures
Lack and loss of genetic diversity	Mining
Unexpected catastrophic events	Compromised fence integrity
Wildfire	Loss of ecological and cultural knowledge of Mala

Figure 1. Current and potential obstacles to achieving the VISION for Mala conservation.



Group 1. Meta-population management issues

Disease

Disease is a natural part of the system. It can reduce the number of individual Mala by death or reduced breeding. Currently this can have a large impact on Mala populations due to their small size. Mala can be more vulnerable to disease when under stress. Increased stress can be caused by overcrowding, poor nutrition, poor husbandry and habitat degradation due to poor management. Inadequate biosecurity for inter-site moves can also increase risk of disease by spreading undetected disease from one population to another.

What we know	What we assume	What we need to know
There is a range of diseases in other macropod species.	Large populations can cope with natural ebbs and flows of disease (and smaller populations can't).	Baseline health of Mala populations
Disease can be a natural process	Increased genetic diversity is a safeguard against a catastrophic disease event.	
Toxoplasmosis is an issue in intensively managed macropod populations (including small species)	Mala are susceptible to toxoplasmosis	Level of exposure of Mala populations to toxoplasmosis (via cats)
We have intensively managed populations and there has been no evidence of disease to date.	Managing sites well will reduce stress and therefore decrease vulnerability to disease.	Effects of management strategies on drivers of stress

Overcrowding

Overcrowding causes stress in Mala, reduces the carrying capacity of the site and limits expansion to viable, self-sustaining numbers. Overcrowding is caused by the landscape (or site) not being conducive to self-regulation (not being able to expand is a component of this) and there are no management strategies to deal with overcrowding (neither for individual sites nor for the meta-population as a whole).

What we know	What we assume	What we need to know
Overcrowding causes stress		What are the indicators of carrying capacity?
Overcrowding causes intraspecific aggression	Increases chance of dominant animals being over-represented in the gene pool.	

Overcrowding reduces access to feed and shelter		What is the carrying capacity of each site? What are our options for dealing with populations reaching carrying capacity?
Overcrowding limits population growth	Reduces breeding, recruitment and survival, increases predation by birds of prey	
Overcrowding reduces carrying capacity (habitat degradation)		

Potential loss of wild behaviour

Loss of wild behaviour can reduce the ability of Mala to live in the “wild”. This can be via an inability to find food and shelter, loss of predator avoidance behaviours, changes in social and mating systems. This can result in a reduction of natural selective pressures and increased inbreeding. Loss of wild behaviour can be caused by reliance on human mediated resources, (shelters, food and water), containment (elevated numbers of individuals (changes social systems) and changing interactions with other native species (including predators).

What we know	What we assume	What we need to know
No studies of wild behaviour of Mala on the mainland	In the absence of introduced predators we still have Mala suitable to be put into the wild.	
Mala at Uluru are behaving the same way as described by Geoff Lundie-Jenkins	Lundie-Jenkins’ paper (1993, *Australian Mammalogy*, volume 16(1), pages 29-34) identifies wild behaviour.	
Uluru Mala feed on a combination of provided food and natural food and some do not use provided food at all		
Mala have successfully moved from captivity to being wild on islands within a couple of generations.	Captive animals (in absence of overcrowding) have retained natural predator avoidance behaviour.	

Lack and loss of genetic diversity

Lack (and ongoing loss) of genetic diversity reduces the vigour of a population (survival and reproduction), adaptability (to everything) and increases vulnerability to disease. Caused by a small founder population housed separately in several isolated small populations, unresolved taxonomy and unknown genetic variability within current populations. Populations are isolated because there is no coordinated system for mixing. There is no coordinated system for mixing because there is a perceived lack of knowledge of the current diversity and expertise for decision making to increase diversity and there is no money to implement translocations.

What we know	What we assume	What we need to know
Size of founder population (22).		
There were several significant bottlenecks prior to them being brought into captivity and there have been some since, within populations.		
Loss of genetic diversity results in higher mortality and lower reproduction rates and reduces resilience to disease, to new environments and to catastrophic events, in other species.	That this applies to Mala.	
Some strategies for improving the current situation.		How best to retain our current genetic diversity and if possible increase it.

Unexpected catastrophic events

Unexpected catastrophic events can reduce the number of individuals or potentially the loss of a whole population, this can further reduce genetic diversity see point 4.

What we know	What we assume	What we need to know
These things happen despite best efforts.	These events will not happen at every site at the same time so having Mala at multiple locations will reduce the impact of these events.	
Trimouille Island population has survived cyclones.		
Mala populations behind fences can survive wild fire and predator incursion in the presence of an appropriate management response.	Increasing the size/internal diversity of sites where Mala are present can reduce the impact.	

Group 2. Site management issues

Wildfire

This issue describes uncontrolled wildfires either coming from outside enclosures or generated inside enclosures by lightning strike etc. These events can kill animals and destroy enclosure habitat, temporarily reducing food resources and predator refuges. This in turn can lead to starvation, depressed carrying capacity and constrained population growth rate.

What We Know	What We Assume	What We Need to Know
Extensive wildfire can lead to high immediate mortality (Sangster's Bore last extant population, cf. Watarrka 2002, Watarrka 2013)	Any small population exposed to wildfire is exposed to a high risk of extinction	
Extensive wildfire can reduce habitat quality significantly & reduce carrying capacity (Watarrka 2002, Watarrka 2013)		
Extensive wildfire can lead to high post-event mortality from increased aerial predation (Watarrka 2002)		
Fire return intervals in spinifex grasslands (7-10 years)		We need to confirm the frequency with which fire can return & the influence on this of post-fire rainfall in a range of habitat types as part of the development of site specific predictive fire response models.

Sub-optimal habitat within enclosures

Sub-optimal habitat for Mala inside enclosures can result from sub-optimal fire regimes. This can decrease carrying capacity due to reduced food and shelter, resulting in decreased population size and consequent loss of genetic diversity. Further, it can increase the damage caused by wildfires.

What We Know	What We Assume	What We Need to Know
Spinifex growth stage that provides good refuge for Mala (mature spinifex)		Appropriate fire management for Mala in habitat other than spinifex grassland
The suite of food plants of Mala and what fire management can maximise the availability of these (fire manipulation)		
Effective methods to create fire breaks within enclosures		

Rabbits in enclosures

Rabbits can be ‘fenced in’ when enclosures are constructed or can enter subsequently if the wire gauge is too large. There is also the possibility of them being ‘dropped in’ by birds of prey. Rabbits eat supplementary feed and can attract birds of prey. This can reduce Mala food resources and shelter through direct competition and by suppressing regeneration of vegetation.

What We Know	What We Assume	What We Need to Know
There is a large overlap between Mala and rabbit diet	Presence of rabbits in an enclosure can lead to increased predation pressure on Mala within the enclosure from aerial predators (wedge-tailed eagle)	Is there an acceptable rabbit to Mala density that will enable rabbit management to be minimal (e.g. bi-annual RCD release) without negatively affecting Mala carrying capacity
Having rabbits in an enclosure will reduce carrying capacity for Mala & increase total grazing/browsing pressure	Rabbits can decrease shelter quality for Mala which can increase predation pressure on Mala	Optimal monitoring protocols to detect breaches before they have significant impacts for each site
Fence design (mesh size) to exclude rabbit kittens		

Inability to expand populations in current enclosures

This issue refers to the number of Mala we have in relation to the size of the fenced-off space i.e. this is an enclosure size issue. Mala populations grow within enclosures to a level where there is no longer space for more individuals. This can result in overcrowding and a reduction in the condition of animals. Also, the maximum sizes reached may not be of sufficient size for local viability.

What We Know	What We Assume	What We Need to Know
An enclosure can carry a finite number of Mala while still maintaining near natural behaviours	That our Vision is correct.	How many animals and locations are needed to maintain the Vision.
Current enclosures cannot support the number of Mala required to reach the Vision		

Mining

Mining companies can have precedence over land use, which can lead to uncertainty with respect to the future of any enclosures built near resource deposits. This was considered to be a governance issue.

Compromised fence integrity

Compromised fence integrity can result from poor design, poor maintenance and monitoring, and through camel damage. A compromised fence can allow predator incursion and Mala escape, which can in turn lead to decreased carrying capacity, reduced population size and consequent loss of genetic diversity.

What We Know	What We Assume	What We Need to Know
Best practice fence design	That mammalian predator incursion will reduce the Mala population	Camel-proof fence designs
Despite best practice fence design, breaches of fences will occur for various reasons (camels, human error, inadequate management & monitoring)		Effective life of fences and the maintenance regime required to ensure fence integrity.

Loss of ecological and cultural knowledge of Mala

Delay in the engagement of Traditional Owners, especially senior Indigenous people, can lead to loss of important ecological and cultural knowledge and understanding. Specifically:

1. Loss of knowledge that may assist in the implementation of Mala recovery actions.
2. Loss of intrinsically valuable cultural knowledge.
3. Loss of opportunities (e.g. passing knowledge to tourists).

These impact on the successful management of Mala in direct and indirect ways.

What We Know	What We Assume	What We Need to Know
Ecological & cultural knowledge still exists	Interest in holding knowledge among young people	How best to facilitate the preservation of Mala knowledge
High risk that knowledge could be lost (because of age of knowledge holders)		
Old people hold knowledge in various forms		
In some areas there is a lack of interest among younger people in obtaining traditional knowledge		

Goals

Goals were developed against each of the issues identified. Goals were framed as a desired shift in a state or condition and were written in the form “Our goal is to….” Where groups felt able to do so, each goal was linked to a time-frame and to a specific measure, to allow achievement of the goal to be evaluated. Working groups brought their goals to the plenary discussion. Goals dealing with similar issues were grouped into “themes” and these themes were prioritised by participants (using sticky dots) according to: 1) expected impact on achieving the VISION and 2) urgency. The ranking of “goal themes” is shown in Table 8.

As shown in the table, maintaining good site management everywhere was seen as the single most important goal identified. Initially the individual aspects of site management were scored separately but were amalgamated to enable comparison with other areas of work. The second most important goal related to carrying capacity. This also included a number of items and overlapped in some areas with site management goals, many of which are also aimed towards maximising and stabilising usable space for Mala.

Maintaining cultural and ecological knowledge was considered urgent because some Mala-related customs are now known only to a small number of Traditional Owners and the window for passing on this knowledge is relatively short.

Though disease management scored low on both counts it was still considered an essential aspect of management, especially as the next phase of the project is likely to include regular exchanges between sites, increasing opportunities for any disease to spread across the meta-population.

Table 1: Goals listed with their scores and ranks with respect to 1) Importance and 2) Urgency

Goals	Importance rank (score)	Urgency rank (score)	Overall rank
Maintain good site management everywhere: • **Ensure no extensive wildfires within Mala enclosures** • **Use fire to create optimal habitat for Mala** • **To manage the impact of rabbits in Mala enclosures** • **Manage to minimise fence breaches and their impacts**	1 (14)	4 (5)	1
Understand/resolve carrying capacity issues and increase capacity. • **Establish enough enclosures of sufficient size to achieve vision (at least 3, each holding at least 1500 Mala)**	2 (9)	1(10)	1
Develop and implement a plan for management of gene diversity and inbreeding.	3 (7)	2 (8)	2
Maintain cultural/ecological knowledge.	4 (1)	3 (7)	3
Manage disease risk: • **Baseline health assessments** • **Implement best practice disease risk management** • **Toxoplasmosis**	5 (0)	5 (1)	4

Actions

Group 1. Meta-population actions

Goal 1) Establish enough enclosures of sufficient size to achieve the Vision (at least 3, each holding at least 1500 Mala[1])

Recommended actions:

- expand Lorna Glen (Matuwa) and Uluru within 5 years (Colleen Sims, Kerrie Bennison, Jim Clayton, Craig Woods)
- establish populations on Dirk Hartog Island and at Newhaven (Neil Thomas, Leah Kemp)
- assess a short-term fix for Uluru over-population if required (to be determined)
- develop carrying capacity indicators within 12 months – via a sub-group (Brydie Hill, Leah Kemp, Chris Pavey, Jim Clayton)
- assess carrying capacity of each population to allow ability to receive new individuals (either for improving genetic diversity or taking overflow animals) (Individual site managers using agreed set of indicators)
- progress identification and development of a third site in the south/south-west of former range (TBD)

Goal 2) Develop and implement a plan for management of gene diversity and inbreeding.

Recommended actions:

- agree a genetic management plan for the meta-population (C Lees and All)
- coordinate a plan for moving animals within 12 months (All)
- pursue resolution of the taxonomy of the Bernier and Dorré Island populations within 6 months (Neil Thomas)
- implement the priority actions of the genetic management plan within 5 years (All).

Goal 3) Manage disease risk

Recommended actions:

Sub-goal 3.1) Baseline health assessments within 5 years

- develop a Standard Operating Procedure (SOP) for collection of Mala health samples within 6 months (Kerrie Bennison, Colleen Sims, Leah Kemp)
- opportunistically collect health samples from all new animals as part of on-going monitoring (All)

Sub-goal 3.2) Determine the risk of toxoplasmosis to sub-populations

- develop a SOP for toxoplasma screening within a year (Neil Thomas, Kerrie Bennison, Colleen Sims)
- opportunistically collect samples (scats and blood from euthanized individuals) (All).

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[1] This would bring total Mala numbers to at least 4500, which approaches or exceeds various of the long-term minimum viable population sizes indicated in published studies (e.g. Franklin, 1980; Frankham 1995; Reed et al., 2003; Brook et al., 2006).

Sub-goal 3.3) Have best practice management in place at each site to reduce disease risk

- develop SOP for husbandry practices to reduce disease (Amber Clark, Scott Pullyblank)
- train staff in husbandry actions (All).

Sub-goal 3.4) Retain natural behaviours

- retain human contact at current levels. Don't remove wedge tail eagles. Where supplementary food is provided, feed bins should be filled during the day to minimise disturbance to the mala. Minimise human involvement in paddocks (All).

Group 2. Site management actions

Goal 4) Ensure no extensive wildfires within Mala enclosures.

Recommended actions:

Step 1 – within 12 months, review & consolidate existing knowledge (no new research). (All site managers, collaboratively).

Step 2 – within 18 months, use this information to develop a fire management strategy or to modify existing fire management strategies for each enclosure, as required. (Individual site managers with collaboration as required).

Step 3 – within 18 months, implement strategies. (Individual site managers).

Goal 5) Use fire to create optimal habitat for Mala within all enclosures

Recommended actions:

Step 1 – within 12 months, review and consolidate existing knowledge of optimal Mala habitat within spinifex grasslands (fire age etc.). (All site managers collaboratively).

Concurrently – within 5 years, research appropriate fire management for Mala in habitat other than spinifex grassland (e.g. Acacia shrublands, samphire communities etc) (Jim Clayton, Colleen Sims, Chris Pavey)

Step 2 - use this information to develop a fire management strategy or modify existing fire management strategies for each enclosure, as required. (Individual site managers with collaboration as required).

Step 3 - implement strategies. (Individual site managers).

Goal 6) Maintain cultural/ecological knowledge.

Recommended actions:

Step 1 - within 12 months identify language groups within Mala's former range (UKTNP & Mala Recovery Team).

Direct Action - investigate whether it will be possible to use live animals for knowledge transfer (including investigating institutional/legislative impediments to traditional hunting).

Step 2 - within 12 months, review & consolidate existing knowledge (Jim Clayton, Craig Woods).

Step 3 – within 18-24 months approach appropriate bodies/representative agencies to ascertain interest with regard to retaining that knowledge and/or being given assistance to hold and transfer knowledge (Jim Clayton, Craig Woods).

Goal 7) Manage to minimise fence breaches and their impacts

Recommended actions (for action by all local site managers):

- within 2 years, ascertain site specific fence longevity.
- within 12 months, develop operational maintenance plan for each enclosure.
- within 12 months, develop operational monitoring plan for each enclosure.
- within 12 months, develop operational response plan for each enclosure.
- Within 12 months, develop risk management plan for human error/vandalism.

Goal 8): To manage the impact of rabbits in Mala enclosures.

Recommended actions:

- do research to better understand suitable rabbit to Mala ratios within enclosures (TBD)
- within 5 years, eliminate or reduce to acceptable levels rabbits from existing enclosures (All).
- ongoing, eliminate and exclude rabbits from all future enclosures (those that are not currently constructed but will be e.g. Newhaven) (Managing agencies).

2015 Mala Population Viability Analysis Update

Summary

[Note that the conclusions drawn here are based on the data, estimates and views present at the time of the 2015 Mala workshop. These conclusions and the population models that underpin them, should be revisited as more information becomes available, as views shift and as new insights emerge. Note also that this brief description of results should be read in conjunction with the discussion at the end of the section, and with reference to the figures and illustrations provided].

Computer modelling can be a valuable tool for quantitatively assessing risk of decline and extinction of wildlife populations, both free ranging and managed. Complex and interacting factors that influence population persistence and health can be explored, including natural and anthropogenic causes. Models can also be used to assess the relative impact of alternative management strategies, to help identify the most effective conservation actions for a population or species, and to identify research needs. This kind of analysis is commonly referred to as Population Viability Analysis (PVA). One of the goals of the 2016 workshop was to refine a population model for Mala, for use as a tool for exploring population viability under existing conditions, and to evaluate alternative approaches to meta-population management.

An update to the 2009 Population Viability Analysis (PVA) was carried and is reported here. Prior to and during the planning workshop, model inputs were reviewed and revised, and some initial in-roads were made into quantifying threats in addition to those considered in 2009. The resulting models were used to explore the likely trajectories of current sites in the presence and absence of close management. The result of these analyses are presented here and will be used to inform meta-population planning during 2016.

The 2015 Baseline Mala model, representing a population in absence of catastrophic events such as exotic predator incursion, wildfire, rabbits or disease outbreak, grew at an annual rate of approximately 7% per year (lambda=0.0710).

Sensitivity analyses performed on the baseline confirm the following key biological contributors to population performance:

- female reproductive rate;
    - percentage of females breeding each year;

    - annual number of progeny produced per female;
- female mortality rates.

In the absence of threats such as wildfire, predator incursion and habitat degradation by rabbits, the main “situational” factors contributing substantially to modelled population resilience are starting population size and site carrying capacity. Modelled populations beginning with at least 70 individuals and able to grow to and remain above 250 individuals, are resilient to chance demographic events (random shifts in birth and death rates or sex-ratio) and accumulate inbreeding slowly enough to show little or no depression in growth over the 50-year period modelled. At present only **Uluru**, **Trimouille** and **Lorna Glen (Matuwa)** conform to these characteristics.

Introducing external threats (wildfire, predator incursion and rabbits) customised for individual sites using estimated values, changes the trajectories of some site models more than others:

The **Alice Springs Desert Park** population shows very high extinction risks both with and without the added external threats due to its small size and carrying capacity; it is recognised that this population will require ongoing support through supplementation and inter-site exchanges.

Scotia Sanctuary models showed little change as a result of adding additional threats. This may be optimistic however, as breeding rates at Scotia have been lower than expected (not currently factored into the models) and it is likely that all individuals will be transferred to the Newhaven predator-proof enclosure, construction of the first stage of which will commence in mid-2016. Further work on Scotia population models may be of lower priority.

Adding site-specific catastrophes to the **Watarrka** model more than halved expected population size and elevated extinction risk approximately three-fold, highlighting the importance of intensive management at this site.

Similarly the addition of catastrophes to the **Lorna Glen (Matuwa)** models reduced expected population size by approximately two-thirds and produced a four-fold increase in extinction risk, again highlighting the importance of best practice fire and other threat management at this site.

Uluru performs well both with and without the added threats. Its resilience is attributable to its relatively large starting size (N=250) and carrying capacity (K=300); its higher, more consistent breeding rate (annual % females breeding=75 ± 5; elsewhere=65 ± 10) and its fire management regime (“Best Practice”). These elements in combination ensure that the population recovers rapidly from every downward turn and rarely if ever decreases to the point where small population effects exert undue influence.

Trimouille Island performs well without the added risks due to its comparatively large starting size (N=300±40) and carrying capacity (K=400), which slow the rate of inbreeding accumulation and buffer against demographic stochasticity. However, introducing wildfire to the models (in absence of fire management) takes a heavy toll, gradually depressing average population size by around a third (though extinction risk remains close to zero). As the least observed population, threats to the Trimouille population may have been overestimated in the models. However, in absence of more information on the dynamics of that population, the current models serve as a precautionary estimate of current risk status.

Newhaven is a planned site, potentially open in 2018 and able to house several thousand Mala (Stage 1 K≈3000) because of the enormous size of the area being constructed. Once in these large numbers, populations would be expected to be resilient to extinction in the long-term, that is, beyond the length of the 50-year period modelled. Models indicate that to have a good chance of reaching these numbers quickly, the site should be seeded with 70 or more individuals and ideally at least 90-100 (though this can be staged).

Some of the inbreeding effects impacting on population viability could be mitigated by periodic inter-site exchanges and this will be the focus of meta-population planning over the coming year.

Introduction

The purpose of the modelling exercises in 2004, 2009 and also in 2015 have been:

1) To consider in detail the biological and environmental factors likely to influence the viability of remaining Mala populations.

2) To assign quantities to these elements based on the best available information and expert opinion and to build from this a simulation model for use in the following areas:

- To identify through sensitivity analyses which factors carry the most influence and as a result identify:
    - key areas of data uncertainty which should be the focus of study
    - key targets for management intervention
- To estimate the relative importance of threats such as: wildfire, poor fire management within enclosures, rabbit presence and fence breaches by introduced predators.
- To compare the estimated extinction risk of each population under current and "ideal" management.
- To explore the relative impact of different management interventions.
- Through the steps identified above to gain insights into the current strengths and weaknesses of each site as a precursor to developing a meta-population plan.

Vortex

Computer modelling is a valuable and versatile tool for quantitatively assessing risk of decline and extinction of wildlife populations, both free ranging and managed. Complex and interacting factors that influence population persistence and health can be explored, including natural and anthropogenic causes. Models can also be used to evaluate the effects of alternative management strategies to identify the most effective conservation actions for a population or species and to identify research needs. Such an evaluation of population persistence under current and varying conditions is commonly referred to as a population viability analysis (PVA).

The software used in these analyses is the simulation program *VORTEX* (v.10.1.5.0) (Lacy et al., 2015). *VORTEX* is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events, on small wild or captive populations. *VORTEX* models population dynamics as discrete, sequential events that occur according to defined probabilities. The program begins by either creating individuals to form the starting population, or by importing individuals from a studbook database. It then steps through life cycle events (e.g., births, deaths, dispersal, catastrophic events), for each individual and typically on an annual basis. Events such as breeding success, litter size, sex at birth, and survival are determined based upon designated probabilities that incorporate both demographic stochasticity and annual environmental variation. Consequently, each run (iteration) of the model gives a different result. By running the model hundreds of times, it is possible to examine the probable outcome and range of possibilities. For a more detailed explanation of *Vortex* and its use in population viability analysis, see Lacy (1993, 2000) and Miller and Lacy (2005).

The following section describes in detail the parameters used to build a series of Mala models in *Vortex*, for the purpose of exploring the questions described above.

Baseline model

A baseline model was built as an initial basis for these analyses. The baseline was not set up to emulate any of the living populations but rather to describe a generic fenced Mala population in the absence of environmental catastrophes, introduced predators and rabbits. Data inputs for the baseline were largely those used in the 2009 PVA, modified on the basis of expert opinion and site-specific data gathered since 2009. The details are provided below.

Data input

Number of iterations:	1000
Number of years:	50 years
Extinction definition:	Only one sex remains
Number of populations:	Single population
Percent males at birth:	50% (no evidence found to date that suggests sex ratio at birth differs statistically from 50:50)
Catastrophes:	Not included in baseline models
Harvest:	Not included in baseline models
Supplementation:	Not included in baseline models
Definition of "1 year":	365 days
Density dependence:	Not included (this is an effect likely to be present and influential (see Brook & Bradshaw, 2006) but is excluded here due to lack of confidence in estimates of its impact).
Age at first breeding:	Ages at first breeding of 1 year for females and 2 years for males

Studbook data for the captive population (Phelps, 1998) gave median age at first breeding as 10 months for females (N=104) and 11 months for males (N=76). No published data were available for wild populations, however, anecdotal information from participants indicated that wild females who might otherwise have been considered by observers to be sub-adult, had been observed with pouched young, suggesting that these younger ages are also possible in the wild. For males though, size was thought to play a role in mating opportunity. This effect would be masked in captivity by social management. Ages at first breeding of 1 year for females and 2 years for males were considered to best reflect enclosure conditions**.**

Longevity/age at last breeding: 9 years

In 2009, data on repeat captures were provided by Chris Pavey. If we assume that all females with young at first capture were at least 1-year-old at the time, then the mean age at last capture for the females listed was 5.4 years. The oldest animal was 7.67 years and the maximum known span of breeding years (that is, the distance between first and last known breeding) was 7 years (no. 583). In 2015, Neil Thomas provided a record of a female living to 10 years in the wild.

Given that:

- it is possible for wild females to live as long as 10 years (and possibly longer);
- there was a record in the 2009 sample of a female with young, aged at least 7.67 years;
- it was agreed that trap avoidance may increase in older, more experienced animals (such that data from trapped animals may underestimate both longevity and length of reproductive life);
- captive data indicate that it is biologically possible for females to breed at 10 years;
- animals are expected to die earlier in semi-captive conditions (e.g. those in fenced enclosures).

The 2015 model set reproductive senescence at 9 years, but with a steep decline in survival of females from 6 years on.

Number of broods per year: one

Mala may have multiple offspring during the year, one at a time. This was modelled as 1 brood per year of varying number.

Fertility: 65% of females breed each year, on average

In 2004 captive rates were calculated from 10 years of data when the population was relatively unmanaged. Mean = 54% (S.D.=12%). At that time, 3 years of Watarrka data showed a mean rate of 70%.

In 2009 new field data were provided (by C. Pavey) which showed a mean of 52.6%, a range of 43.2% – 61.9% and a standard deviation of 7.7%. In gathering data for 2015, submissions were highly variable:

2015 info from Watarrka: across years 2000-2015 percentage of females with pouch young or young at foot at each census: range 38-100%; Mean 59% BUT variation in annual sample size was large.

Comparisons with Bernier & Dorre (currently considered to be different subspecies) - fertility was reported as weight-based:

- 43% (1215-1660g)
- 61% (1661-2015g)
- 100% (>2015g)

Proportions in each weight class were not provided.

In summary, the total range reported was 38 - 100%. Mean values mostly fell within the range 50 - 70. This was discussed during the 2015 workshop, it was agreed that there are likely to be some inter-site differences in female reproductive rates but gathering sufficient data to understand the differences remains a work in progress. At present most of the data available are for Watarrka and Uluru. In these analyses 65% ± 10% was applied in the baseline. [This was also used as a default for all sites except Uluru, for which data were available to support a higher and less variable value of 75% ± 5%].

Litter sizes: 1=59%; 2=31%; 3=10%

No data were available from wild populations. Studbook data for the captive population (from Phelps, 1998) gave the maximum number of progeny per year as 4, with the following distribution of offspring numbers:

- 1= 59%
- 2= 31%
- 3= 7%
- 4= 3%

It is likely that this distribution reflects captive management. Participants agreed that the upper limit of 4 offspring per year was unrealistic outside benign captive conditions, but that 2-3 offspring per year might be more common in the absence of captive population controls. A modified version of the captive distribution of progeny sizes is used as baseline data; these figures represent a conservative estimate and one known from data to be biologically plausible: 1 = 59%, 2 = 31%, 3 = 10%

Age-specific mortality: Year 1=40%; >Year 1=20% (SD=20% of mean in all age-classes)

Age- and sex-specific mortality rates were calculated from studbook data for the captive populations (Phelps, 1998). Ten consecutive, representative years were chosen and mean and standard deviations calculated for juvenile, sub-adult and adult mortality. These rates may not adequately reflect the increased stresses placed on animals in the semi-wild environment.

Female mortality	Captivity	2015 Baseline
0-1	28(6)	40 (8)
> 1	15 (6)	20 (4)

Male mortality	Captivity	2015 Baseline
0-1	37 (7)	40 (8)
1-2	27 (7)	20 (4)
> 2	13 (7)	20 (4)

Mortality for the 2015 models was set at 40% in the first year and 20% beyond that, for both sexes. SD was set at 20% of the mean for all age-classes.

Initial population size: 100 individuals at stable-age structure

In the baseline the initial population size is set to 100. This is a hypothetical figure designed to be large enough to allow model dynamics to be observed without undue influence from inbreeding and demographic stochasticity.

Genetic Management: None in the baseline

Results

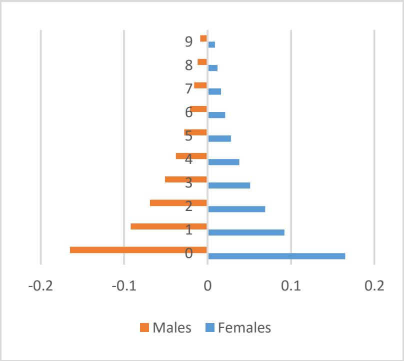
Deterministic outputs

The demographic rates (reproduction and mortality) included in the baseline model can be used to calculate deterministic characteristics of the model population. These characteristics reflect the biology of the modelled population in the absence of: stochastic fluctuations in demographic rates and environmental impacts; inbreeding depression; limitation of mates; and any immigration or dispersal. It is valuable to examine deterministic characteristics (lambda, generation length, and age structure) to assess whether they appear realistic for the species.

Table 2. Deterministic qualities of the baseline (wild) model:

Measure	Value
Ro (growth per generation)	1.2746
T (generation time in years)	3.825
λ (lambda – annual growth rate)	1.0736
r (instantaneous growth rate)	0.0710
Ratio of adult males to adult females:	0.726 (due to the later first age of breeding attributed to males.)

Figure 2. Stable age structure



The baseline model describes a population that grows at around 7% each year (lambda=0.0736). Average generation time across both sexes is approximately 4 years (T=3.42 for females; T=4.23 for males). Figure 2 indicates that at a stable age structure roughly 50% of individuals will be aged 0-2 years and approximately 1 in 10 animals will exceed 5 years of age. Though there are few data from real populations to validate this, the results are roughly consistent with documented observations.

Stochastic outputs

With stochastic fluctuations in both demographic and environmental influences, and inbreeding included at default levels, mean growth rate over the 50-year time-frame is halved (from stoch-r=0.071 to stoch-r=0.034). Mean population size at 50 years is well below available carrying capacity of 150 individuals and varies between iterations (N=113.46; S.D.=36.12). Extinction risk is close to zero (PE_{50}=0.003) and gene diversity declines over the period from an initial 99.50% (that expected to be captured in a founder base of 100 individuals) to 90.61%. Figure 3. illustrates the average behaviour of the population over 50 years with respect to population size. The steady downward trend is the result of inbreeding depression.

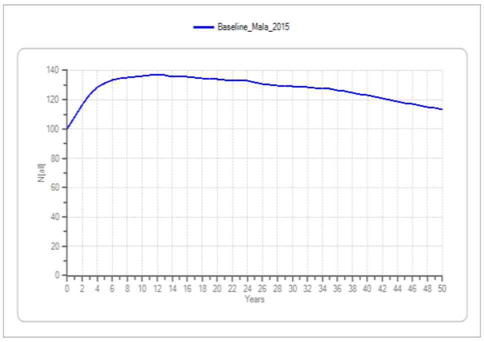


Fig 3. Mean population size over 50 years across 1000 simulations of the Mala baseline model.

Sensitivity Testing

Wherever possible, real data have been used to inform model parameters. However, many of the parameters are estimates and subject to varying levels of uncertainty.

We are unable to reduce parameter uncertainty in this exercise as that would require further research and data collection. However, it is useful to know which of the areas of uncertainty has the greatest impact on model performance, so that we can:

a) understand where key pressure points in the species' biology and environment are.
b) design management interventions accordingly.
c) prioritise future research and data collection to improve the predictive value of the models.

To develop an understanding of where the key "pressure points" are, we can test the sensitivity of the models to each parameter in turn, by varying each across a plausible range of values.

The following sensitivity tests (Table 3.) were carried out on the Wild Baseline model (BOLD indicates the baseline value):

Sensitivity testing was carried out in 2004 and the results are provided in Appendix II. Additional sensitivity tests were carried out in 2015 to illustrate the impact of current parameter uncertainty in key areas and the results are described here.

Table 3. Summary of Mala baseline parameters and sensitivity tests carried out for each.

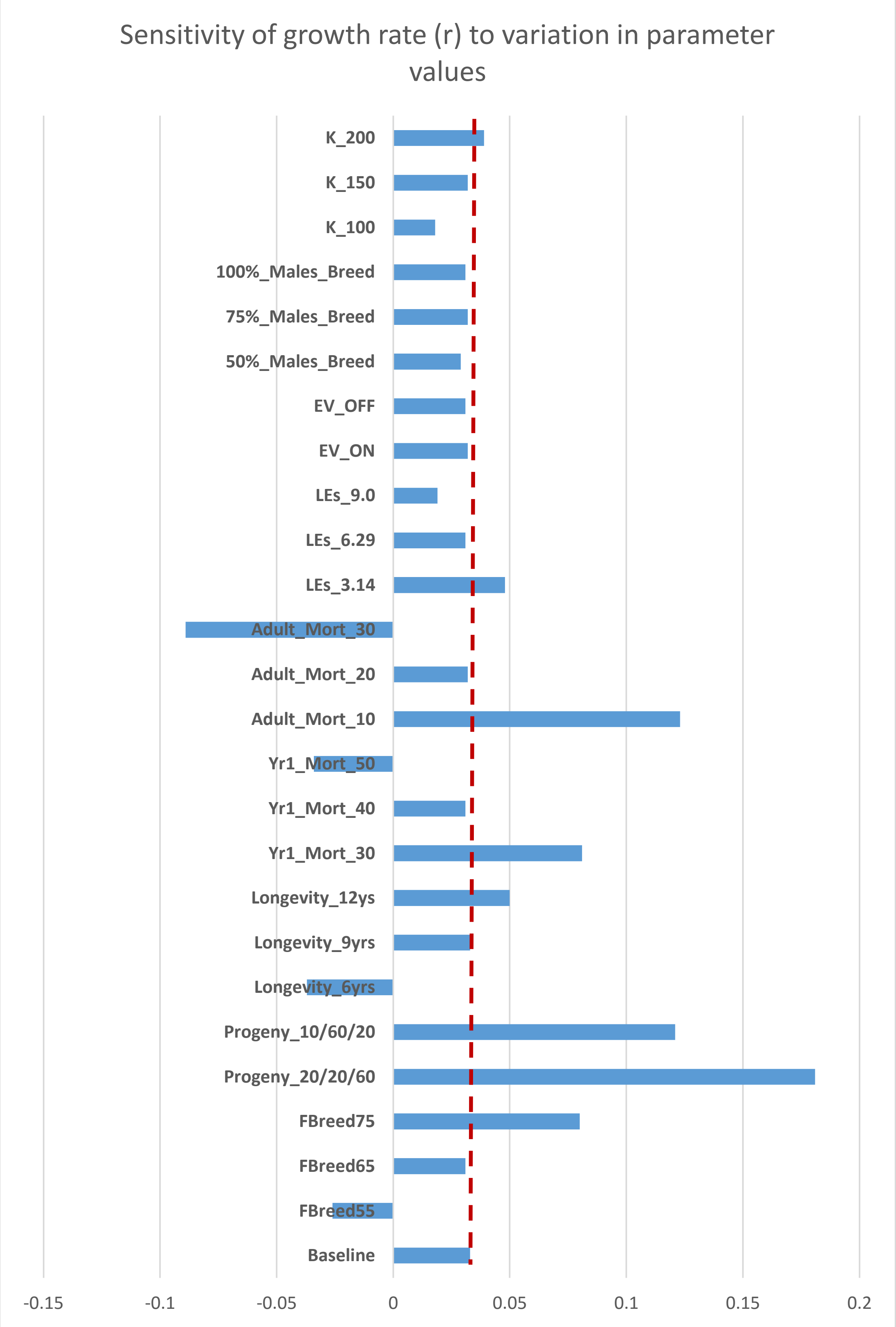
VORTEX Parameter	2015 Baseline	Sensitivity Tests
Number of iterations	1000	n/a
Number of years	50	n/a
Duration of each year in days	365	n/a
Extinction definition	Only 1 sex remains	n/a
Inbreeding depression	6.29 LEs distributed 50:50	3.14 and 9.00LEs distributed 50:50
EV concordance of breeding and survival	Yes	Yes and No
Reproductive system	Polygynous	n/a
Age at first breeding (Females)	1 year	n/a
Age at first breeding (Females)	2 years	n/a
Maximum lifespan	9 years	6, 7, 8, 9, 10, 11, 12 years
Maximum number of broods per year	1	n/a
Maximum number of progeny per brood	3	n/a
Sex-ratio at birth	50:50	n/a
% Adult females breeding annually	65% (S.D. 10%)	45,55,65,75,85,95
Annual offspring number	1=59%; 2=31%; 3=10%	1 = 20%; 2 = 60%; 3 = 20% 1 = 20%, 2 = 20%, 3 = 60%
Mortality rates (both sexes)	Age 0-1: 40% (SD=8%) Age >1: 20% (SD=4%)	Age 0-1: 20%, 30%, 40%, 50% 60% Age > 1: 10%, 20% 30% 40%
Catastrophes	None in the baseline	n/a
% Males in the breeding pool	100%	n/a
Initial population size	100	n/a
Carrying capacity	150	100, 150, 200

As illustrated in Figure 4., across the ranges of values explored the most influential factors were:

- annual progeny production;
- adult and juvenile mortality rates;
- the percentage of females breeding each year.

Environmental concordance (that is, whether a good year for breeding is also a good year for reproduction) and the degree of male monopolisation of females (i.e. the percentage of males in the breeding pool) have relatively little influence. The number of lethal equivalents (which elevates the severity of the component of inbreeding that operates though expression of lethal recessive alleles) and carrying capacity, show an intermediate level of influence for the limited range modelled.

Figure 4. Sensitivity of stochastic growth to variation in parameter values. Uncertain parameters were varied across a plausible range; a subset of results is presented. Baseline growth rate is indicated by the dashed red line.



Treatment of population genetics

By default, in the *VORTEX* model all individuals in the starting population are treated as though randomly sampled from a large, genetically diverse population whose members are susceptible to inbreeding depression. The model represents this by assigning each individual two unique alleles (a user-specified number of which will be recessive and lethal), by setting all inbreeding coefficients to zero and by calibrating inter-founder relationships to zero; that is, each individual in the starting population is considered non-inbred and unrelated to any other individual present. The relationships between all individuals are re-calculated at the end of each year and, along with information about allelic inheritance, are used to manipulate mortality rates: Mala born into the population carrying two copies of a recessive lethal allele are “purged” from the population; Mala born as offspring of related individuals are assigned a coefficient of inbreeding which will confer increased likelihood of first year mortality – the higher the coefficient the greater the likelihood. The severity of this impact in the Mala models is set to rates calculated from studies on populations of many different species (O’Grady et al, 2006).

All remaining mainland Mala are known to be recently descended from the 22 individuals captured during the 1980s. Those 22 animals were themselves sampled from a wild population that had been small for a significant period of time (from at least 1959 – the year of discovery of the populations – onwards) Thus the animals had been reproducing in a small population for many generations. Since then the population has grown but has also been sub-divided amongst various sites, some of which have undergone subsequent bottlenecks, with little inter-site movement.

As a result, remaining animals are expected to show higher levels of inter-relatedness and inbreeding, and lower levels of allelic diversity, than might a similar number of individuals selected randomly from a large, wild population. This is at odds with the way that the model is representing the population and concerns were raised about this during the meeting.

The aim of representing and projecting forwards the genetic composition of the population is not to provide us with a detailed picture of the current and future gene pool. Instead the aim is:

- from the current starting point, to estimate the likely extent of gene diversity loss over time, under current conditions;
- from the current starting point, to estimate the likely impact of inbreeding depression over time;
- to compare the relative effectiveness of different management strategies on retaining gene diversity and slowing inbreeding accumulation.

As current mortality and fertility rates in the models are based on observations taken from the current (i.e. inbred) population, the impact of any existing inbreeding depression is already accounted for. Therefore, calibrating inbreeding coefficients and inter-founder relationships to zero in the starting population should not result, overall, in an overestimation of population viability.

Values reported for gene diversity and for population mean inbreeding coefficient in this report should be interpreted as relative to this starting point. They should not be used in direct comparisons with values generated in other studies or through other methods.

The models consider inbreeding depression to have two components: 1) a lethal recessive component through which individuals born homozygous for a lethal recessive trait die immediately and 2) a non-lethal component in which mildly deleterious alleles accumulate in inbred individuals, contributing to depressed fitness. This non-lethal component produces a steady rate of increasing mortality in line with the rate of increase in inbreeding.

In a 1995 paper, Frankham reported empirical evidence for a threshold inbreeding effect on extinction risk; that is, a steeper increase in extinction risk once population mean inbreeding reaches critical levels. If this is the case for Mala then the current models could underestimate the likely impact of inbreeding as no such threshold effect is included; that is, under a threshold hypothesis remaining Mala could be on the verge of collapse, depending on how much inbreeding has accumulated to date.

However, if Mala are susceptible to a threshold effect the most effective management interventions are likely to be 1) to grow each site population to maximum carrying capacity and to keep them there through close site management 2) to restore connectivity between sites and 3) to extend the distribution of Mala as soon as possible to new, larger sites, to further increase overall abundance

All of these actions are already recommended here and, if they are implemented in full, a precautionary approach to inbreeding mitigation will have been taken.

A potential fourth intervention discussed at the workshop but unable to be recommended at this time, is the introduction of Mala from Bernier and Dorré Islands into the mainland population. This would be expected to increase gene diversity and reduce any inbreeding depression. However, Mala from these islands are currently considered a separate subspecies and there are some concerns about outbreeding depression. To encourage further development of this option, resolution of taxonomy is a recommended action in this report. Contained “hybridisation” trials have been used in similar species to investigate the potential for outbreeding depression and could be a useful exercise in this context.

Importance of starting size and carrying capacity

Before considering site-specific characteristics, additional modelling was carried out to explore the influence of starting population size and carrying capacity on population performance. When populations are small they are disproportionately susceptible to chance effects: year-to-year environment-related fluctuations in vital rates, demographic stochasticity and inbreeding. As they grow larger these effects diminish. Where Mala populations begin small, or where they are constrained by carrying capacity from growing large enough to show resilience to these effects, they may perform poorly even with all recommended management systems in place.

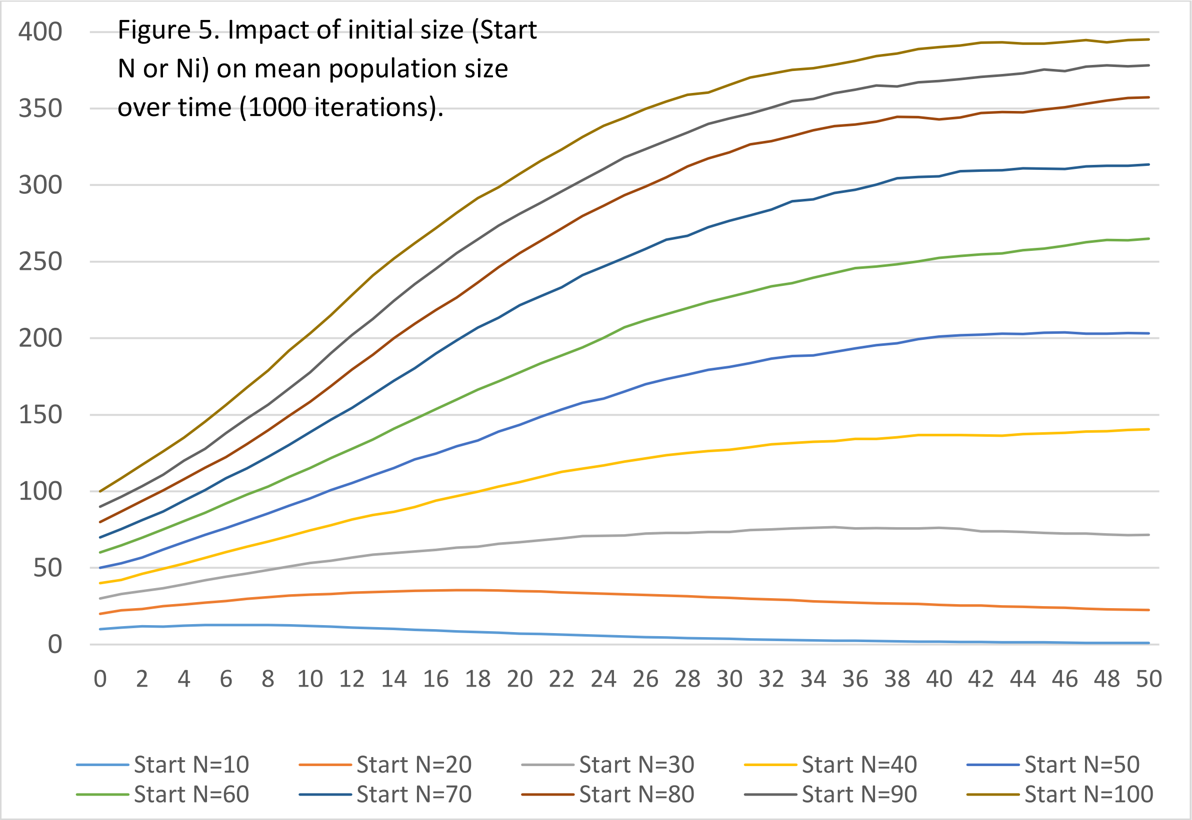


Figure 5. Impact of initial size (Start N or Ni) on mean population size over time (1000 iterations).

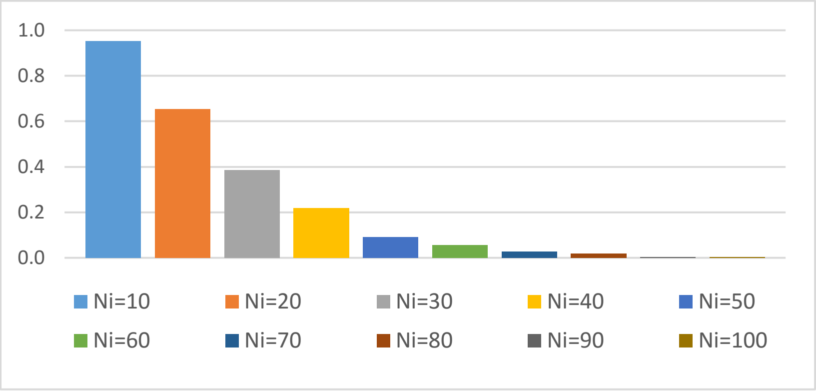


Figure 6: P(Extinct) at 50 years for modelled populations of varied initial size.

In the examples shown in Figures 5 and 6, carrying capacity is fixed at K=500 and starting size is varied from Ni=10 to Ni=100. As depicted, founding a population with only a small number of individuals confers a high likelihood of extinction by 50 years. Extinction risk drops below 5% at a starting size of Ni=70 (PE=0.0280), and below 2% for a starting size of Ni=90

(PE=0.004). Note that of the existing populations, only Uluru and Trimouille sit comfortably above these thresholds at present.

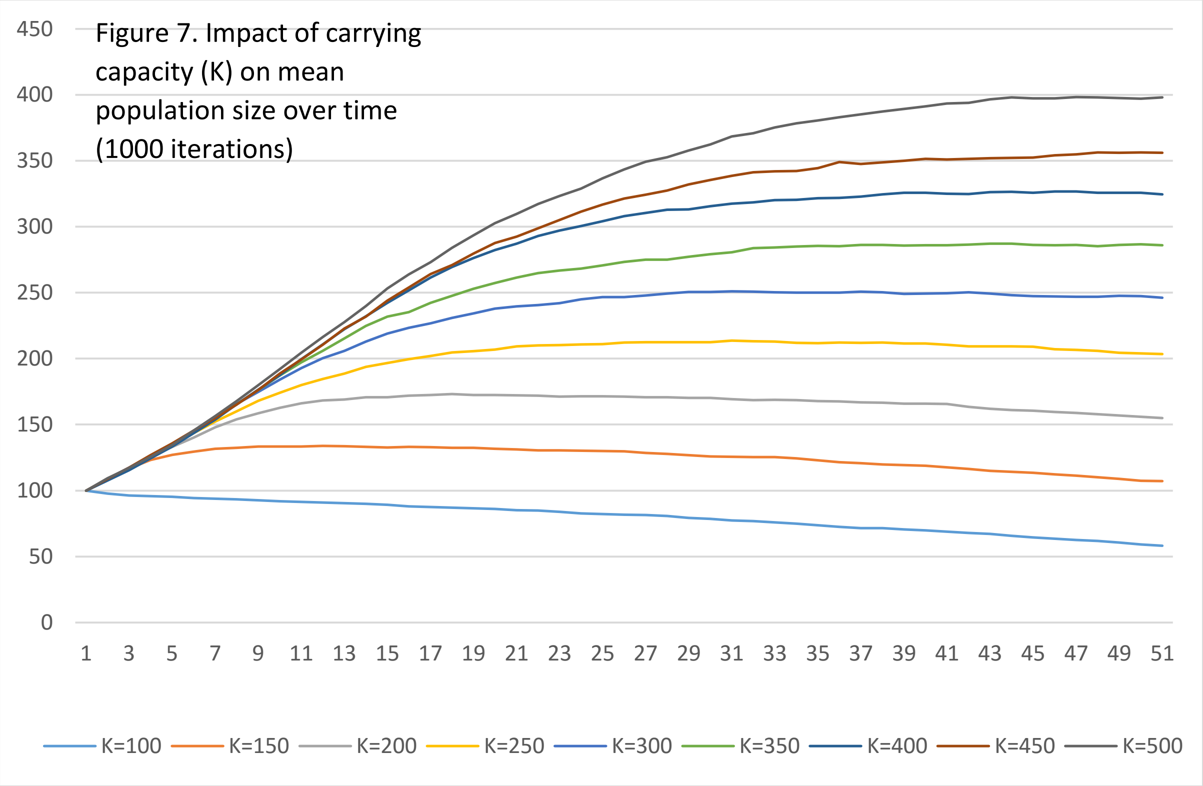


Figure 7. Impact of carrying capacity (K) on mean population size over time (1000 iterations)

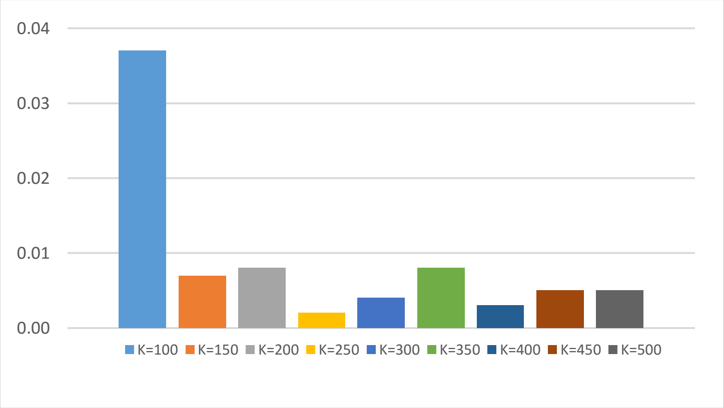


Figure 8: P(Extinct) at 50 years for modelled populations of varied carrying capacity (K).

All populations modelled showed low likelihoods of extinction over the 50 year period (PE<4%). Carrying capacities of K=250 or below put constraints on growth, accelerating inbreeding and thereby causing a downward trend in population size towards the end of the period. Carrying capacities of K=300 or above showed no discernible inbreeding-related downward trend over the period considered. Note that Trimouille, Uluru and Lorna Glen have estimated carrying capacities of K=300 or above.

Figure 9. illustrates the loss of gene diversity over the 50 year period as a proportion of the modelled starting level. Gene diversity declines at a rate inversely proportional to the (effective) population size, so those site populations that remain small for longer show the greatest losses. As populations become more homozygous they may become less resilient to environmental change. This effect is not explicitly included in the Mala models.

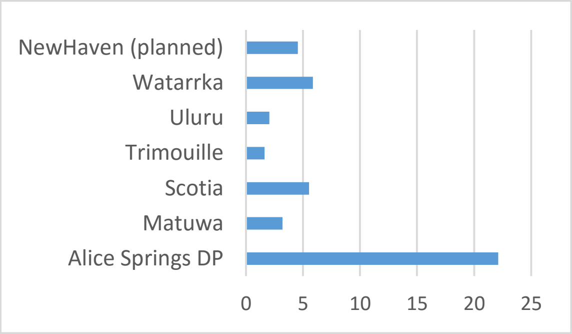


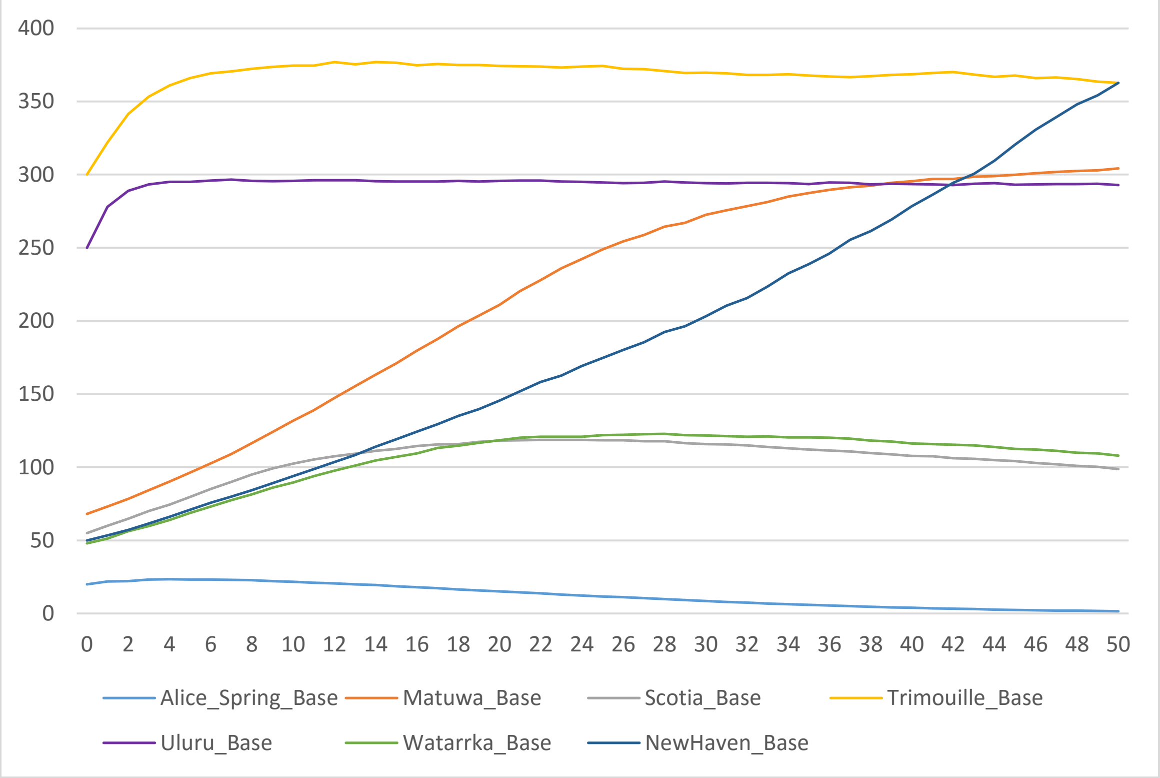
Figure 9. Decline in gene diversity as a proportion of starting value, for each site.

Site-specific models

Site-specific models were built for each of the current sites holding Mala (site details shown in Table 7.). Models were customised to reflect known or estimated current population sizes and carrying capacities, to explore the combined effects of these on performance over 50 years under “ideal” conditions, that is, in absence of any extreme mortality or reproductive events such as those that could result from wildfire, predator incursion, over-population with rabbits or disease outbreak. The results are illustrated in Figures 10 and 11.

Uluru and Trimouille perform well and show zero risk of extinction. The slight but discernible downward trends in the later years of the program are attributable to inbreeding depression. The high extinction risk shown by Alice Springs (PE=0.84) results from its current small size and limited carrying capacity, which accelerates inbreeding depression and causes it to remain susceptible to demographic stochasticity throughout the period. Scotia, Watarrka, and Newhaven (planned site), show similar risks of extinction (PE=0.09–0.10) resulting from relatively small starting sizes (ranging from N=48 to N=55) which confer an elevated risk in the first few years. As Figures 10 and 11 illustrate, those populations that overcome the early risks show positive growth towards carrying capacity, though for the smaller sites (Scotia and Watarrka), once capacity is reached there is a discernible downward trend caused by inbreeding depression. No such effect is seen in the hypothetical Newhaven site, which is large enough to support ongoing positive growth throughout the 50-year period and beyond.

Figure 10. Site-specific models under “ideal” conditions.



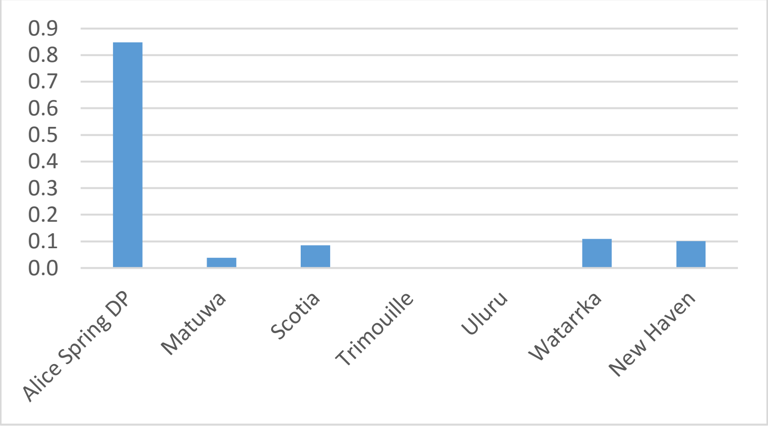


Figure 11: P(Extinct) at 50 years for site-specific models under “ideal” management.

Adding additional risks

The baseline site-specific models include risks from year-to-year environmental variation, demographic stochasticity and inbreeding depression. The mortality rates included incorporate “normal” mortality factors such as aerial predation, predation by native species within the enclosure, and disease. Baseline models exclude any extreme mortality events or reductions in carrying capacity expected to arise from rabbit over-population, wildfire, fence incursion by exotic predators or the outbreak of a novel disease. As a result they are expected to paint an optimistic picture of the future for these populations; i.e. one under constant close and effective management.

Tables 4 and 5 summarise discussions of these risks and attempts to quantify them. On the basis of this summary, and the site-specific characteristics outlined in Table 6, a further set of models was developed, to explore the potential impact of these risks on the populations that could be affected by them. There is limited information on which to base estimates of the occurrence of these risks and their likely frequency and severity of impact on Mala populations. The models are not expected to present an accurate picture of likely impact but rather to illustrate the likely relative importance of these risk factors, and to further describe the possible weaknesses of the different sites at this time, based on the best information available during the workshop.

Table 4. Additional risk factors and their treatment

Risk factor	Treatment	Rationale/supporting info.
Mild Fire	Once every 10 years. Includes post-fire predation. Impact varies depending on management regime (see below).	Consensus estimate of participants at 2009 PVA, confirmed in 2015
Severe Fire	Once every 25 years. Cannot re-occur within 7 years. Includes post-fire predation. Impact varies depending on management regime (see below).	Consensus estimate of participants at 2009 PVA, confirmed in 2015
Rabbits	Frequency and severity of occurrence will depend on management regime in place and any lapses in rigour or changes in management over time. For illustration here rabbits are modelled as over-populating sites once at 15 years and once at 30 years. The impact is a 17% reduction in carrying capacity in the year of occurrence.	Affects sites only where rabbits are inside the fence or can gain access (due to the larger gauge). 17% calculated from estimated increase in K at Uluru following rabbit control (K≈250 increased to K≈300)
Predator Incursion	For illustration, every site experiences a predator incursion risk of 4% (i.e. likely to occur, on average, twice every 50 years) resulting in a 10% decrease in survival, in the year of occurrence.	Anecdotal evidence of a fox killing 70 Mala before being removed. This is assumed to be an extreme event. The rate applied here is lower and would result in a loss of no more than 50 individuals, even at the largest sites.
Disease Outbreak	No attempt was made to include this in the models, though actions were agreed that are aimed at minimising the risk of such an occurrence.	"Normal" disease-related mortality is included in the models. It was acknowledged that a novel disease outbreak could have a dramatic impact, especially when the population is at or close to carrying capacity.

Table 5. Categorisation of fire management practices and their impact on likely severity of impact of a fire event on the resident Mala population, modified from 2009 PVA.

	Severe Fire (once in 25 years)	***Mild Fire (once in 10 years)***
Best Practice Fire Management (Baseline): **Fire management practices installed as for Uluru (regular patch burning, -mosaic habitat)** **Fires are small and localised. Big fires are infrequent.**	10% drop in survival	No expected impact.
Fire Management **Fires more extensive but impact somewhat ameliorated.**	30% drop in survival reduced from 2009 estimate of 50%	10% drop in survival
No Fire Management: **Fires widespread and catastrophic. Big fires have considerable impact, small fires impact slightly more than in intermediate management scenario.**	50% drop in survival reduced from 2009 estimate of 70%	20% drop in survival

Table 6. Risk allocation across sites based on known site characteristics

Site	**Risks**	**Notes**
Alice Springs DP	Wildfire (Best Practice Mgmt). Predator incursion. Rabbits are excluded.	Small site, population permanently exposed to small population risks.
Matuwa	Rabbits. Wildfire (Fire Mgmt in place). Predator incursion.	Fire management inside and outside the fence is in place but only since 2015. As a precaution the site is not assigned best practice fire management characteristics.
Scotia	Rabbits are excluded. Wildfire (Best Practice Mgmt). Predator incursion.	Scotia population is not growing as well as expected – likely to be moved to the planned new site – Newhaven. Refining risk estimates for this site may not be necessary.
Trimouille Island	Rabbits are excluded. Wildfire (No Fire Mgmt). Predators are excluded.	Unmanaged site but an island, so well protected from terrestrial predator and rabbit incursions.
Uluru	Rabbits. Wildfire (Best Practice Mgmt). Predator incursion.	Site has been managed consistently to control these risks.
Watarrka	Rabbits. Wildfire (Fire Mgmt in place). Predator incursion.	Rabbits and wildfire have been issues in the past and their management has been periodically constrained by resources.
Newhaven Stage 1. (planned)	Rabbits. Wildfire (Fire Mgmt in place). Predator incursion.	As this is a planned site, details were not available. For illustration, models include the risk of encroachment by rabbits and the risk of not applying best practice fire management.

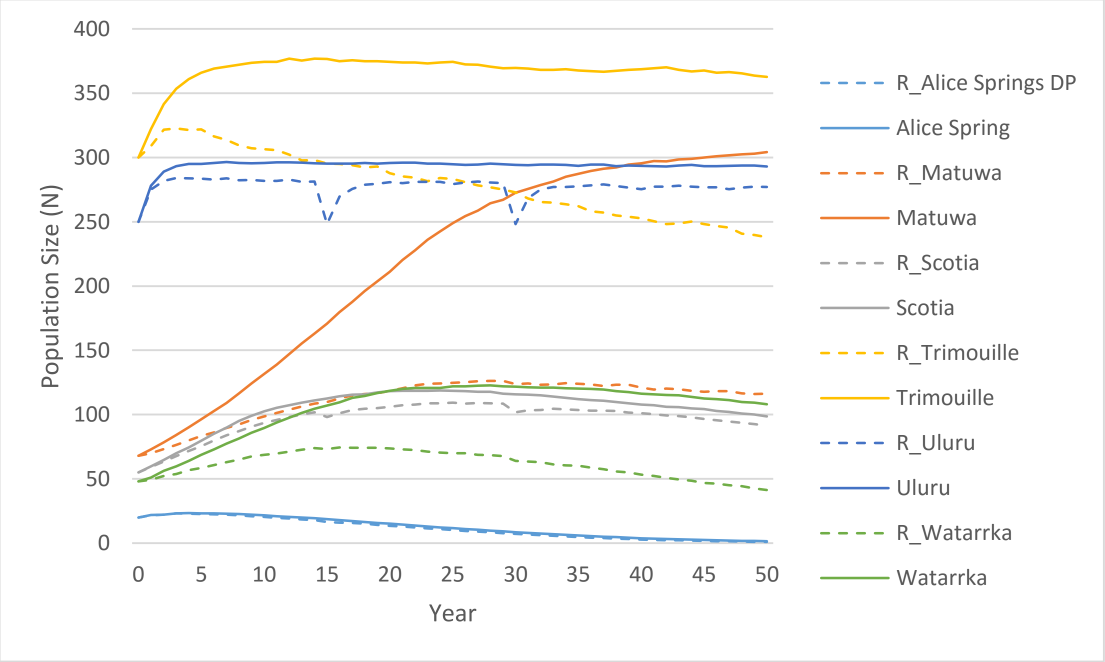
Figures 12 and 13. Illustrate the impact of adding these estimated site-specific risks to the baseline models for each site (note that Newhaven is excluded – site-specific risks were not discussed at the workshop but could be added later). Adding predator incursion and wildfire risks to the Alice Springs model made relatively little difference to performance as extinction risk was already high due to demographic stochasticity and inbreeding (PE= 0.8480 without extra risks; PE= 0.9020 with extra risks). This is not surprising given its small size and carrying capacity. Participants recognised that sustaining this population will require regular animal acquisition and exchange.

Adding wildfire (assuming Best Practice fire management) at Scotia also made little difference to performance. 50-year extinction risks were and similar (PE=0.0760 without extra risks; PE=0.0850 with extra risks) and expected population size over time decreased only slightly. Breeding rates at Scotia have been lower than expected (not currently factored into the models) and it is likely that all individuals will be transferred to the Newhaven project. Further work on Scotia population models may not be a priority.

A more dramatic shift in prospects is seen by adding to the Watarrka model the risks of rabbit and predator incursion, and wildfire (under a less than optimal regime of fire management). These are realistic risks for this site, which has seen periodic resource constraints resulting in less than optimal management of both rabbits and fire. In this example the inclusion of additional risks elevates extinction risk from PE=1090 to PE=0.3470 and depresses expected population size to an increasing extent over time (N@50 years = 108 without extra risks; N@50 years = 41 with extra risks).

An even larger gap is seen between the Lorna Glen (Matuwa) models, with and without the extra risks of rabbits, predators and wildfire (under less than optimal management). Extinction risk rises from less than 5% to almost 20% (PE=0.0390 without extra risks; to PE=0.1820). Expected population size is depressed considerably ((N@50 years = 304 without extra risks; N@50 years = 116 with extra risks). This highlights the importance of best practice fire and other risk management at this site, the population residing at which is currently particularly vulnerable due to its small size (n=68)

Figure 12. Impact of added risk on performance of site-specific models (solid lines indicate mean trajectory for 1000 iterations of the site-specific baseline models, dashed lines show effect of adding estimated site-specific risks).



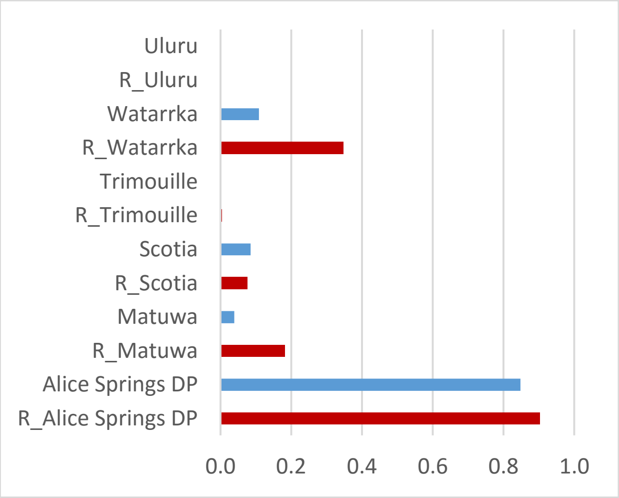
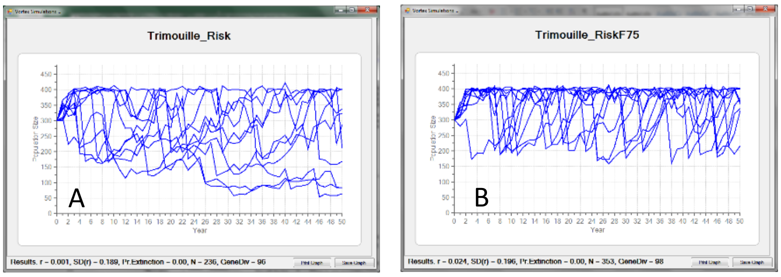


Figure 13. Impact of adding estimated site-specific risks on risk of extinction at 50 years (RED and R_prefix indicates result with extra risks included)

Uluru performs well both with and without the added threats of rabbits, predators and wildfire (under a regime of best practice fire management). Extinction risk is zero in both instances, there is a sharp drop in numbers attributable to periodic predator incursion from which the population recovers quickly, and the overall depression in expected population size over time is relative small and does not increase noticeably over time (without external threats N@50 years = 293; with external threats N@50 years = 277). Uluru's performance in the models is attributable to its larger starting size (N=250) and carrying capacity (K=300); its higher, more consistent breeding rate (annual % females breeding=75 ± 5; elsewhere=65 ± 10) and its fire management regime ("Best Practice"). These elements in combination ensure that the population recovers rapidly from every downward turn and that it rarely if ever decreases to the point where small population effects exert undue influence.

Trimouille Island performs well without the added risks due to its comparatively large starting size (N=300±40) and carrying capacity (K=400), which slow the rate of inbreeding accumulation and buffer against demographic stochasticity. Introducing wildfire (in absence of fire management) takes a heavy toll. Each time a severe fire occurs (approximately twice every 50 years), the population drops by roughly 50%. Each time a mild fire occurs (approximately once every 10 years) the population drops by roughly 20%. This ongoing (though probabilistic) "cycle" of fires has the effect, on average across iterations, of gradually depressing average population size across iterations from N > 350 in the scenario without fire, to N < 250 in the scenario with it. Extinction risk is very low in both scenarios (PE=0.0000 without the threat of fire; PE=0.0040 with it). Note that the trajectory illustrated in Figure 12 plots average size across 1000 iterations and as a result shows a relatively smooth population trajectory. In contrast, each individual iteration is characterised



Results. r = 0.001, SD(r) = 0.189, Pr.Extinction = 0.00, N = 236, GeneDiv = 96

Results. r = 0.024, SD(r) = 0.196, Pr.Extinction = 0.00, N = 353, GeneDiv = 98

Figure 14. Ten iterations of the Trimouille Island model with A. Baseline female breeding rates of 65%±10% and B. Uluru female breeding rates of 75%±5%.

by highly variable population size caused by these wildfire events (see Figures 14a and b). The Trimouille Island population is probably the least well observed and this characterisation of risk may overestimate the way that fire would affect the resident population. Birth rates on the island may be higher than currently set in the models (e.g. they could be similar to those observed at Uluru) which would allow the population to bounce-back faster following a fire event (see Figure 14b for an example of the impact of elevating female breeding rate from the Baseline default of 65%±10 to the Uluru rate of 75%±5). However, in absence of more information on the dynamics of that population, the current models serve as a precautionary estimate of current risk status.

Discussion and conclusions

[Note that the conclusions drawn here are based on the data, estimates and views present at the time of the 2015 Mala workshop. These conclusions and the population models that underpin them, should be revisited as more information becomes available, as views shift and as new insights emerge].

The analyses confirm the following key biological contributors to population performance:

- female reproductive rate;
    - percentage of females breeding each year;
    - annual number of progeny produced per female;
- female mortality rates.

Site and management-specific factors are expected to influence these rates and current data support the presence of inter-site differences (e.g. Uluru rates appear higher and less variable than those at Watarrka). Understanding more about these rates, their variability and the factors influencing them both generally and at each site, will remain a priority while populations are small (i.e. numbering in the low hundreds). Related to this is the likely importance of density dependent effects on population dynamics (see Brook and Bradshaw, 2006). Lack of data and of confidence in estimates of likely impact, led to its exclusion from this exercise but including it in an informed way would provide for a richer analysis of potential site dynamics.

In the absence of threats such as wildfire, predator incursion and habitat degradation by rabbits, the main “situational” factors contributing substantially to modelled population resilience are starting population size and site carrying capacity. Where modelled populations begin with at least 70 individuals and can grow to and remain above 250 individuals, they display resilience to chance demographic events (random shifts in birth and death rates or sex-ratio) and inbreeding accumulates slowly enough to manifest little or no depression in growth over the 50-year period modelled. For example, populations that begin smaller than N=70 show an elevated risk of extinction in the early years (PE>5%). Populations beginning with 100 individuals but with limited carrying capacity (K=100) show an extinction risk of almost 4% (PE@50 years=0.0370) whereas at K=150 or above this risk drops to below 1% (for K=150, PE@50 years=0.0070) Note that of the sites considered, **Uluru**, **Trimouille** and **Lorna Glen (Matuwa)** carry starting populations of around 70 or above and carrying capacities of more than K=250.

The analyses described above explore the dynamics of population in absence of the extreme impacts on mortality or reproduction that can be caused by site-specific threats related to wildfire, rabbits and predator incursion. The introduction of these, customised for individual sites using estimated values, changes the trajectories of some site models more than others. The results are summarised below.

The **Alice Springs Desert Park** population performed similarly with and without the extra risks. Its small size (N=20) and carrying capacity (K=30) confer a high risk of extinction from chance demographic events and inbreeding depression; adding wildfire and periodic predator incursion (at the rates modelled) increases this risk but by comparatively little (PE@50 years without external threats=0.08480; with external risks PE=0.9020). Participants recognised the need for ongoing support to this population through supplementation and inter-site exchanges.

Adding wildfire (assuming best practice fire management) at **Scotia** also made little difference to performance. 50-year extinction risks were similar (PE=0.0760 without external threats; PE=0.0850 with them) and expected population size over time decreased only slightly (N@50 years without external threats=108; N=99 with them). Breeding rates at Scotia have been lower than expected (not currently factored into the models) and it is likely that all individuals will be transferred to the Newhaven project. Further work on Scotia population models may be of lower priority.

A more dramatic shift in prospects is seen by adding to the **Watarrka** model the threat of rabbit and predator incursion, and wildfire (under a less than optimal regime of fire management). These are realistic threats to the population at this site, which has seen periodic resource constraints resulting in less than optimal management of both rabbits and fire. In this example the inclusion of additional threats elevates 50-year extinction risk from PE=0.1090 to PE=0.3470 and depresses expected population size over time (without external threats N@50 years = 108; with external threats N@50 years = 41).

An even larger gap is seen between the Lorna Glen (Matuwa) models, with and without the extra threats due to rabbits, predators and wildfire (under less than optimal fire management). Extinction risk rises from less than 5% to almost 20% (PE=0.0390 without external threats; to PE=0.1820 with them). Expected population size is depressed considerably (without external threats N@50 years = 304; with them N@50 years = 116). This highlights the importance of best practice fire and other threat management at this site, the population residing at which is currently vulnerable due to its size (N≈68) which is at the modelled borderline for increased resilience (N=70).

Uluru performs well both with and without the added threats of rabbits, predators and wildfire (under a regime of best practice fire management). Extinction risk is zero in both instances, there is a sharp drop in numbers attributable to periodic predator incursion from which the population recovers quickly, and the overall depression in expected population size over time is relative small and does not increase noticeably over time (without external threats N@50 years = 293; with external threats N@50 years = 277). Uluru's performance in the models is attributable to its larger starting size (N=250) and carrying capacity (K=300); its higher, more consistent breeding rate (annual % females breeding=75 ± 5; elsewhere=65 ± 10) and its fire management regime ("Best Practice"). These elements in combination ensure that the population recovers rapidly from every downward turn and that it rarely if ever decreases to the point where small population effects exert undue influence.

Trimouille Island performs well without the added risks due to its comparatively large starting size (N=300±40) and carrying capacity (K=400), which slow the rate of inbreeding accumulation and buffer against demographic stochasticity. Introducing wildfire (in absence of fire management) takes a heavy toll. Each time a severe fire occurs (approximately twice every 50 years), the population drops by roughly 50%. Each time a mild fire occurs (approximately once every 10 years) the population drops by roughly 20%. This ongoing (though probabilistic) cycle of fires has the effect, on average across iterations, of gradually depressing average population size from N > 350 in the scenario without fire, to N < 250 in the scenario with it. Extinction risk is very low in both scenarios (PE=0.0000 without the threat of fire; PE=0.0040 with it). The Trimouille Island population is probably the least well observed and this characterisation of risk may overestimate the way that fire would affect the resident population. Birth rates on the island may be higher than currently set in the models (e.g. they could be similar to those observed at Uluru) which would allow the population to bounce-back faster following a fire event. However, in absence of more information on the dynamics of that population, the current models serve as a precautionary estimate of current risk status.

Newhaven is a planned site, potentially open in 2018 and able to house several thousand Mala (Stage 1 K≈3000). Once in these large numbers populations would be expected to be resilient to extinction in the long-term, that is, beyond the length of the 50-year period modelled. Models indicate that to have a good chance of reaching these numbers quickly, the site should be seeded with 70 or more individuals and ideally at least 90-100. This number may be difficult to access in the short-term and staged releases could work provided that the gap between successive releases does not leave the resident population too exposed to chance demographic and environmental events.

Some of the inbreeding effects described here could be mitigated by periodic inter-site exchanges and this will be the focus of meta-population planning over the coming year.

Summary of implications

In general, based on the current information, models indicate the following:

- Populations constrained to N≤70 individuals are inherently vulnerable to chance demographic and genetic risks, even in the absence of external threats such as rabbits, wildlife and predator incursion. Ongoing supplementation from larger populations will be required to support viability.
- All populations will require protection from external threats such as rabbit and predator incursion and wildfire. However, healthy populations of N≥250 may be expected to bounce back from these threats if they are removed quickly. Populations of N<250, or those in which reproductive performance or survivorship is depressed, cannot be expected to do so reliably and may require additional support through supplementation.
- Over the 50 year period considered all populations of K<300 showed some signs of inbreeding depression. This can be mitigated through regular inter-site exchanges, the frequency and number of individuals involved to be determined through additional modelling in 2016.
- Age-specific female survivorship and annual female breeding rates are pivotal to model projections. Better, long-term, site-specific estimates of these would enhance the predictive value of the models.

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Table 7. Summary of Vortex outputs for scenarios relating to starting population size, carrying capacity and site performance with and without external threats.

Scenario	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	SD(GD)	AlleleN	SD(A)	MeanTE
Baseline with varied starting size (K=500)												
Start_10_K500	-0.0476	0.2347	0.9520	18.38	23.07	0.90	6.37	0.5567	0.2030	4.13	2.45	20.0
Start_20_K500	-0.0282	0.1922	0.6530	64.66	99.84	22.53	66.31	0.7176	0.1634	7.30	4.39	30.1
Start_30_K500	-0.0100	0.1703	0.3850	116.25	133.71	71.59	119.07	0.7936	0.1311	10.76	6.01	34.4
Start_40_K500	0.0052	0.1517	0.2190	179.99	168.03	140.62	166.06	0.8461	0.0976	14.92	7.94	37.0
Start_50_K500	0.0170	0.1395	0.0910	223.54	173.83	203.23	177.73	0.8752	0.0861	18.57	9.03	40.0
Start_60_K500	0.0250	0.1334	0.0570	280.87	175.94	264.90	182.80	0.8958	0.0803	22.70	10.01	41.2
Start_70_K500	0.0321	0.1284	0.0280	322.37	166.52	313.36	172.54	0.9171	0.0563	27.21	10.79	41.7
Start_80_K500	0.0380	0.1250	0.0180	363.86	147.79	357.32	154.22	0.9317	0.0405	31.27	10.55	41.2
Start_90_K500	0.0404	0.1225	0.0040	379.71	141.58	378.19	143.32	0.9363	0.0431	34.20	10.92	39.8
Start_100_K500	0.0428	0.1219	0.0050	397.06	131.69	395.08	134.31	0.9437	0.0461	37.90	11.40	34.2
Baseline with varied carrying capacity (starting size=100)												
K100_Start100	0.0183	0.1400	0.0370	60.45	28.39	58.25	30.05	0.8474	0.0730	12.19	3.39	44.2
K150_Start100	0.0312	0.1292	0.0070	107.93	37.68	107.18	38.58	0.8993	0.0437	18.77	4.15	44.6
K200_Start100	0.0369	0.1251	0.0080	156.21	46.04	154.96	47.92	0.9211	0.0341	23.98	4.79	41.8
K250_Start100	0.0404	0.1227	0.0020	203.91	54.38	203.51	55.07	0.9306	0.0320	27.99	5.92	48.0
K300_Start100	0.0422	0.1227	0.0040	247.25	65.07	246.26	66.79	0.9376	0.0277	31.25	6.86	43.0
K350_Start100	0.0418	0.1227	0.0080	288.27	78.10	285.97	81.91	0.9400	0.0311	33.41	8.13	44.4
K400_Start100	0.0439	0.1217	0.0030	325.45	95.64	324.47	97.14	0.9422	0.0359	35.43	9.40	41.0
K450_Start100	0.0419	0.1222	0.0050	357.87	115.65	356.09	118.08	0.9427	0.0330	36.40	10.58	39.8
K500_Start100	0.0432	0.1216	0.0050	400.21	123.21	398.21	126.10	0.9454	0.0308	38.22	11.00	43.8
K600_Start100	0.0429	0.1219	0.0050	462.89	171.36	460.58	174.02	0.9444	0.0371	39.51	13.12	40.0
K700_Start100	0.0416	0.1219	0.0060	518.76	208.41	515.65	211.61	0.9428	0.0414	39.91	14.05	43.3
Site-specific models without external threats												
Alice Springs	-0.0413	0.2050	0.8480	9.54	6.80	1.54	4.32	0.6101	0.1605	3.80	1.29	31.6

Scenario	stoch-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	SD(GD)	AlleleN	SD(A)	MeanTE
Matuwa_Base	0.0304	0.1309	0.0390	316.60	170.67	304.27	178.16	0.9115	0.0675	26.35	10.84	38.3
Scotia_Base	0.0183	0.1403	0.0850	107.81	51.57	98.67	57.73	0.8733	0.0796	15.99	5.24	38.2
Trimouille_Base	0.0550	0.1177	0.0000	362.76	52.92	362.76	52.92	0.9662	0.0058	54.93	5.43	0.0
Uluru_Base	0.0952	0.1028	0.0000	292.90	17.42	292.90	17.42	0.9573	0.0067	42.98	3.69	0.0
Watarrka_Base	0.0146	0.1421	0.1090	121.13	69.10	107.97	75.30	0.8606	0.0975	15.54	6.12	38.4
NewHaven_Base	0.0172	0.1401	0.1010	403.35	571.97	362.64	555.73	0.8761	0.0862	19.26	10.11	38.6
Site-specific models with external threats												
Alice_Spring_Risk	-0.0466	0.2120	0.9020	9.30	6.56	0.98	3.44	0.6109	0.1521	3.98	1.54	30.7
Matuwa_Risk	-0.0095	0.1723	0.1820	141.97	141.93	116.21	139.50	0.8870	0.0923	21.16	12.33	39.2
Scotia_Risk	0.0052	0.1408	0.0760	99.00	48.13	91.50	53.15	0.8994	0.0690	19.60	7.02	38.6
Trimouille_Risk	0.0022	0.1945	0.0040	238.84	116.72	237.89	117.46	0.9621	0.0268	51.22	16.42	47.3
Watarrka_Risk	-0.0224	0.1849	0.3470	63.12	57.36	41.32	55.16	0.8418	0.1134	13.58	7.29	37.1
Uluru_Risk	0.0162	0.1068	0.0000	276.97	24.16	276.97	24.16	0.9737	0.0034	62.29	4.99	0.0

Summary of 2015 Meta-population Characteristics

The purpose of this section is to summarise the information gathered at the workshop on the characteristics of the current Mala meta-population and on the factors and constraints that will need to be taken into account in building a plan for its longer term genetic and demographic management.

The section includes the following:

1) Estimates for each site of:
    - size;
    - current Mala numbers (estimated);
    - carrying capacity (estimated);
2) A summary, for each site, of the status of key characteristics of the site environment and its management, including:
    - presence of other species that Mala may interact with or be affected by;
    - current types and intensity of management intervention;
    - census frequencies;
    - opportunities for pursuing aspects of the VISION.
3) A visual representation of the planned meta-population indicating likely patterns of animal exchanges.

Access to some sites (e.g. Trimouille Island) is challenging and distances between sites varies considerably. Some inter-site exchanges are therefore more difficult and costly than others. Any meta-population plan will have a greater chance of implementation if cost and difficulty can be minimised. Further, any plan for strategic animal exchanges will need to be responsive to the condition of populations at the time of transfer. For example, translocations into sites will not necessarily achieve the required result if the resident population is saturated; translocations out may pose an unacceptable risk to the source population if it is precariously small.

The information included in these summaries will be used to inform further analysis during 2016 towards a more detailed meta-population management plan.

Table 8: Management and characteristics of current sites

	Watarrka	Trimouille	Uluru-KT	Lorna Glen (Matuwa)	Scotia	Alice Springs DP*
SITE CHARACTERISTICS						
Area (hectares)	120	522	170	1100	115	4
Current N (estimated)	48±20	300±40	250	68	55	20
Estimated K	210	400	300	500	170	30
Established	2000	1998	2005	2011	2004	1997
Starting N**	96	10.20.11	24	40.28	33	18.35
INTERACTION WITH NATIVE SPECIES						
Other species present	Spinifex hopping mouse, native reptiles and birds	None (some sea-birds)	Native reptiles and birds, brush-tailed mulgara, great desert skink, spinifex hopping mouse	Burrowing bettong, golden bandicoots, brush-tailed mulgara, native rodents, reptiles	Malleefowl	Burrowing bettong, brush-tailed bettong, spectacled hare wallaby, golden bandicoot, echidna
PREDATION PRESSURE						
Raptors	Yes	Yes	Yes (WT eagle)	Yes	Yes	Yes
Goanas	Yes	No	Yes	Yes	Maybe	?
Snakes	Yes (possible)	No	Yes	Yes	Maybe	?
PRESENCE OF FERAL ANIMALS						
Rabbits	Yes	No	Yes	Yes	No	Excluded
Cats	Excluded	No	Excluded	No	No	Excluded
Foxes	Not local	No	Excluded	No	No	Excluded
ON-GROUND MANAGEMENT						
Supplementary food	Yes	No	Yes	No	Yes	Yes
Supplementary water	Yes	No	Yes	No	Yes	Yes
Population growth controls (to prevent overcrowding)	No	No	No	No	No	Yes

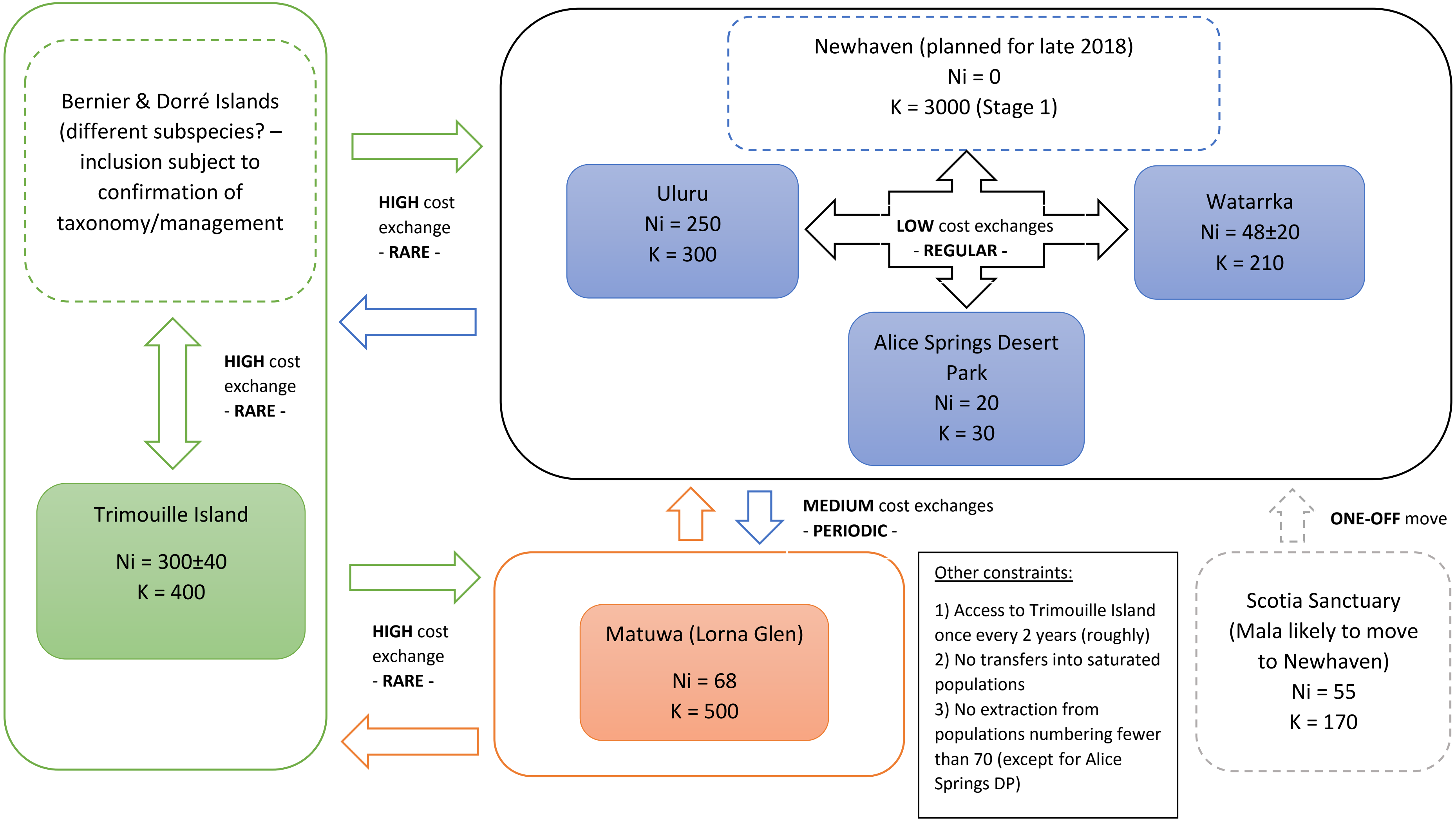
	Watarrka	Trimouille	Uluru-KT	Lorna Glen (Matuwa)	Scotia	Alice Springs DP*
Wild fire prevention	Limited by ranger capacity	No	Controlled burns inside and outside (different techniques)	Yes – (started 2015) inside and outside fence	Yes	Suppress weeds & fire breaks
Habitat management inside enclosure to improve carrying capacity?	Revegetation of sites post fire	No	Trial exclusion zones	Yes	Yes	Suppress weeds
OTHER						
Potential for habituation to humans	Minimal	No	Minimal (maybe around feeders)	Minimal	Yes	Yes - high
Potential for close reproductive management	No	No	No	No	Possibly	Yes - high
Regular census	1 per year (needs more effort)	Started 2014 – hope to continue	Annual survey	No	Yes annually	Yes (6 months)
Traditional owner involvement	Not specifically the paddock – some TO managers	No	Yes – especially surveys and controlled burns	Yes	No	No

Note that details of the planned AWC Newhaven site were not discussed in detail. It is estimated that Stage 1 of the project, planned to be operating by 2017, will include 13,000 ha and be able to hold up to 3,000 Mala.

*Alice Springs Desert Park is an intensively managed facility that includes, in addition to the 4 ha paddock, some individual pens in which animals can be paired for breeding or held for other close management purposes.

** Denotes Males.Females.Unsexed

Figure 15. Diagram of the proposed meta-population with preferred or likely patterns of exchange, taking into account access difficulty/cost.



Bernier & Dorré Islands (different subspecies? – inclusion subject to confirmation of taxonomy/management

HIGH cost exchange
- **RARE** -

Trimouille Island

Ni = 300±40

K = 400

HIGH cost exchange
- **RARE** -

Newhaven (planned for late 2018)

Ni = 0

K = 3000 (Stage 1)

Uluru

Ni = 250

K = 300

LOW cost exchanges
- **REGULAR** -

Watarrka

Ni = 48±20

K = 210

Alice Springs Desert Park

Ni = 20

K = 30

MEDIUM cost exchanges
- **PERIODIC** -

ONE-OFF move

HIGH cost exchange
- **RARE** -

Matuwa (Lorna Glen)

Ni = 68

K = 500

Other constraints:

1) Access to Trimouille Island once every 2 years (roughly)
2) No transfers into saturated populations
3) No extraction from populations numbering fewer than 70 (except for Alice Springs DP)

Scotia Sanctuary (Mala likely to move to Newhaven)

Ni = 55

K = 170

Appendix I: FINAL Workshop Programme

Mala Population Viability Assessment Workshop

3-5 November 2015, Alice Springs, NT

Background

The last wild colony of Mala (*Lagorchestes hirsutus*) on mainland Australia became extinct in 1991 as a result of a wildfire. Fortunately, in 1980 a captive colony had been established at the Arid Zone Research Institute, Alice Springs, from a small number of individuals captured in the Tanami Desert. This colony has formed the basis for several translocations.

As a result of these translocations, the mainland form of Mala now exists as one island population (Trimouille Island, WA) and four populations held in predator-proof enclosures at: Watarrka, NT; Uluru – Kata-Juta, NT; Lorna Glen, WA and Scotia Sanctuary, NSW. In addition to these, a small captive population remains at Alice Springs Desert Park.

As well as the mainland form, an island subspecies of Mala has been identified. It occurs on Dorre and Bernier Islands (Western Australia).

The species is currently classified as Vulnerable by the IUCN Red-List, based on a 2008 assessment.

In 2004 and again in 2009, population simulation models were built to help recovery contributors assess:

1) the likely viability of mainland Mala stocks given their vulnerability to risks such as wildfire, predator incursions and the impact of rabbits;
2) the relative performance of alternative approaches to risk mitigation.

In particular, the modelling exercises were aimed at eventually answering the following questions:

- What does the mainland Mala meta-population look like now?
    - Where are the remaining Mala now?
    - In what numbers?
    - Of what genetic/demographic quality?
    - Under what kind of management?
    - With what potential for growth?
    - With what level of connectivity?

  - Subject to what kinds of risk?
- What should the mainland Mala meta-population look like?
  - Where would we like Mala to be?
  - In what numbers?
  - In what kinds of environments/ecosystems or species assemblages?
  - Of what genetic/demographic quality?
  - Under what kinds of management?
  - Subject to what magnitude of risk?
- How might we get from here to there?

In both 2004 and 2009, led by the Alice Springs Desert Park in partnership with the Mala Recovery Team, efforts focussed on establishing and then reviewing baseline parameters for the population in the Watarrka paddock, as a starting point for considering other meta-population components. This 2015 effort will be aimed at expanding the model to include the wider meta-population and using this, with other tools and information, to inform agreed estimates and answers to the questions posed.

Modelling and workshop facilitation will be done, as previously, by the IUCN SSC Conservation Breeding Specialist Group at the request of and in partnership with, the Mala Recovery Team, building on the work of previous Mala recovery teams.

The workshop is sponsored by the Australian public through their generous donations to the Mala program at Uluṟu-Kata Tjuṯa National Park.

Workshop Program

DAY 1

	Item	Process Notes
DAY 1		
9.00am	**Welcome**	
9.15am	**Introduction**	Introduction to the workshop, its goals and intended products – Kerry B. (15) Introduction to IUCN SSC CBSG, its philosophy and proposed workshop process (15)
9.45am	**Participant Introductions**	Participants introduce themselves, their affiliation and interest in the species.
10.00am	**Scene setting Presentations**	**The Mala Story** – a quick tour of the decline, rescue and chequered history of Mala conservation action since the late 1970s, past & present distribution and threats. Jim Clayton (30) **Recovery Efforts-** a discussion of the challenges and successes of the previous and current recovery plan. Chris Pavey (30)
11.00am	**TEA/COFFEE**	
11.15am		**Current populations** – captive, fenced and semi-wild/wild (State or facility-based presentations detailing, for each site or facility: main characteristics and location, estimated number of Mala present, source and number of founder stock and year of arrival, observed population growth rates (if available),

		monitoring/management methods, relevant successes and challenges, and any future plans. (State/Site representatives) (40) **Population Viability Assessment Tools** –introduction to the ones we'll be using, how they work, what we'll use them for (key questions), preliminary findings. (Caroline L.) (20)
12.15pm	**LUNCH**	
1.15pm	**Task 1. Visioning**	Participants work to develop a VISION (a desired future state) for the Mala in Australia, over an appropriate time-frame. A sub-group will be formed to craft brainstormed ideas into an aspirational description of a future state and then to convert this into a number of "High-level Goals". This sub-group will work during the following session.
2.00pm	**Task 2. Agree model parameters**	A second sub-group will convene to review model parameters and agree DRAFT starting characteristics for each potential component of the meta-population (including best estimate of Mala numbers, carrying capacity and vital rates).
3.00pm	**TEA/COFFEE**	
3.15pm	**Task 3. High-level Goals**	The DRAFT vision statement is presented. Participants "operationalise" this by converting it into a series of "High-level Goals". For each, participants will agree an estimate of the current situation.
4.00pm	**Task 4. Issue identification**	Participants identify the "issues" (threats/obstacles/opportunities) relevant to achieving the VISION, given the current situation.
5.00pm	**Task 5. Issue prioritisation**	Issues are prioritised for further work.
5.30pm	**Close**	

DAY 2.

	Item	Process Notes
DAY 2		
9.00am	**Introduction to the day**	Where we got to yesterday, where we're going today.
9.15am	**Model revisions**	Summary of model outcomes resulting from the previous day's parameter review.
9.30am	**Working group formation**	Introduction to working group roles and responsibilities. Working groups are formed around the issues/obstacles identified (15).
9.45am	**Task 6. Issue Statements**	Working Groups clarify key issues/obstacles and agree an explanatory statement and working title for each.
11.00am	**TEA/COFFEE**	
11.15am	**Task 7. Data Assembly and Analysis**	Working groups reform to consider, for each issue/obstacle: what do we know about this? What are we assuming? What are our major information gaps?
12.30pm	**LUNCH**	
1.30pm	**Task 8. Goals**	Groups develop 5-year Goals for each issue that answer the questions: what and how much should we do about this issue? And by when?

2.30pm	**Report back**	Groups report back on their work – work is synthesised in plenary and any additional risks to be included in the PVA analyses are agreed.
3.00pm	**TEA**	
3.15pm	**Task 9. Actions**	For each Goal: groups agree at least one action that will constitute the next step in achieving that objective.
4.45pm	**Report back**	Groups report on their Goals and Actions. Alternative approaches/strategies for achieving specific Goals are discussed and factored into the modelling work-plan.
5.30pm	**Close**	

DAY 3.

DAY 3		
9.00am	**Final Presentations**	Summary of work so far and discussion of what is unfinished.
10.00am	**Next steps**	Time-line for project
		Priorities for the next 12 months
		Implementation Framework
		Additional PVA work
		Report-writing team
11.00am	**Final Discussion**	Feedback, other collaborators, evaluation.
12.00pm	**Closing Remarks**	
12.15pm	**Close**	End of workshop

Appendix II: 2009 PVA Report

2009 Virtual Workshop Report: Update to the 2004 Population Viability Analysis for **Mala, *Lagorchestes hirsutus***

Compiled by: Caroline Lees, CBSG Australasia

Project Team

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Chris Pavey (Biodiversity Unit, NT Government)
Vincenzo Repaci (Macquarie University)
Jonathan Wilcken (Auckland Zoo and CBSG Australasia)

Introduction

The purpose of this exercise was to refresh a 2004 Vortex model for the population of Mala held at Watarrka paddock. The resulting model will provide a basis for planning and ongoing adaptive management of Mala at other locations, and for integrated management of them as a meta-population.

Goals

Participants agreed at the outset that goals for the Watarrka population would be most usefully set in the context of goals for the overall meta-population. Those goals have not been set yet. In their absence some interim goals will be used to guide evaluation of model population performance. These goals are the achievement of:

- positive growth ($r>0$)
- probability of extinction below 5% ($PE<0.05$)
- gene diversity at or above 90% ($GD \geq 0.90$)

VORTEX

The Vortex program was selected for this analysis because it is particularly suited to describing the dynamics of small populations.

Vortex simulates the effects of deterministic forces as well as demographic, environmental and genetic stochastic events on populations. Through Vortex, population dynamics are modelled as discrete, sequential events (e.g. births, deaths, catastrophes etc.) that occur according to defined probabilities. As a result, each run may produce a different result, and so the model is repeated many times to reveal the distribution of fates that the population might experience under a given set of input conditions.

Vortex is not expected to give absolute answers, but it can help to describe the relationship between particular variables and/or the relationship between those variables and population outcomes.

The Vortex software is written by Robert C. Lacy, Max Borbat and JP Pollak, Chicago Zoological Society.

[Adapted from the *Vortex User Manual*, Miller and Lacy, 2003]

Input Parameters for Simulations

This section describes the input parameters used in the 2004 modelling exercise, along with any changes resulting from 2009 discussions.

General approach

2004. The population of animals held at Watarrka is maintained in semi-captive conditions. Participants agreed that animals there would be likely to display traits somewhere more closely but not entirely aligned with wild counterparts.

2009. No change.

Mating system

2004. Both captive and wild data support the assumption of a polygynous mating system. Whilst it was thought that some males might be more successful at achieving matings than others, male monopolisation was not considered to be a significant factor.

2009. No change

Age at first reproduction

2004. Vortex defines breeding as the time when the first offspring are born, not the age of onset of sexual maturity or the age of first conception. In addition, it requires the mean (or median) value, as the earliest age ever observed is unlikely to be a typical indication. Studbook data for the captive population (Phelps, 1998) give median age at first breeding as 10 months for females (N=104) and 11 months for males (N=76). No published data were available for wild populations, however, anecdotal information from participants indicated that wild females who might otherwise have been considered by observers to be sub-adult, had been observed with pouched young, suggesting that these younger ages are also possible in the wild. For males though, size was thought to play a role in mating opportunity. This effect would be masked in captivity by social management. Ages at first breeding of 1 year for females and 2 years for males were considered to best reflect wild conditions.

2009. No change

Age of reproductive senescence

2004. Vortex assumes that animals can breed (at the normal rate) throughout their adult life. Studbook data from captive populations indicate last age of breeding as 10 years for both sexes. However, reproduction drops off in captivity from about 7 years onwards. No data were available for wild populations but participants considered that the relatively benign conditions in captivity would artificially extend reproductive life. More conservative estimates for reproductive senescence were set, at 6 years for both males and females.

2009. A reduction in the mean annual % females breeding, based on real data, led to considerably more pessimistic population projections for the Watarrka population. When run retrospectively they did not produce the robust population inferred from observations at Watarrka between 2000/2001 and 2009. A number of other parameters were revisited in an attempt to correct this, and age of reproductive senescence was one of them. The following data on repeat captures were provided by C. Pavey:

Female ID	Min. lifespan (months)	pre-2000	2000	2001	2002	2003	2004	2005	2006	2007	2008
301	61				N	Y	Y			N	
423	52		Y	Y	Y	Y					
452	92		N	Y	Y	Y		N	Y	N	N
458	61		Y	N	Y			N			
515	73				Y		Y			N	
561	73				Y					N	
583	73				Y		Y	Y	Y	N	Y
760	60			Y	Y			Y			
848	69	?	N				N	N			
562	37						Y			Y	
752	62			Y	N			N			

Female ID	Min. lifespan (months)	pre-2000	2000	2001	2002	2003	2004	2005	2006	2007	2008
	?	captured									
	N	captured w/out offspring									
	Y	captured with offspring									
	🟨	assumed ≥ 1yr @ 1st capture									

Table 1: Re-capture data from Wattarka Paddock (from C. Pavey)

If we assume that all females with young at first capture were at least 1 year old at the time, then the mean age at last capture for the females listed is 5.4 years. The oldest animal is 7.67 years and the maximum known span of breeding years (that is, the distance between first and last known breeding) is 7 years (no. 583). It seems reasonable then, to extend the age of reproductive senescence beyond the 6 years entered in the 2004 model.

Given that:

- there is a record in this sample of a female with young aged at least 7.67 years
- trap avoidance may increase in older, more experienced animals
- captive data indicate that it is biologically possible for females to breed at 10 years
- animals are expected to senesce earlier in semi-captive conditions

The 2009 model has amended reproductive senescence **from 6 to 9 years**, but with a steeper decline in survival of females from 6 years on.

Male breeding pool

2004. With no evidence to the contrary, all males were assumed to be in the breeding pool.

2009. No change.

Sex-ratio at birth

2004. The studbook records 429 births: 183 males, 185 females and 61 unsexed animals. This supports the assumption of a 50:50 sex-ratio at birth.

2009. No change.

Maximum number of progeny per year

2004. No data were available from wild populations. Studbook data for the captive population gave the maximum number of progeny per year as 4, with the following distribution of offspring numbers:
1 = 59%

2 = 31%

3 = 7%

4 – 3%

It is likely that this distribution reflects captive management. Participants agreed that the upper limit of 4 offspring per year was unrealistic outside benign captive conditions, but that 2-3 offspring per year might be more common in the absence of captive population controls. A modified version of the captive distribution of progeny sizes is used as baseline data; these figures represent a conservative estimate and one known from data to be biologically plausible. Participants agreed two additional progeny distributions for trial:

Max. = 3 offspring per year for all scenarios

Baseline:	Annual progeny - low: 1 = 59%, 2 = 31%, 3 = 10%
Trial 1:	Annual progeny - medium: 1 = 20%, 2 = 50%, 3 = 30%
Trial 2:	Annual progeny - high: 1 = 10%, 2 = 60%, 3 = 30%

2009. Baseline figures were retained in the absence of new data.

Percentage of females breeding

2004. Vortex determines the percentage of females breeding each year of the simulation by sampling from a binomial distribution with a specified mean and standard deviation. An initial guide to the percentage of females breeding each year was provided from studbook data (Phelps, 1998). Data were sampled for 10 consecutive, representative years during the captive population growth phase (that is, when population management would be expected to have the least influence on this parameter, and when the population had grown large enough for the influence of small sample size to be reduced). Percentage of females breeding each year was calculated as 54% (12%SD).

Data had been collected for three years from the population under study, indicating figures, in each of those years, of approximately 70%. This figure is used for the baseline data set, with the standard deviation taken from the captive data (in the absence of more accurate data from the field). Additional models are included with values of 60% and 50%.

2009. New field data were provided (by C. Pavey) which showed a mean of 52.6%, a range of 43.2% – 61.9% and a standard deviation of 7.7%. These more conservative values were agreed as a new baseline. Input values of **mean = 53% and S.D. 8%** were used in the model. These values were ultimately displaced by the introduction of density dependence to the model – see Density Dependence.

Density-dependent reproduction

2004. Reproduction was modelled as density-independent. Though no wild data were available, observations by participants indicated that reproductive rate remains constant despite increasing population density. Though the issue has not yet arisen, it was agreed that management intervention would limit any serious effects of over-crowding before they would be able to have any adverse effect on body condition and reproduction. In addition, the finite area in which animals are housed prevents or makes negligible, any Allee effect (whereby reproduction is depressed at low density due to the failure of individuals to find mates).

2009. Allee effect was still excluded but the inclusion of density-dependence was agreed by the Team. Its inclusion is supported by a recent study (Brook & Bradshaw, 2006), provided to the Team by D. Frankham, indicating that most species show density-dependence when there are sufficient data to delineate its presence.

Vortex models density dependence as a decline in the percentage of females breeding as the population approaches carrying capacity. The model requires that values are indicated for the percentage of females breeding at low and high densities, and for the shape of the effect – that is, whether breeding slows down gradually as carrying capacity is approached, or drops suddenly only when carrying capacity is almost achieved. No data were available to indicate likely values, though participants felt the effect would be weak due to the supportive management regime in place.

The following baseline values for % females breeding were used, based on observed minimum and maximum values reported to this and the 2004 workshop:

2009 Baseline: Min = 50%; Max. = 70%; Steepness (B) = 8

In addition, the impact was tested of:

- varying the minimum threshold (to 50% and 60%)
- varying the maximum threshold (to 60% and 80%)
- varying the distance between thresholds (40-80% and 55-65%)
- varying the strength of effect (from a gradual decline in % females breeding towards carrying capacity to a steeper decline at or close to capacity B=4 and 16)

Mortality rates

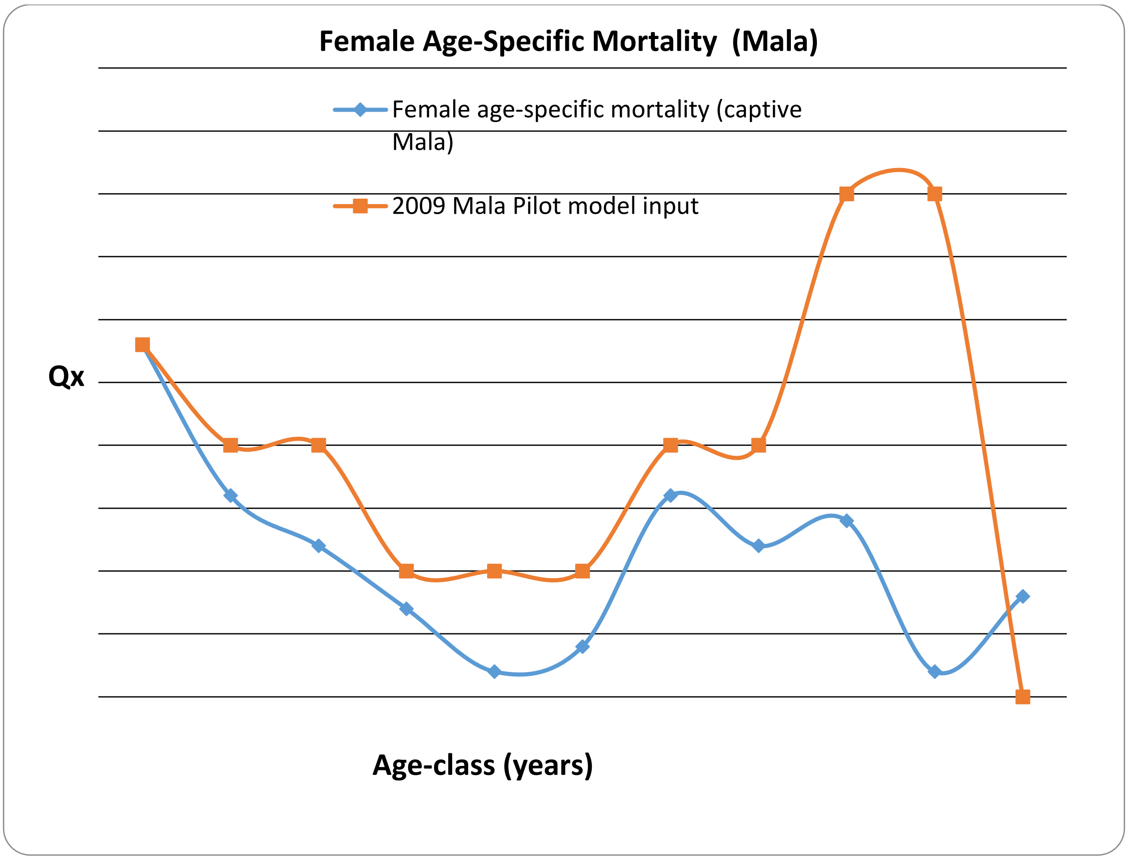
2004. Age- and sex-specific mortality rates were calculated from studbook data for the captive populations (Phelps, 1998). Ten consecutive, representative years were chosen and mean and standard deviations calculated for juvenile, sub-adult and adult mortality. These rates may not adequately reflect the increased stresses placed on animals in the semi-wild environment. To test the sensitivity of the population to this parameter, an alternative model was trialled, in which adult mortality for both sexes was increased to 20%. The following tables give the figures used, with standard deviation resulting from environmental variation (calculated from studbook data) given in parentheses:

Females	***Mortality***	
Age-class	*Captivity (Baseline)*	*Trial*
0-1	28 (6)	28 (6)
> 1	15 (6)	20 (6)

Males	***Mortality***	
Age-class	*Captivity (Baseline)*	*Trial*
0-1	37 (7)	37 (7)
1-2	27 (7)	27 (7)
> 2	13 (7)	20 (7)

2009. Participants initially chose to include the more pessimistic mortality schedule in the baseline model – that is, one in which adult mortality for both sexes is 20% per year. This was revisited later, after maximum age at breeding (and therefore maximum longevity) was amended. The final schedule is one which more closely reflects the shape of the captive mortality curve, but with increased values throughout and especially in the older age-classes, to reflect the expected effect of semi-captive conditions.

Graph 1: *Shows age-specific mortality in captive Mala (blue) and age-specific mortality in the model (red).*



Female adult mortality in the 2009 baseline model is described by the following function:

= 20-((A>=3)*10)+((A>=6)*10)+((A>=8)*20)

Male adult mortality is set at 20% per year.

Environmental Concordance

2004. This considers whether a good year for survival is also a good year for reproduction and vice versa. These two elements were not considered to be linked.

2009. No change.

Catastrophes

2004. No catastrophes were modelled during this initial exercise, though the following possibilities were discussed:

Predation: predators (foxes, cats) are currently excluded from the semi-captive enclosures by a fence. Breaches of this fence by a predator would be likely to be noticed and dealt with swiftly.

Future modelling might usefully consider the numbers of animals that could be killed by one or several predators following damage to a fence, before affecting population viability. This might have implications for setting response times for identifying and fixing fence breaches.

Fire: fire is a genuine threat to these populations and its potential effects were able to be studied first-hand at the Watarrka paddock in earlier in 2004 when a fire swept through. Population survival in this instance was extremely high. The ability to provide supplementary food and where necessary shelter, to compensate in the aftermath of the fire, makes these events potentially manageable. However, there is scope for further discussion in relation to the importance of retaining cover, and the value of vegetation with lower fuel load.

Future modelling could usefully evaluate the frequency and impact of fire.

Disease: disease may impact population health and productivity in a number of different and complex ways. Further, disease may have an increasing impact with decreased gene diversity and increased inbreeding. No data were available on which to base reasonable scenario parameters.

2009. A Catastrophes working group was convened to explore this in more depth. The Group discussed a range of possible catastrophes for inclusion in the model and work will be ongoing in this area. For the 2009 baseline model only “Severe Fire” was included as a catastrophe, with a frequency of once every 25 years, an assumed reduction in survival of 10%, and no impact on reproduction.

The Team agreed that the impact of fire is largely determined by the fire management regime in place and this is further described under **Management Scenarios.**

Initial population size

2004. Participants estimated current population size for the population under study to be about 200 animals. However, it is known that these 200, like all Mala in semi-captive conditions, derive from an initial 27 animals brought into captivity. These were the last remaining wild Mala on the mainland. For the initial population size set, Vortex treats each animal as a unique founder. This treatment would underestimate the degree of relatedness in the existing Mala population and in doing so, underestimate levels of inbreeding and overestimate gene diversity. To better reflect the likely genetic profile of the current semi-captive population, initial population size was set not at the present figure of 200, but at the founder event figure of 27 (starting date for simulations was therefore considered to be 1980 – the start of the breeding program).

2009. No change. Alice Springs Desert Park has engaged the services of Macquarie University, Sydney, to complete a genetic analysis of Mala samples. This will help to refine knowledge of the genetic profile of Mala in the paddock at Watarrka, and any differentiation between populations there and at other locations.

Inbreeding

2004. In the absence of estimates of inbreeding depression specific to Mala, the default value of 3.14 lethal equivalents was used, 50% of which were assigned to lethal alleles and subject to purging. This value is the median LE calculated from studbook data for 38 captive mammal species (Ralls *et al*. 1988). These values were calculated from, and were implemented in the model, as reduced juvenile survival in inbred individuals. As inbreeding depression is known to occur for most aspects of reproductive fitness (e.g., mating ability, juvenile survival, adult survival, fecundity) (Frankham *et al.* 2002), the use of 3.14 lethal equivalents for juvenile survival only, substantially underestimates its impact.

2009. Work on captive populations by Wilcken (2002) indicates that inbreeding depression on survivorship calculated across all age-classes is around 3.55 LEs. Inbreeding depression is expected to be cushioned in captivity as a result of the low stress environment and supportive management. O'Grady *et al*. (2006) concluded that 12 lethal equivalents spread across survival and reproduction is a realistic estimate of inbreeding depression for wild populations. As the Watarrka population is expected to sit somewhere between captive and wild conditions, the values for the 2009 Baseline are set at the mid-point between these extremes:

LE = 4.775 applied to survivorship and the equivalent applied as the following multiplier to % females breeding - E ^ (-I*0.02389).

To test the sensitivity of the model to this effect, the captive and wild extremes were also applied:

Captive: 3.55 LEs applied to survivorship and the equivalent applied as the following multiplier to % females breeding - E ^ (-I*0.01775)

Wild: 6.0 LEs applied to survivorship and the equivalent applied as the following multiplier to % females breeding - E ^ (-I*0.03)

Carrying capacity

2004. The carrying capacity, K, for a given habitat patch defines an upper limit for the population size, above which additional mortality is imposed across all age classes in order to return the population to the value set for K.

Current management practices for the Watarrka paddock allow carrying capacity to be relatively controllable through, for example, supplementary feeding, habitat manipulation and removal of excess animals if necessary. To some extent then, a preferred population size can be set and maintained in this paddock. Despite this, modelling a range of carrying capacities or preferred population sizes can be useful for:

- investigating the potential impact of reducing carrying capacity (which might arise through a reduction in habitat quality and/or a change in management intensity);
- helping to determine parameters for establishing additional populations.

Current carrying capacity (or preferred maximum population size) for the population is set at approximately 200 animals and this was used as the baseline K. In addition, carrying capacities of 50, 100 and 400 were modelled.

2009. The 2009 baseline model has carrying capacity set at 150. Carrying capacity is thought to have been reduced during the 2004 fire and to be recovering only slowly. More work needs to be done on the model to allow for this scaling of K between fire events.

Iterations and years of projection

2004. All scenarios were simulated 1000 times, with population projections extending for 100 years. Output results were summarised at 10-year intervals for use in the tables and graphs.

2009. No change.

Modelling Results

Table Information

Modelling results are described by the following statistics:

stoc-r(SD)	Mean (standard deviation) stochastic growth, calculated directly from the observed annual population sizes across the 1000 simulations.
PE	The probability of population extinction (determined by the proportion of 1000 simulated populations that become extinct during the designated 100-year time-frame)
N-extant (SD)	Mean (standard deviation) population size across those simulated populations which are not extinct at 100 years;
TE	The mean time to extinction for those populations becoming extinct during the simulation.
GD	Mean gene diversity retained by populations surviving to 100 years.

Summary of 2009 Baseline Model characteristics:

- Polygynous mating system
- Females begin mating at 1 year, males at 2 years. Maximum breeding age for females is 9 years, for males 6 years.
- The percentage of adult females breeding each year is density dependent, with 70% of females breeding at low densities and 50% breeding at carrying capacity. On average, those females that breed produce between 1 and 3 progeny, with a respective distribution of 59%, 31%, 10%.
- All adult males are equally capable of breeding in a given year.
- First-year mortality is set at 28% ± 6% for females and 37% ± 7% for males.

- Initial population size is set at 27 individuals, with a carrying capacity of 150.
- A severe fire is set to occur once every 25 years on average, causing a 10% drop in survival.
- Year 1 in the model is considered to be 1980 and simulations are run for 100 years.

New 2009 Baseline

Figure 1: Model Development 2004 - 2009

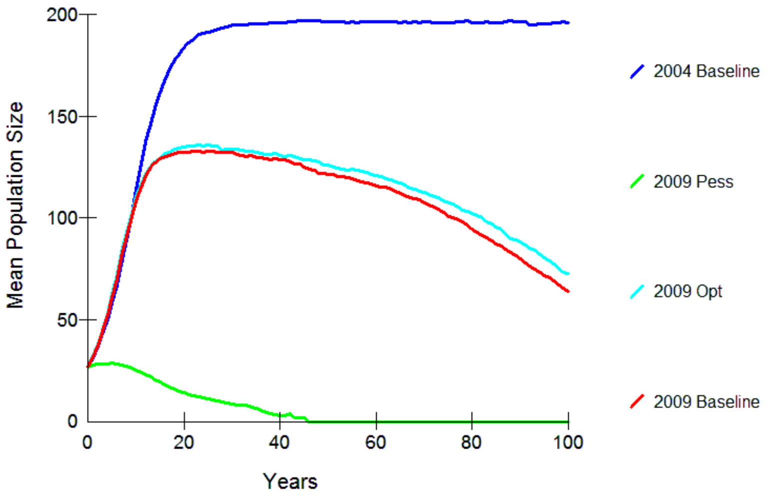


Figure 1. illustrates model development to date. The 2004 baseline model described a healthy, robust population that grew rapidly to carrying capacity and remained there for the 100-year period. Gene diversity at 100 years was 82% which is below standard 90-95% targets but still good given the relatively modest founder number and large number of captive generations.

2009 Pess incorporates the more pessimistic of the 2009 life-history parameters – increased mortality, annual percentage of females breeding lowered to 53%, high adult female mortality (up from 15% to 20%) and carrying capacity (K) reduced from 200 to 150. As can be seen, this considerably reduces population viability – all populations go extinct over the period modelled, with the mean time to extinction only 22.4 years.

2009 Opt introduces the more optimistic of the 2009 changes – increased longevity and extended breeding life for females; and density dependent reproduction, so that the annual percentage of females breeding increases as population size decreases. As expected, this improves viability though does not entirely restore it to 2004 model values – mean population size sits considerably below carrying capacity and is quite variable; probability of extinction is increased to more than 5% (from less than 1% in 2004) and gene diversity is lower, at 77%.

Table 1: Model Development 2004 – 2009

Scenario	det-r	stoc-r	SD(r)	PE	N-extant	SD	GD	TE
2004_Baseline	0.162	0.114	0.116	0.004	196.31	9.97	0.8233	27.3
2009_Pess	0.021	-0.095	0.228	1	0	0	0	22.4
2009_Opt	0.155	0.018	0.13	0.058	72.62	36.81	0.7786	80.1
2009_Baseline	0.151	0.014	0.134	0.097	64.24	36.8	0.7718	83

Finally, the ***2009 Baseline*** introduces a fire catastrophe to the model. This has the effect of further increasing extinction risk (to almost 10%), and slightly reducing mean population size.

Table 1. shows both deterministic and stochastic growth rates for the four scenarios described. There is a much greater difference between deterministic and stochastic values in the 2009 Baseline compared with the 2004 one, indicating that chance plays a much greater role in shaping population performance.

Population Growth

Stochastic growth incorporates the variation in parameters expected to result from chance and so should carry more predictive value than deterministic growth, which does not include this aspect.

Stochastic growth was positive for all but seven scenarios. These were:

- ***2009_ Pess:*** which incorporates all of the more pessimistic estimates agreed during 2009 modelling discussions.
- ***ST_Inb_High:*** which includes the highest level of inbreeding depression modelled
- ***ST_DD_High_60:*** in which the percentage of females breeding at low density is reduced to the lowest of the values modelled.
- ***ST_K50*** and ***ST_K100:*** in which carrying capacity (K) is reduced to 50 and 100 respectively)
- ***Mgmt_Poor*** and ***Mgmt_Med:*** in which fire management practices are less than optimal, increasing the impact of the fire catastrophe.

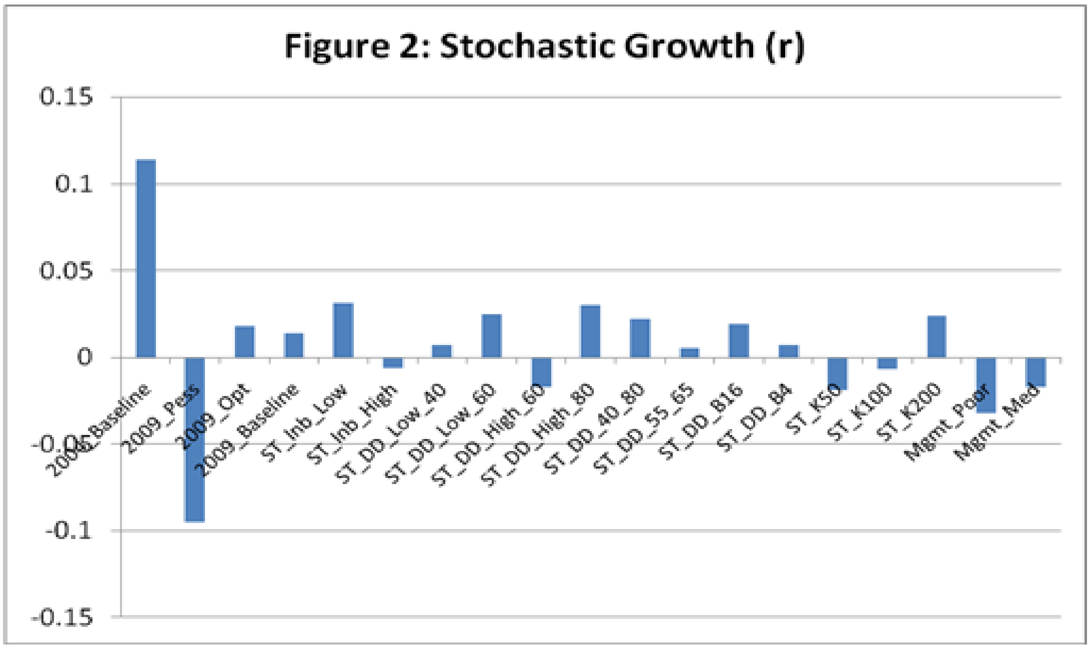


Figure 2: Stochastic Growth (r)

Growth rates are noticeably reduced in the 2009 models. The effect has been magnified by the addition of density dependence, which depresses growth at and around carrying capacity (K).

For the 2009 Baseline a better indication of population potential can be derived from the growth rate seen before capacity is reached. For the first ten years when growth is least constrained, **r = 0.140 (S.D.=0.137)**, which is ten times the mean value over the 100 year time-frame.

<u>Inbreeding</u>

Figure 3. shows mean inbreeding in simulated populations over time, for the 2009 Baseline scenario.

Mean inbreeding is approaching F=0.20 at 100 years, which is slightly less than that predicted for offspring of a full-sib mating (F=0.25).

Figure 4. illustrates the potential impact of this level of inbreeding on population viability. At the level of inbreeding predicted, the 2009 Baseline model performs poorly under simulated wild conditions. Growth is negative and extinction risk high.

Under simulated captive conditions the impact is apparent but relatively slight. The 2009 Baseline model sits in between these extremes.

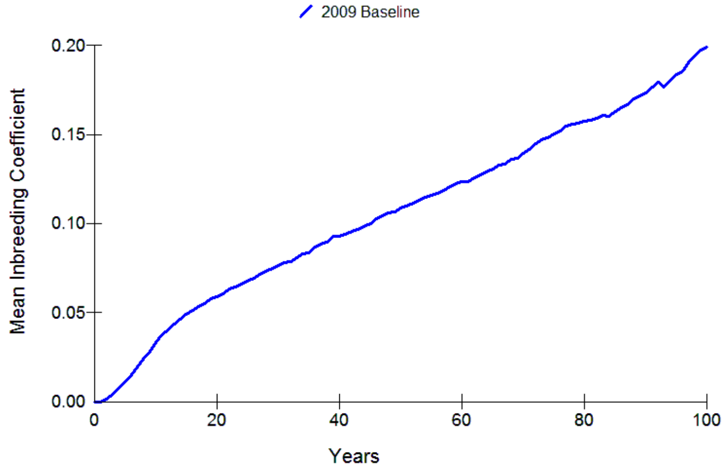


Figure 3. Inbreeding Accumulation

Scenario	det-r	stoc-r	SD(r)	PE	N-extant	SD(Next)	GD	TE
ST_Inb_Low (Captive LE))	0.151	0.031	0.126	0.012	111.16	30.43	0.8034	61.3
2009_Baseline	0.151	0.014	0.134	0.097	64.24	36.8	0.7718	83
ST_Inb_High (Wild LE)	0.151	-0.006	0.152	0.462	25.33	21.41	0.7058	83.6

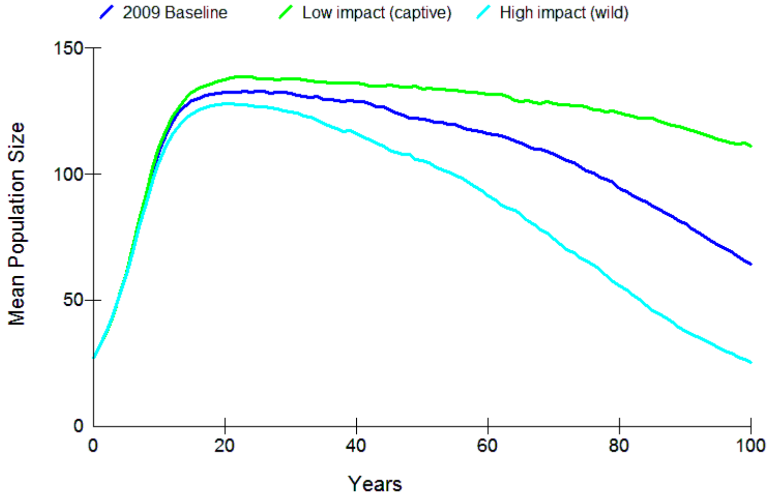


Figure 4. Inbreeding and Viability

Carrying Capacity

The population described by the 2009 Baseline model does poorly at carrying capacities below 150 with negative growth and high extinction risk. As illustrated in Figure 4 and described in Table 3., raising carrying capacity to 200 lifts population performance noticeably for the period considered.

Table 3: Impact of Carrying Capacity

Scenario	stoc-r	SD(r)	PE	N-extant	SD(Next)	GD	TE
K50	-0.019	0.187	1	0	0	0	60.4
K100	-0.007	0.161	0.602	16.72	14.5	0.6356	85.9
2009_Baseline (K150)	0.014	0.134	0.097	64.24	36.8	0.7718	83
K200	0.024	0.126	0.046	124.53	47	0.8287	65.8

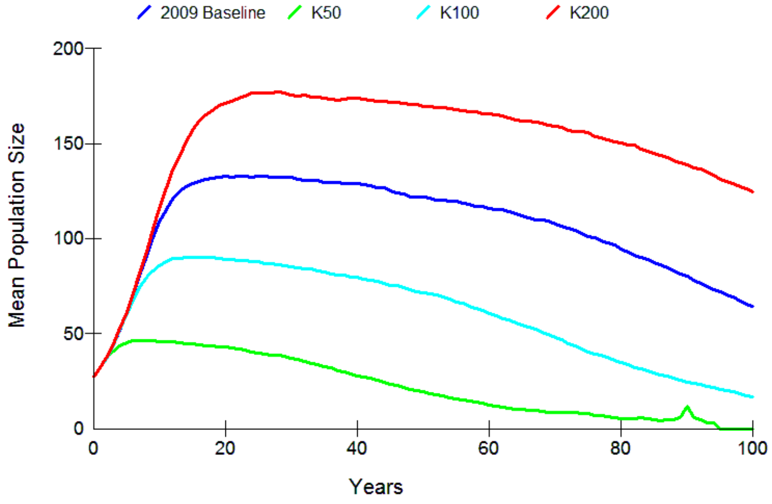


Figure 5. Carrying Capacity and Viability

Density Dependence

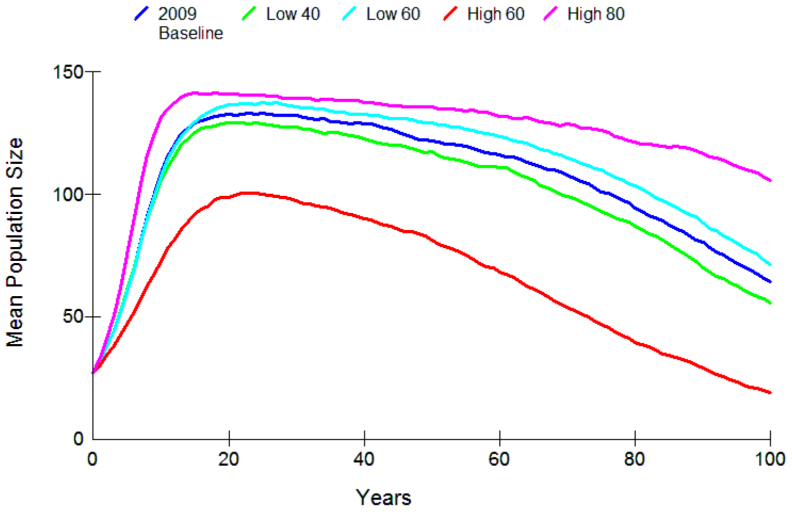
Density dependence was added to the model for the first time in 2009. The 2009 Baseline model has 70% of females breeding at low density and 50% breeding at carrying capacity.

Table 4. Impact of Density Dependence

Scenario	stoc-r	SD(r)	PE	N-extant	SD(Next)	GD	TE
2009_Baseline	0.014	0.134	0.097	64.24	36.8	0.7718	83
DD_Low_40	0.007	0.138	0.115	55.79	33.3	0.7613	83.1
DD_Low_60	0.025	0.132	0.088	71.2	38.42	0.7796	78.3
DD_High_60	-0.017	0.162	0.72	19.15	17.48	0.676	71.7
DD_High_80	0.03	0.13	0.004	105.65	28.35	0.8141	59.5
DD_40_80	0.022	0.135	0.003	99.76	29.96	0.8074	75
DD_55_65	0.005	0.143	0.298	44.73	33.15	0.7438	78.4
DD_B16	0.019	0.133	0.06	71.53	38.74	0.7793	82.9
DD_B4	0.007	0.138	0.146	49.59	31.46	0.7445	86.4

In **Table 4** and **Figure 6**, the LOW values refer to the percentage of females breeding (carrying capacity). The HIGH values refer to the percentage breeding at low densities. As illustrated in Figure 6., changes to the HIGH values have the greatest impact on population performance, with a reduction to 60% showing an extremely high extinction risk (>70%) and negative growth.

Figure 6. Density Dependence and Viability



Management scenarios

When fire was discussed as a potential catastrophe by the Team it became apparent that its impact in the Watarrka paddock is likely to be almost entirely determined by the fire management regime in place. Three management regimes were explored by altering the impact of fire as a catastrophe:

	Severe Fire (once in 25 years)	***Mild Fire (once in 10 years)***
Best Practice Fire Management (Baseline): Fire management practices installed as for Uluru: -regular patch burning -mosaic habitat Fires are small and localised. Big fires are infrequent.	10% drop in survival	No expected impact.
Intermediate Fire Management Fires more extensive but impact somewhat ameliorated.	50% drop in survival	10% drop in survival
Poor Fire Management: Fires widespread and catastrophic. Big fires have considerable impact, small fires impact slightly more than in intermediate management scenario.	70% drop in survival	20% drop in survival

As can be seen from Figure 7. and from Table 5. below it, the population described by the model shows little tolerance for sub-optimal fire management regimes. The Intermediate and Poor regimes described delivered extinction probabilities of 78% and 96% respectively.

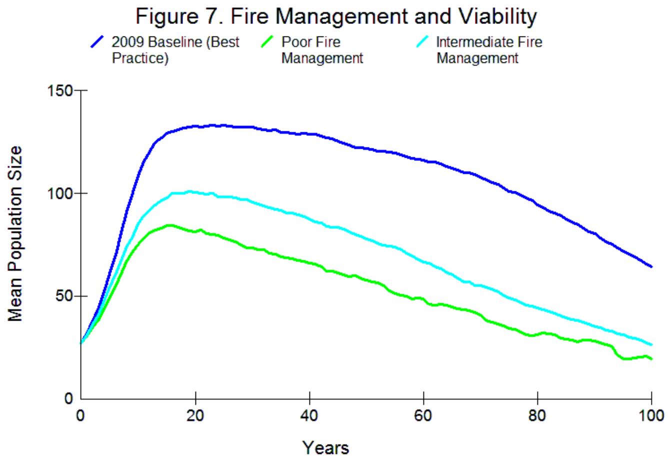


Table 5. Impact of Fire Management Regime

Scenario	stoc-r	SD(r)	PE	N-extant	SD(Next)	GD	TE
Fire_ Mgmt_Poor	-0.032	0.292	0.962	19.58	18.82	0.676	49.2
Fire_Mgmt_Med	-0.017	0.214	0.781	26.26	25.42	0.6967	67.9
Best_Practice (2009_Baseline)	0.014	0.134	0.097	64.24	36.8	0.7718	83

Summary and Conclusions

The population described by the 2009 Baseline model is less robust than that described in 2004 and meets only one of the interim viability goals set at the start of this exercise – the goal of positive growth. Almost 1 in 10 simulated populations went extinct over the 100-year time-frame (up from 4 in 1000 for the 2004 model); and gene diversity at 100 years was down by 5.2%, to 77.2%.

Key predictors of population viability are:

Female reproductive limits

- annual percentage of females breeding at low and high density - especially the former;
- female age-specific mortality
- annual progeny number (high progeny number becomes particularly important at lower population sizes – see 2004 report)

Carrying capacity

As for the 2004 model, populations performed poorly in scenarios where carrying capacity was less than 150.

Catastrophes

Only fire was included as a catastrophe. Its inclusion had a considerable negative impact on population viability in those scenarios where best practice fire management was not in place.

Implications for Management

Assuming that model parameters provide a reasonable characterisation of the population at Watarrka, the following implications for management may be inferred:

Best practice fire management is essential

Potential fire impacts could only be roughly estimated and were not exhaustively modelled. However, it seems fair to conclude that populations show low tolerance for fire management regimes operating at less than best practice.

Carrying capacity should be sustained at or above 150

Supportive management at Watarrka is possible and already in place through provisioning of food, water and shelter. This is expected to facilitate artificially high stocking densities. Smaller population are inherently less stable and more prone to extinction. Maintaining carrying capacity at or above 150 through supportive management, should avoid the extremes of this effect.

Research Priorities

Longitudinal studies remain a priority for validating the following:

- Annual percentage of females breeding at varied population densities
- Age-specific mortality – especially for females
- Annual progeny number

In discussions with the Team it was agreed that:

- current sampling methodologies for catch-ups at the Watarrka paddock could be modified to capture much of the data required and work will continue on this through the Mala Site.
- analysis of the captive records of a group of Mala held at Alice Springs Desert Park could yield useful data on % females breeding at low density and on annual progeny number. This will be progressed over the coming months.
- the population at Uluru could provide an opportunity to study low density reproduction.

Catastrophes still require work. Adequately factoring in the impact of fire will require further research and model manipulation. Disease has not yet been considered but could have a severe impact on a population, particularly one that has become inbred. Studies in these areas will be pursued as part of the broader meta-population analysis

Inbreeding can impact the population in several ways, including:

- reduced fertility
- reduced progeny number
- reduced survival across all age-classes
- increased expression of rare and damaging disorders

Genetic research currently underway at Macquarie University may help better characterise inbreeding effects in the model by:

- filling in Mala studbook pedigrees to assist analysis of specific inbreeding-related effects in Mala;
- helping to assess the percentage of males successfully siring offspring in the Watarrka paddock to hone projections of inbreeding in the model.

In addition, this work may help with the characterisation and management of genetic diversity across the Mala meta-population. A list of outstanding genetic questions or issues is included in Appendix I.

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Summary of simulations

Scenario	det-r	stoc-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GeneDiv	SD(GD)	AllelN	SD(A)	MedianTE	MeanTE
2004_Baseline	0.162	0.114	0.116	0.004	196.31	9.97	195.53	15.9	0.8233	0.0543	10.33	1.99	0	27.3
2009_Pess	0.021	-0.095	0.228	1	0	0	0	0	0	0	0	0	22	22.4
2009_Opt	0.155	0.018	0.13	0.058	72.62	36.81	68.43	39.52	0.7786	0.0968	8.3	2.28	0	80.1
2009_Baseline	0.151	0.014	0.134	0.097	64.24	36.8	58.04	39.76	0.7718	0.0949	7.97	2.25	0	83
ST_Inb_Low	0.151	0.031	0.126	0.012	111.16	30.43	109.82	32.57	0.8034	0.0646	9.18	1.93	0	61.3
ST_Inb_High	0.151	-0.006	0.152	0.462	25.33	21.41	13.76	20.07	0.7058	0.1377	6.11	2.4	0	83.6
ST_DD_Low_40	0.151	0.007	0.138	0.115	55.79	33.3	49.44	35.95	0.7613	0.1023	7.59	2.26	0	83.1
ST_DD_Low_60	0.151	0.025	0.132	0.088	71.2	38.42	64.96	41.83	0.7796	0.0924	8.31	2.31	0	78.3
ST_DD_High_60	0.099	-0.017	0.162	0.72	19.15	17.48	5.46	12.59	0.676	0.1437	5.19	2.16	87	71.7
ST_DD_High_80	0.199	0.03	0.13	0.004	105.65	28.35	105.23	29.06	0.8141	0.0588	9.66	1.88	0	59.5
ST_DD_40_80	0.199	0.022	0.135	0.003	99.76	29.96	99.46	30.41	0.8074	0.0614	9.32	1.93	0	75
ST_DD_55_65	0.126	0.005	0.143	0.298	44.73	33.15	31.51	34.4	0.7438	0.1173	7.15	2.42	0	78.4
ST_DD_B16	0.151	0.019	0.133	0.06	71.53	38.74	67.27	41.18	0.7793	0.0911	8.36	2.31	0	82.9
ST_DD_B4	0.151	0.007	0.138	0.146	49.59	31.46	42.42	33.85	0.7445	0.117	7.21	2.36	0	86.4
ST_K50	0.151	-0.019	0.187	1	0	0	0	0	0	0	0	0	61	60.4
ST_K100	0.151	-0.007	0.161	0.602	16.72	14.5	6.81	12.2	0.6356	0.1551	4.55	1.67	97	85.9
ST_K200	0.151	0.024	0.126	0.046	124.53	47	118.8	52.79	0.8287	0.0608	10.77	2.48	0	65.8
Mgmt_Poor	0.107	-0.032	0.292	0.962	19.58	18.82	0.78	5.21	0.676	0.1647	5.18	2.26	50	49.2
Mgmt_Med	0.125	-0.017	0.214	0.781	26.26	25.42	5.81	16.07	0.6967	0.1338	5.73	2.34	80	67.9

Appendix III: Workshop Participants

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