Black-flanked rock-wallaby (*Petrogale lateralis lateralis*) Population Management Strategy

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1. Acknowledgments

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2. Executive summary

The threatened black-flanked rock-wallaby (BFRW - *Petrogale lateralis lateralis*) is distributed across several disjunct populations across Western Australia making them susceptible to loss of genetic diversity and increased extinction risk. A Population Management Strategy (PMS) is therefore necessary, with the aim of providing management options for BFRW to ensure genetically viable colonies are maintained across current distribution. Here we present a review of recent research of BFRW populations, the current management, their key threatening processes, and genetic studies. A decision support process and workbook are included that will provide options to assist decisions for future management to secure the genetic diversity and demographic resilience of populations in the long-term.

3. Background

The black-flanked rock-wallaby is a medium-sized macropod endemic to Western Australia (WA). Since European settlement, populations have been in decline and local extinction of several colonies have severely reduced the species range to a handful of isolated populations at Kalbarri National Park (NP), Cape Range, Calvert Range, Barrow and Salisbury Islands, and sub-populations in the Wheatbelt.

BFRW inhabits Australia's semi-arid to arid zone in patchy areas of suitable rocky habitat (Pearson, 1992, Eldridge and Close, 1995, Pearson, 2013). It is a crepuscular and nocturnal central place forager, returning between trips to a central rock refuge for protection from predators and thermal extremes (Boyd et al., 2014, Pearson, 2013, Pentland, 2014). Their foraging behaviour is inherently restricted and can be even further constrained by its perceived risk of predation from introduced predators (Pentland, 2014).

BFRW display a linear dominance hierarchy within their social group, primarily enforced by agonistic behaviours. Females display these same behaviours over both female and male subordinates to assert breeding rights (Pentland, 2014).

BFRW does not exhibit the same water conservation physiology as other arid-zone macropods, instead, the species relies on behavioural rather than physiological responses for survival during adverse conditions occupying caves and foraging nocturnally (Bradshaw et al., 2001, King and Bradshaw, 2008). Therefore, species occurrence is likely linked to refuge availability.

Home range sizes appear to vary significantly, from just a few hectares up to 160 hectares, however many studies have suggested that *Petrogale* spp forage within 400 m of their diurnal refuge (Telfer and Griffiths, 2006, Sharp, 2009, Lim, 1987, Jarman and Bayne, 1997). The longest recorded distance travelled by any Petrogale is a female that traversed 8 km of agricultural land to establish a new colony (Eldridge et al., 2001).

BFRW was once widespread and considered locally abundant in Western Australia, throughout most of WA south of the Kimberley region. It is known to have occurred on the southern coastline of WA (Pearson and Kinnear, 1997, Burbidge et al., 1988), possibly as far east as Mount Ragged (Pearson & Kinnear 1997). There are sub-fossil records from Devil's Lair Cave near Margaret River (Dortch & Merrilees 1971; Merrilees 1979), although there are no records from this area since European settlement. There is also evidence (old scats) from several rocks in the WA Wheatbelt near Mukinbudin and at Knungajin Hill, 35 km north-west of Merredin (Pearson 2013).

A primary objective under the BFRW Recovery Plan (Pearson, 2013), is to increase the number of sites occupied by the species in a 10-year period. Of the 14 sites occupied in 2012, 11 remain inhabited in 2022. The reasons for the loss of three populations are unclear but are likely related to several threatening processes including predation from introduced predators, competition for thermal refuges by introduced goats and bees, and drought. Between 2016 and 2018, BFRW were reintroduced into several locations within the gorges of Kalbarri NP and this is now considered a viable population, bringing the number of viable populations to 12, in 2023.

The remaining colonies of BFRW (as of 2023) exist in either highly fragmented habitats or they are physically isolated by either fences or geography. As such, there are very few opportunities for natural gene flow. All populations and sub-populations are therefore at risk from genetic drift, demographic and environmental stochasticity, and catastrophic events - small population paradigm *sensu* (Caughley, 1994) with little to no prospect of natural re-establishment.

The BFRW Recovery Plan assigns high priority to:

- establish new populations,
- enhance the isolated Wheatbelt sub-populations to maintain genetic diversity and,
- prevent overpopulation through translocations.

A Population Management Strategy (PMS) is therefore necessary, with the aim of providing management options for BFRW in which the genetic resilience of each population is managed to maximise the long-term persistence of the subspecies in the wild. This PMS provides options for the management of all BFRW populations at existing sites and provides a decision-making process for the determination of suitable future sites with the aim of facilitating the species persistence and recovery in the wild.

4. PMS Overview

The 2013 Recovery Plan outlines broad objectives and management actions for rock-wallaby species occurring in WA (Pearson, 2013), including BFRW, focused on ensuring persistence of extant populations and increasing the number of sites occupied. This 2023 PMS is focused on the actions required to achieve effective population management and the primary aim of the BFRW PMS is to ensure genetically viable populations and sub-populations are maintained across their current distribution, with the goal of increasing the size, resilience, and distribution to meet the requirements of the 2013 Recovery Plan (Pearson, 2013). General guidance on threat management is provided by the Recovery Plan (RP).

4.1 Considerations

- The most significant threat to BFRW continues to be predation by feral cats and foxes. Habitat degradation exacerbated by drought, over-grazing, inappropriate fire regimes and weed invasion also pose a major risk to some colonies.
- Almost all the remaining populations and sub-populations are either small and/or highly isolated and increasingly prone to extinction from genetic loss and/or catastrophic events. These risks are exacerbated because of the limited capacity for natural migration and the threatening processes mentioned above.
- The ongoing loss of wild populations and the fragmentation of habitat effectively isolating sub-populations from one another has led to an erosion of genetic diversity that will continue if not adequately managed. The retention of the remaining genetic variability will maximise the taxon’s resilience to threats such as disease and environmental change, and improve capacity to recover in the future.

4.2 Objectives

- Maximise the genetic diversity, fitness, and resilience of BFRW through appropriate harvesting and supplementation actions.
- Manage the abundance of individuals within each sub-population to maximise the potential to maintain the long-term viability of the meta-population.

- Identify, evaluate, and prioritise locations likely to be suitable for BFRW population re-establish or supplementation.

Refer to Appendix 1 for actions and performance measures under each objective.

5. Current BFRW distribution and population status

Active population management of BFRW populations in Western Australia using translocation commenced in the 1990's. Between 2001 and 2018 the species was reintroduced to a number of reserves in the Avon Valley, Pilbara, Midwest, Wheatbelt, and the South Coast (Figure 1). Indigenous populations persist at Barrow and Salisbury Islands; Kaalpi (Calvert Range, Little Sandy Desert); parts of Cape Range NP; and isolated granite rocks in the Wheatbelt (Nangeen, Mount Caroline, Mount Stirling, Sales Rock, Gundaring Nature Reserve).

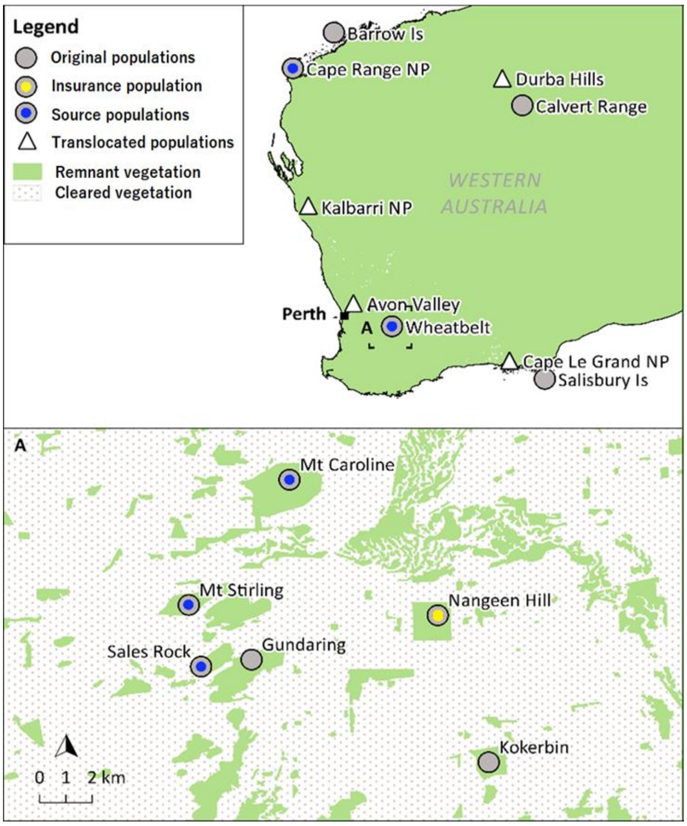

Figure 1: Current distribution of BFRW and translocated populations. (A) Wheatbelt sub-populations, green indicates uncleared native vegetation, and dotted pattern indicates cleared vegetation (adapted from: Nilsson et al., 2023)

Of the 15 BFRW sites identified as occupied in 2011 (see Pearson, 2013), 11 remain extant, one is extinct (Walyunga National Park) and three, Avon Valley National Park, Kokerbin Rock Nature Reserve and Querekin Rock, are considered functionally extinct since numbers have declined such that they are no longer considered viable without intervention. In response to population declines from 2011, a need for further translocations was identified as a high priority conservation action to address recovery targets. Several sub-populations were identified as most suitable as sources that could be used to support declining or to establish new sub-populations. These were initially identified as Cape Range NP, Mt. Caroline, Mt. Stirling, and Nangeen (Table 1). If conservation of genetic diversity is the aim of a translocation, smaller populations can also be considered to contribute individuals, although with careful consideration of the impact to the source population of removing individuals.

One population, Kalbarri National Park, was rediscovered in 2015 and has since been supplemented from Wheatbelt and Cape Range animals. The population at Kalbarri NP is currently increasing and expanding its distribution.

The performance criteria for BFRW stated in the 2013 rock-wallaby recovery plan (Pearson, 2013) is "*The area or number of sites occupied by mainland P. lateralis populations increase* [from 2011 to 2021]". A re-evaluation of the current status and management strategy of BFRW populations in Western Australia will assist in achieving this criterion.

A summary of the population management history and current status of each of the currently extant BFRW populations is provided in section 9 and Table 1.

6. Summary of BFRW conservation translocations

Conservation translocations of BFRW to date have aimed to reintroduce BFRW back to their former range, to supplement genetically at-risk populations and/or to manage population size with the fundamental aim of providing positive conservation outcomes for the species. Since 2003 there have been multiple translocations involving over 390 BFRW to 10 locations.

In 2022, five of these receiving locations were considered viable, two were declining and require intervention under the Recovery Plan, and the remainder were considered functionally extinct. Information relating to the success or failure of each translocation is detailed below and the learnings incorporated into the PMS decision framework.

Table 2 summarises each of the translocations based on the receiving location. In most instances the long-term success of each supplement/translocated population has largely been related to the activities of the managing agency to reduce the threats. Of the sites that are declining or are considered functionally extinct, in all cases the failure of the population to persist has related to either introduced predators and/or feral goats. In most cases fox management has been ongoing and initially the populations thrived but have subsequently declined most likely due to feral cats, goats and/or drought.

In contrast, all of the sites where there has been ongoing intensive fox, feral cat and goat management are stable or increasing. Implementation of intensive management of feral species will be fundamental to re-establishing populations and ensuring the persistence of currently extant populations.

Table 1. Summary of known BFRW populations, current management, and actions (blue) that could be improved or implemented (pending funding) prior to further translocation, supplementation and/or relocation. *Key code: Yes* ***Y,*** *No* ***N*** *and Not Applicable* ***NA.***

Location (Carrying capacity)	Tenure (Total site area)	Population estimates (status 2022)	[1] Monitoring (Year last monitored)	Regular feral Control (since)	Fire management	Weed and foraging habitat management	Need PVA? (Y/N)	Genetic diversity
Avon Valley National Park (To be defined)	DBCA Perth Hills (4,366ha)	1 (Functionally extinct)	Camera trapping (2021)	Aerial fox baiting (1999). Goat and pig trapping and shooting (2019). Feral cat trapping (2020)	Prescribed burn	Require ground-truthing and management	Y	To be defined
Barrow Island (To be defined)	DBCA Exmouth (20,200ha)	150 (Extant)	Walking transect (2021)	Absence of feral species	Exclusion	Active	Y	Extremely low (To be Reviewed)
Calvert Range (250)	DBCA Karratha (6,000ha)	<50 (Extant)	Visual surveys (2021)	Annual aerial feral cat baiting (Eradicat) since 2003	Require ground-truthing and management	Require ground-truthing and management	Y	Moderate
Cape Le Grand NP (30-60)	DBCA South Coast (31,801ha)	<30 (Declining)	Camera trapping (2022)	Aerial Fox (aerial biannual (1996 - ongoing)	Require ground-truthing and management	NA	Y	To be defined
Cape Range NP (1000)	DBCA Exmouth (100,000ha)	200+ (Extant)	Camera trapping (2022)	Annual cat baiting. Goat control (2016-ongoing)	Require ground-truthing and management	Active	Y	High
Durba Hills (350)	DBCA Karratha (23,000ha)	13 (Extant)	Trapping (2021) Camera trapping (2022)	Aerial and ground, fox, and cat baiting (2012-ongoing)	Nil	Nil	Y	To be defined
Gardiner's Rock (<10)	Private (55ha)	0 (Extinct)	2008	NA	NA	NA	N	NA
Gundaring (40-50)	Nature Reserve (127ha)	15-25 (Extant)	Live and camera trapping (2018)	Fortnightly ground fox baiting	Require ground-truthing and management	Nil	N	High

Location (Carrying capacity)	Tenure (Total area)	Population estimates (status 2022)	[1] Monitoring (Year last monitored)	Regular feral Control (Since)	Fire management	Weed and foraging habitat management	Need PVA? (Y/N)	Genetic diversity
Kalbarri NP (500)	DBCA Midwest (186,000ha)	100 (Extant)	Camera trapping 2022	Fox (biannual) and feral cat baiting (annual) (2016). Goat control (2018)	Prescribed burn	Nil	N	High
Kokerbin (30)	Nature Reserve (89ha)	<10 (functionally extinct)	Camera trapping (2018)	NA	NA	NA	N	Moderate small sample size (To be Reviewed)
Mt. Caroline (300)	DBCA Reserve (350ha)	180 (Extant)	Live and camera trapping (2021)	Ground fox baiting (1982) trapping and shooting (2017) Rabbit control (2018)	Prescribed burn (2014/2015)	Active	N	High
Mt. Stirling (30)	DBCA Nature Reserve (225ha)	<10 (functionally extinct)	Live trapping (2018)	Ground fox baiting (ongoing) trapping and shooting (2017) Rabbit control (2018)	Prescribed burn	Nil	N	High (To be Reviewed)
Nangeen (120-150)	DBCA Central Wheatbelt (176ha)	169 (Extant)	Live trapping (2014-2020) and Camera trap (2022)	Fenced; Ground fox baiting (1982-ongoing) Rabbit control (2018)	Prescribed burn (2015)	Weed control and revegetation to repair over-grazing	N	Low
Querekin (20)	Private	0 (Relocated)	Live trapping (2013)	Landholder refused to have 1080 baits laid on his land	NA	NA	NA	NA (Low)
Paruna (50-70)	AWC (2000ha)	<8 (Declining)	Annual trapping (2021), irregular scats survey and camera trap (2020)	Fox (150x1080 baits per month) and feral cat trapping (2015)	Prescribed burn	Weed control	Y	Moderate small sample size (To be Reviewed)
Sales Rock (40-50)	Private (75ha)	15-25 (Extant)	Live and camera trapping (2018)	Fortnightly ground fox baiting	To be discussed with landowner	Occasional	N	High

Salisbury Islands (500)	DBCA South Coast (320ha)	500 (Extant)	Camera trap (2017)	Absence of feral species	NA	NA	Y	Extremely low (May be an artefact of limited sampling)
Walyunga National Park (To be defined)	DBCA Perth Hills (1,812 ha)	0 (Extinct)	Camera trap (2019)	Ground fox baiting	Prescribed burn	Nil	NA	NA

[1] Recommended regular monitoring to be conducted on an annual basis (if funds permit) to collect information on the health of populations (body weight, parasites, reproductive output) and collection of genetic material of recruits. In addition, camera traps should be deployed to monitor feral species.

Table 2. Summary of translocations from each source, with the number of additional reintroduced through the years and the number of animals Known To Be Alive (KTBA). The long-term translocation success, reason for success or failure, and recommendation for intervention.

Location	Classification	Total animals translocated	Source	Year received additional animals	KTBA (Year last monitored)	Long term success	Reason for failure/success	[1] Intervention
Avon Valley NP	Reintroduction	40 33	Mt. Caroline Granites/Querekin	2001-2010 2002-2009	1 (2021)	Functionally extinct	Predation by feral cat and goat competition	Additional management of feral species (fox, cat, goat)
Cape Le Grand National Park	Reintroduction	22 10	Mt. Caroline The Granites/Querekin	2003-2004 2004	<30 (2022)	Declining	Most likely predation by feral cats	Additional predator management, genetic analysis, PVA
Durba Hills	Reintroduction	26	Calvert Range (Kaalpi)	2013	13 (2022)	Successful	Feral cat management (2012-2020)	NA
Gundaring/ Sales Rock	Wild + Reintroduction	2	Mt. Stirling	2013	37 (2018)	Successful	Intensive fox (1990s) and feral cat management (2016-2021)	NA
Kalbarri NP	Wild + Reintroduction	67 5	Mt. Caroline, Sales, Nangeen Exmouth	2016-2018 2018	70 (2019)	Successful	Integrated management of foxes, feral cats and goats	NA
Mt. Caroline	Wild + Reintroduction	21	Querekin	2013	180 (2022)	Successful	Intensive fox (1990s) and feral cat management (2016-2021)	NA
Nangeen	Wild + Reintroduction	17 1	Querekin Mt. Caroline	2013 2016	70+ (2020) 170 (2022)	Successful	Exclusion of all feral predators/other herbivores	Genetic augmentation + removal animals
Paruna Sanctuary	Wild + Reintroduction	19 59	Mt. Caroline Granites/Querekin Rock	2001-2007 2002-2010	<8 (2022)	Declining	Predation by feral cat and goat competition	Determine cause of decline

Querekin/The granites	Reintroduction	10 2	Nangeen Mt. Stirling	1990 2009-2010	Animals removed (2013)	Removed	Removal of land-holder permission to lay predator baits	NA
Walyunga	Reintroduction	29 27	Mt. Caroline The Granites/Querekin Rock	2002 2004	0	functionally extinct	Most likely predation and competition	Additional predator management

[1] Intervention is recommended if cause of the decline or failure (i.e., predation or low genetic diversity) is defined and managed.

Table 3. Sites within the historical range of rock wallabies, that can potentially support introductions or reintroductions (>50 carrying capacity, complex granite and feeding habitat).

Location (Carrying capacity)	Tenure (Total area)	Population estimates (status 2022)	[1] Monitoring (Year last monitored)	Regular feral Control (since)	Fire management	Weed and foraging habitat management
Cape Arid (100)	DBCA South Coast (280,000ha)	0	Nil	Fox (1996) and feral cat baiting (2011)	Prescribed burn	Require ground-truthing and management
Depuch Island (To be defined)	Karratha (155,399ha)	0	NA	Potential fox access at low tide	Require ground-truthing and management	Require ground-truthing and management
Jourdine Nature Reserve (To be defined)	DBCA Central Wheatbelt (1,816ha)	0	NA	Nil	Require ground-truthing and management	Require ground-truthing and management
Knungajin Hill Reserve (To be defined)	Dept. of Water (165ha)	0	NA	Nil	Require ground-truthing and management	Require ground-truthing and management
Peak Charles NP (To be defined)	DBCA South Coast (39,900ha)	0	NA	Nil	Require ground-truthing and management	Require ground-truthing and management
Karroun Hill Reserve (To be defined)	Central Wheatbelt (309,700ha)	0	NA	Nil	Require ground-truthing and management	Require ground-truthing and management

[1] Recommended regular monitoring to be conducted on an annual basis (if funds permit) to collect information on the health of populations (body weight, parasites, reproductive output) and collection of genetic material of recruits. In addition, camera traps should be deployed to monitor feral species.

7. Genetic diversity of BFRW populations

The success of translocations depends on the persistence of viable populations, on the preservation of genetic fitness and evolutionary potential (IUCN, 2012, Mijangos et al., 2015, Pacioni et al., 2018, Pacioni et al., 2020). Post-translocation monitoring is crucial to assess the short-to long-term demographic, and genetic success, including the harvest threshold of the source populations. Several unpublished genetic studies are available based on contemporary sampling of extant mainland BFRW populations using microsatellite genetic markers (Nilsson, 2022, Eldridge and Ottewell, 2015) and more recently, single nucleotide polymorphism (SNP) genetic markers (Ottewell, 2023, Buckley, 2023). Microsatellite markers are highly variable at the individual level and have been informative in describing population structure and genetic diversity but are often limited to small numbers of loci (10 – 20 loci). SNP markers are ubiquitous through the genome and are easily assayed through next generation sequencing, with population genetic studies based on many 1000's of loci offering higher precision in assessment of genome-wide genetic diversity.

7.1 Genetic structure amongst populations

Each of the genetic studies conducted have included slightly different subsets of BFRW populations due to the nature of the research question and/or as samples became available over time. Overall, however, each of the studies consistently show clear genetic distinction between each of the main geographic regions in Principal Component Analysis (PCoA), with Wheatbelt populations forming a distinct genetic cluster from Mid West (Cape Range, Kalbarri), Pilbara (Barrow Island) and Goldfields (Calvert Ranges/Kaalpi) populations (Figure 7a,b). Of the populations sampled, the Wheatbelt and Calvert Ranges populations are the most genetically differentiated. Only a small number of endemic Kalbarri BFRW individuals have been genetically analysed, but analyses indicate this population is intermediate between the Cape Range and Wheatbelt (Figure 7b).

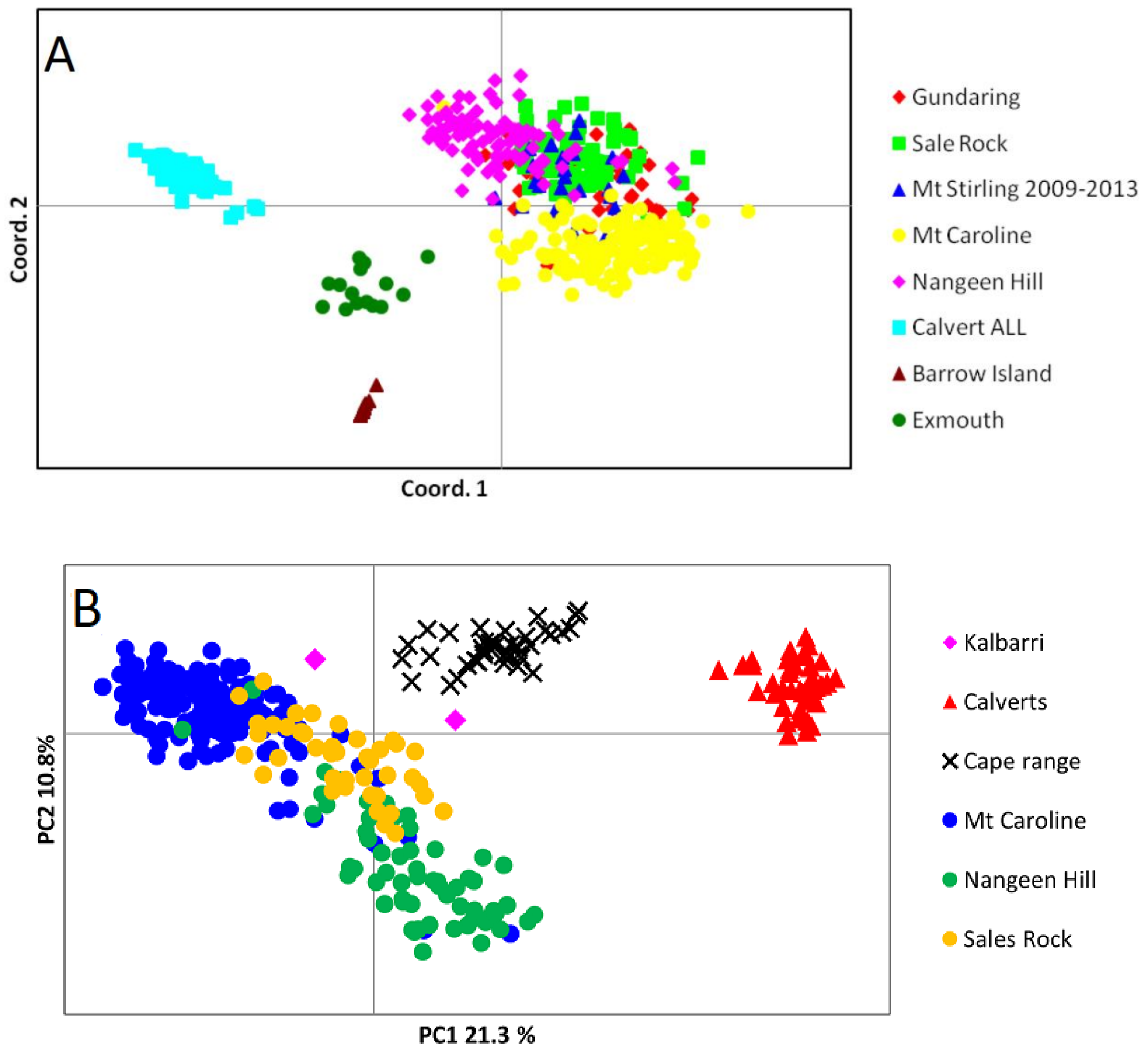

Figure 7. Similarity matrix (principal component analysis) indicating the genetic differentiation between the Wheatbelt, Mid West (Cape Range/Exmouth, Kalbarri), Pilbara (Barrow Island) and Goldfields (Calvert Ranges) populations of rock wallabies. Each point represents an individual's genotype. A: Similarity matrix based on microsatellite data from Eldridge and Ottewell, 2015. Data includes Barrow Island. B: Similarity matrix based on microsatellite data from Nilsson et al 2023. Data includes Kalbarri individuals.

Due to the ongoing interest in Wheatbelt populations as a source for translocations and supplementation, there have been several investigations of genetic diversity and genetic structure in this region. Broadly, the Wheatbelt subpopulations resolve into three genetic clusters (Figure 9A, E); one cluster includes Kokerbin, Sales Rock, Gundaring and Mt Stirling, another includes Nangeen, Paruna and Querekin and Mt Caroline forms its own genetic cluster. These groupings are present in both microsatellite (Nilsson, 2022) and SNP data (Buckley, 2023). Nilsson et al (2023) indicates a moderate amount of genetic differentiation amongst individual Wheatbelt populations sampled (Mt Caroline, Nangeen and Sales Rock; (F_{ST} = 0.107-0.146, p< 0.001) and comparatively greater differentiation between Wheatbelt and Cape Range BFRW populations (F_{ST} = 0.153-0.193, p< 0.001).

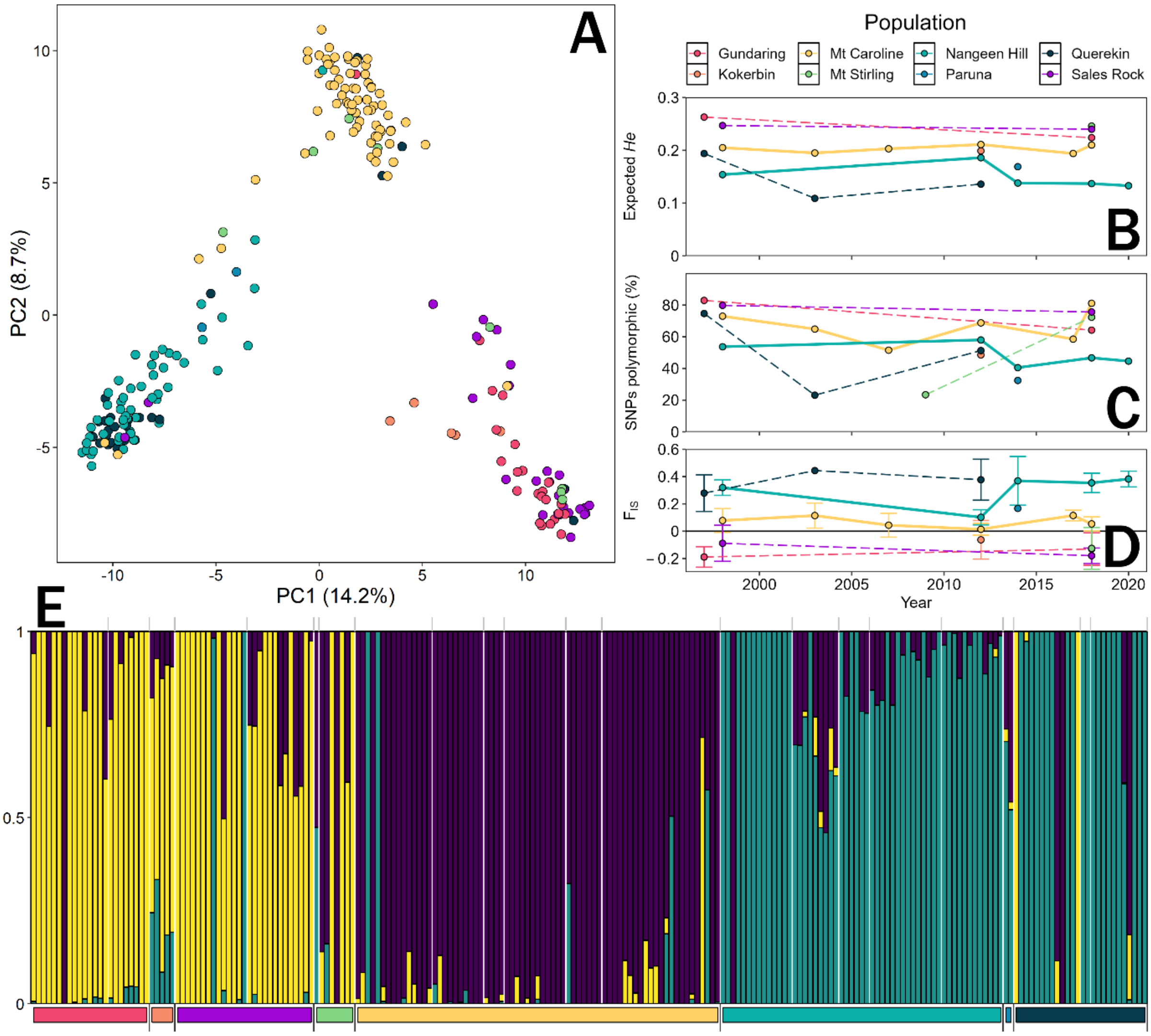

Figure 9. Population structure

and genetic diversity of black-flanked rock wallabies in the Western Australian Wheatbelt based on SNPs obtained from genomic (ddRAD) data (S. Buckley, unpubl. data). A) Principal coordinates analysis (PCoA). Colours indicate localities. B) Expected heterozygosity per population and cohort. C) The percentage of SNPs polymorphic within each population and cohort. D) Individual FIS per population and cohort. E) Admixture plot with K = 3. Coloured boxes on the lower axis indicate localities and white lines/gray tick marks separate temporal cohorts, with the oldest cohorts on the left.

7.3 Genetic diversity of possible source populations

Broad scale genetic diversity assessment indicates that the Cape Range BFRW populations contain the highest genetic diversity of the populations sampled, in terms of SNP heterozygosity (Figure 10a), microsatellite heterozygosity and microsatellite allelic diversity (Figure 10b). The Cape Range population also retains high numbers of private alleles (i.e. diversity unique to that population; Figure 10b). Expected heterozygosity and allelic richness is statistically higher in the Cape Range population relative to Wheatbelt populations ($p<0.001$, Table 4; (Nilsson et al., 2023)).

The Calvert Ranges/Kaalpi population shows reduced genetic diversity in microsatellite data compared to Wheatbelt and Cape Range populations, but in SNP data, observed heterozygosity in this population is moderate and comparable to some Wheatbelt populations (Figure 10a, b). The Calvert population, however, does exhibit some unique alleles (Figure 10b).

Amongst Wheatbelt populations, both Mt Caroline and Sales Rock retain significantly higher expected heterozygosity than Nangeen ($p<0.05$ Table 4; Nilsson et al, 2023). Genetic analysis of the Mt Stirling population has indicated it has quite high levels of genetic diversity in both SNP (K. Ottewell, 2023) and microsatellite data (Eldridge & Ottewell, 2015) relative to other Wheatbelt populations (Figure 10A). However, genetic analyses were conducted on samples collected in 2018 and the population has declined significantly since then (<10 animals estimated in 2022). Genetic re-assessment is likely to be required to confirm contemporary genetic diversity estimates, especially since genetic erosion has been documented for several wheatbelt populations between the 1990's and more recent estimates (2011 – 2012; Eldridge & Ottewell, 2015). Sales Rock and Gundaring represent similar genetic diversity to Mt Stirling and may be used as alternative sources.

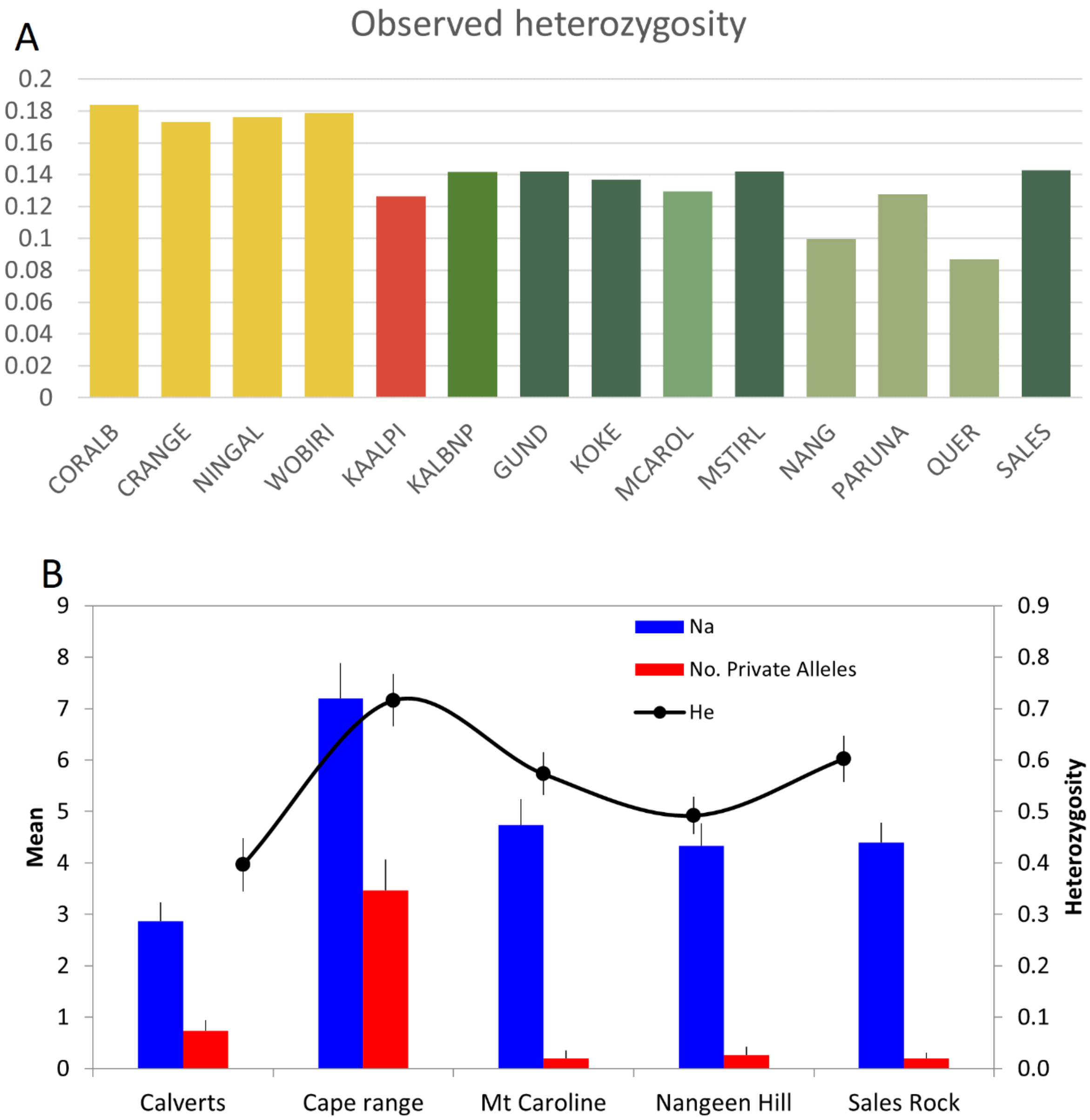

Figure 10. Genetic diversity estimates from BFRW populations from (A) SNP data obtained from genomic (ddRAD) sequencing (K. Ottewell, unpubl. data) and (B) A comparison of the genetic diversity parameters (number of alleles Na, number of private alleles [i.e. alleles unique to that population] and expected heterozygosity) from microsatellite data from Nilsson 2022.

7.4 Genetic diversity of the Kalbarri translocated population

The Kalbarri translocation was comprised of BFRW selected from multiple source populations, i.e. Mt Caroline, Nangeen, Sales Rock and Cape Range. As a result of mixing multiple populations the Kalbarri translocated population overall showed greater H_e and A_R estimates relative to the two main source populations, Mt. Caroline and Nangeen Hill (Table 4). Tukey pair-wise comparisons indicated that all Kalbarri translocated populations had a significantly higher H_e and A_R than Nangeen Hill ($p<0.001$), except for Hawks Head site 1, and only Z Bend and Four Ways had a significantly higher H_e and A_R than Mt. Caroline ($p<0.001$). Across Kalbarri translocated populations, Z Bend and Four Ways showed the greatest genetic diversity, with a significantly higher A_R ($p<0.05$). Parentage analyses have also indicated breeding between Wheatbelt and indigenous Kalbarri BFRWs at these sites (Nilsson et al., 2023).

In conclusion, the analysis of genetic diversity in three Wheatbelt and one Cape Range source populations and Kalbarri translocated populations, shows significant genetic structuring amongst populations, and that mixing of animals from multiple sources led to an increase in genetic diversity in the translocated populations at Kalbarri compared to Wheatbelt source populations. The average relatedness was also lower in the released populations than in each of the source populations. This successful translocation demonstrates that admixture is a viable strategy to supplement existing small populations and to establish new, diverse populations (see: Nilsson et al., 2023). Similar monitoring and genetic studies are recommended for further conservation translocations.

Table 4. Mean and standard error of genetic diversity parameters of the source populations, translocated populations at the end of the last monitoring session in 2020 (Nilsson et al., 2023). N = sample size, A_R = Allelic richness; H_o = Observed heterozygosity; H_e = Expected heterozygosity.

Population	*N*	A_R	H_o	H_e
Source populations				
Mt. Caroline	139.5 (0.2)	2.54 (0.14)	0.55 (0.041)	0.55 (0.041)
Nangeen Hill	55.3 (0.2)	2.31 (0.1)	0.468 (0.043)	0.486 (0.036)
Sales Rock	38 (0)	2.61 (0.12)	0.616 (0.053)	0.574 (0.041)
Cape Range	40 (0)	3.46 (0.21)	0.717 (0.055)	0.714 (0.051)
Translocated populations (Kalbarri)				
Z Bend	5.4 (0.2)	3.05 (0.14)	0.441 (0.055)	0.659 (0.021)
Four Ways	29.9 (0.1)	3.06 (0.14)	0.568 (0.027)	0.663 (0.032)
Hawks Head site 1	30.8 (0.1)	2.7 (0.14)	0.520 (0.037)	0.578 (0.043)
Hawks Head site 2	24.9 (0.1)	2.79 (0.1)	0.547 (0.036)	0.606 (0.028)

7.5 Population viability analysis

Population viability analyses (PVA) are used in planning and evaluating conservation actions to assist with managing trade-offs when planning translocations. One of the PVA aims is to assess the probability that a population will persist for a specified time period, which may include sensitivity analysis, harvesting threshold and supplementation.

Recent PVA modelling shows the smaller Wheatbelt sub-populations are sensitive to changing demographic rates, especially adult and juvenile rate mortality, and female reproductive rate (Figure 11).

Modelling estimated that harvesting large numbers of animals at frequent intervals of five years had greater impacts on the Nangeen Hill population than at Mt. Caroline. Additional simulations at 10 years post-harvest estimated that Nangeen has a harvest rate threshold of approximately 40 animals (Figure 12) and Mt. Caroline approximately 50 animals (Nilsson, 2022).

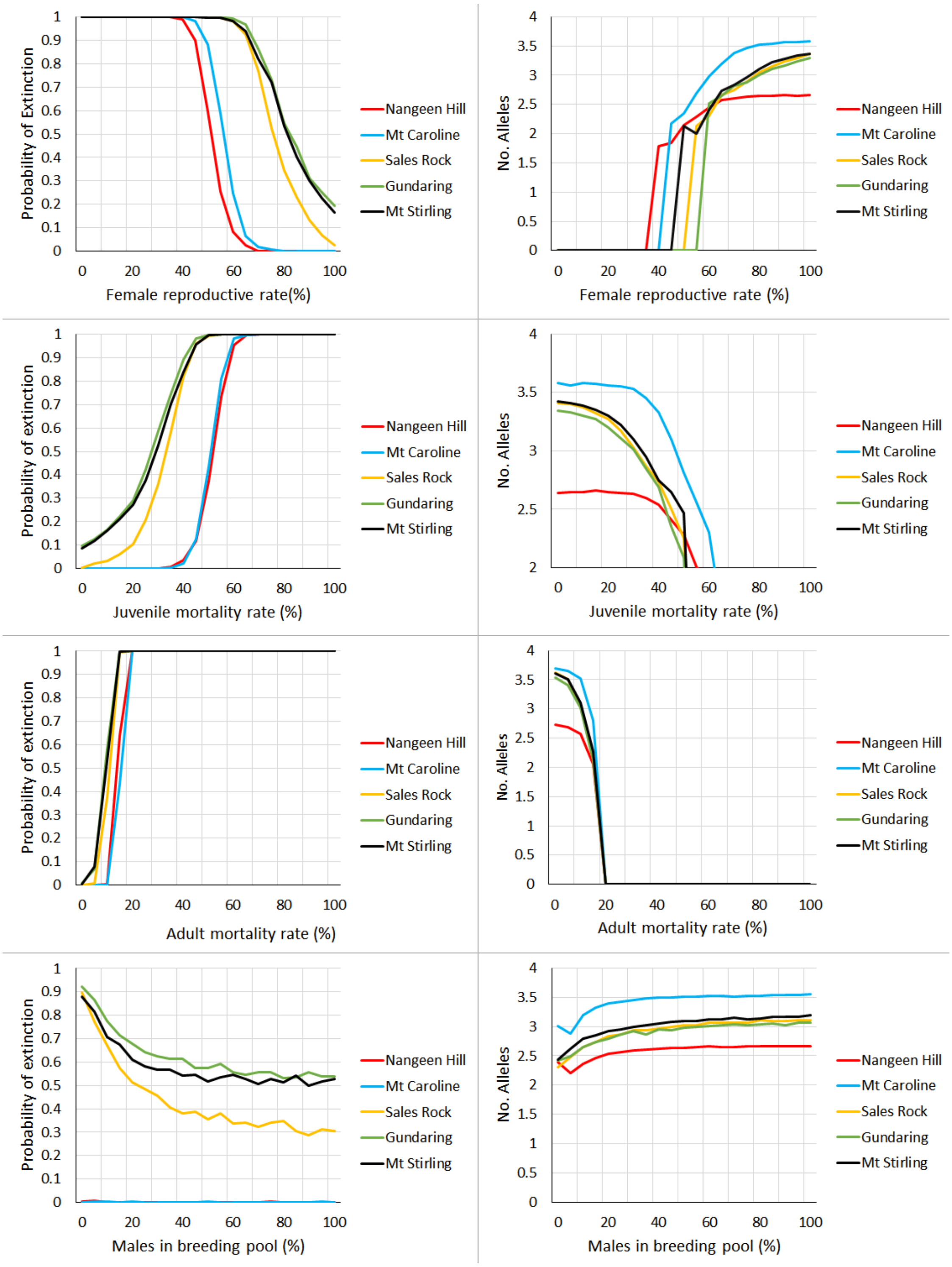

Figure 11. Sensitivity testing demonstrating the probability of extinction and no. of alleles as a response to varying demographic parameters in the PVA model.

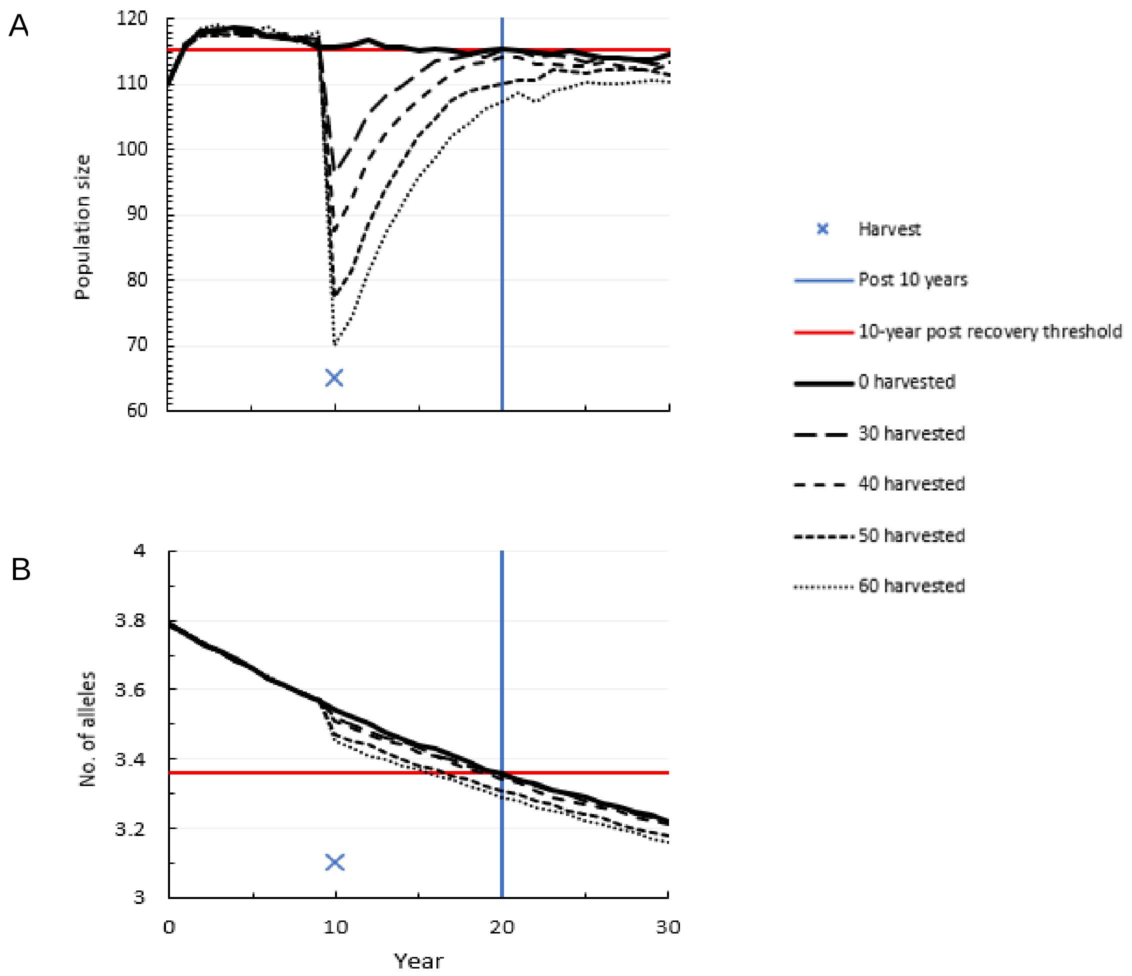

Figure 12. Nangeen population PVA harvest simulation, 1:1 sex ratio, 30 harvested comprises of 15 males and 15 females. A) Nangeen population size 10 years post-harvest in response to varying harvest rates. B) Number of alleles 10 years post-harvest in response to varying harvest rates.

Further simulations estimated the supplementation rates required to increase genetic diversity within the Nangeen Hill population. Analyses indicated that supplementation with a minimum of ~12 individuals from Mt Caroline and Sales Rock/Mt Stirling would greatly increase allelic diversity within the Nangeen Hill population. Supplementation with larger numbers of individuals contributes additional diversity but the genetic gain per individual added to the population is less and plateaus around 30 individuals (Figure 13a). Supplementing from multiple source locations to Nangeen Hill only appears to make a difference (in allelic diversity and expected heterozygosity) when more than ~15 males are supplemented and even then, differences are minor in comparison to sourcing all animals for supplementation from the large Mt Caroline population (Figure 13a,b). Given the capability of the Mt Caroline population to sustain a larger harvest, the best approach would be to source directly from Mt. Caroline or from a mixture of Mt. Caroline and Sales with a 3:1 ratio.

These results are an effective guidance for Nangeen population management. Further simulations should be performed if considering translocations for other sub-populations to assist the decision-making context.

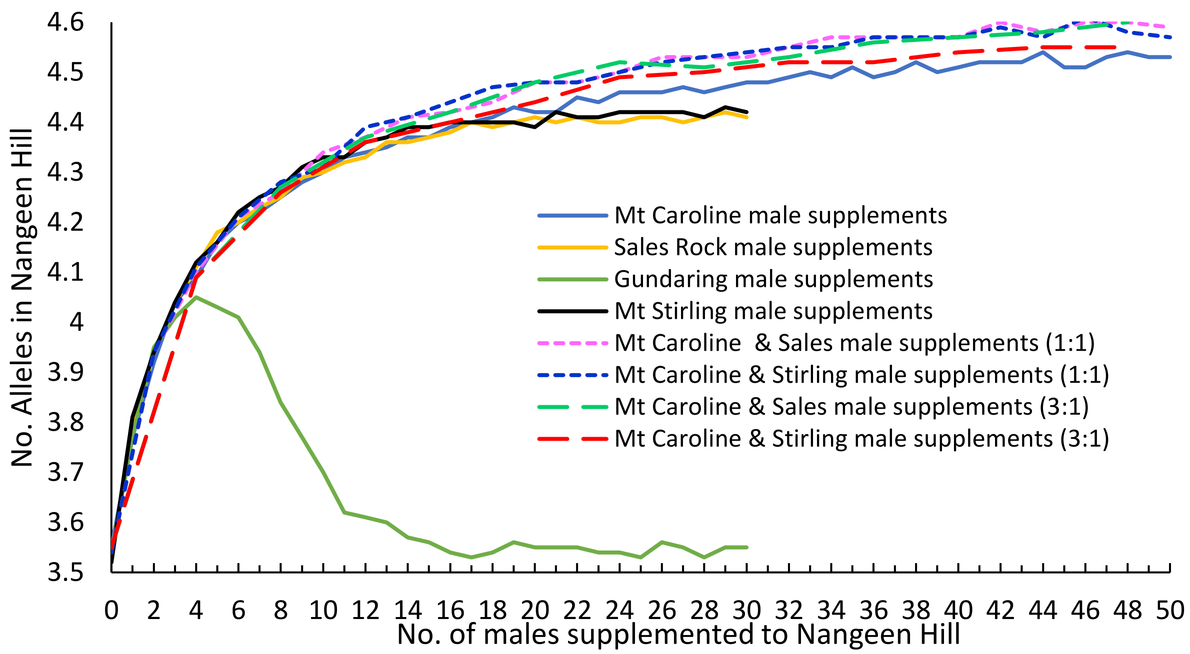

Figure 13a. Number of alleles present in Nangeen Hill in response to varying male supplementation rates. 1:1 ratio indicates equal number of supplements (e.g., 12 supplements consist of 6 from Mt Caroline and 6 from Sales Rock), and the 3:1 ratio indicates non-equal number of supplements (e.g., 12 supplements consist of 9 from Mt Caroline and 3 from Sales Rock).

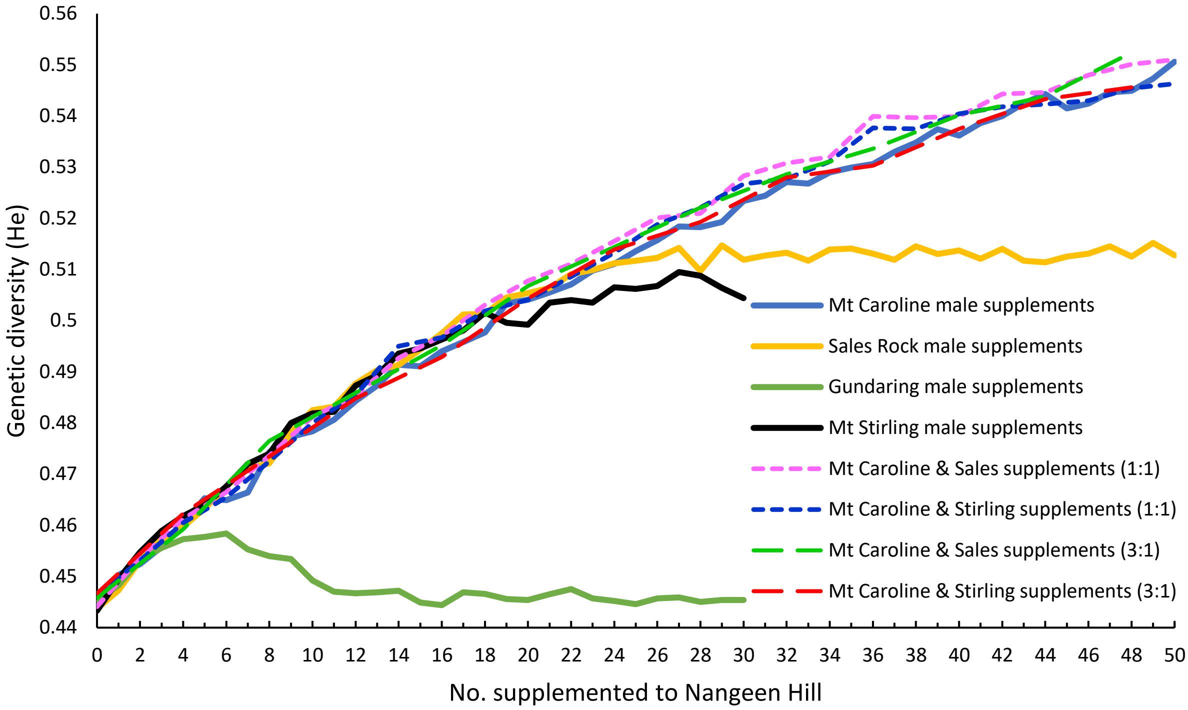

Figure 13b. Genetic diversity in Nangeen Hill in response to varying male supplementation rates. 1:1 ratio indicates equal number of supplements (e.g., 12 supplements consist of 6 from Mt Caroline and 6 from Sales Rock), and the 3:1 ratio indicates non-equal number of supplements (e.g., 12 supplements consist of 9 from Mt Caroline and 3 from Sales Rock).

8. Decisions drivers for population re-establishment or sites requiring intervention

Many processes can contribute to the decline and extinction of populations, such as predation by foxes (*Vulpes vulpes*) and feral cats (*Felis catus*), competition for resources by feral goats (*Capra hircus*), rabbits (*Oryctolagus cuniculus*) and camels (*Camelus dromedarius*) (see: Pearson, 2013). These factors are exacerbated when combined with habitat fragmentation and loss, habitat degradation (i.e., weed incursion), dietary competition from native herbivores, variable climatic conditions, and inappropriate fire regime. The 2013 recovery plan has defined objectives and actions to manage these processes to ensure the survival of BFRW within each population. However, many of these processes will need to be considered in the decision-making process as part of this PMS. Below is a summary of current knowledge of these processes providing background for the development of the decision framework.

8.1 Climate change

Predictions indicate that south-western Australia is likely to experience a decline in rainfall, higher summer temperatures and more variable weather patterns in the future (Andrys, 2016). This will increase the likelihood and frequency of drought and subsequent habitat degradation. Rainfall is positively correlated with body condition and reproductive rates in wheatbelt rock-wallabies, therefore declines in rainfall may lead to declines in population abundances (Willers et al., 2011). The extinction of the rock-wallaby from the Leeuwin-Naturaliste Region in the Mid-Holocene has been attributed to climatically driven encroachment of closed habitat (Dortch, 2004). All the remaining rock-wallaby sub-populations in WA are effectively genetically closed populations, restricting any possible evolutionary response to climate change, therefore highly susceptible to climate driven changes in their habitat.

8.2 Fire

Fire has played a fundamental role in the evolution of Australia's biota and continues to be a key driver of many of its ecosystems. Changes to the frequency and intensity of fire due to direct human activities and climate change can have devastating impacts for a range of species (Povh et al., 2022). Climate change models suggest that the number of extreme weather days will increase and there will be greater risk of wildfires (Di Virgilio et al., 2019, Van Oldenborgh et al., 2021), that are likely to burn with greater intensity. This poses a high risk to animals in highly fragmentated landscapes as individuals cannot readily move away from burned areas to find appropriate habitat (Povh et al., 2022), and the loss of food resources immediately after the fire may result in starvation for surviving individuals. Therefore, fire management is crucial to minimise the impacts to BFRW and their habitats.

Fire management may involve smaller low intensity prescribed burns to reduce the intensity of unplanned fires and to regenerate senescing vegetation. Research on the impacts of prescribed burning on fauna is limited and responses are likely to be site specific. Fire management should be a key consideration when considering a site for supplementation or re-establishment of BFRW.

8.3 Habitat degradation

The reduction in native vegetation cover due to clearing, drought and over-grazing has led to weed invasion within many rock-wallaby habitats. These weeds are often not palatable or hold very little nutritional value but grow quickly excluding native or more appropriate species, resulting in reduced availability of food resources (Pearson, 2013). At many of the wheatbelt sites *Cleretum papulsum* has become established preventing more palatable plants from growing.

8.4 Habitat fragmentation and genetic drift

Many remaining rock-wallaby sub-populations in WA are extremely small (less than 50 individuals) and all populations are either in highly fragmented landscapes or are physically isolated by either fences or geography (Jones Lennon et al., 2011, Pearson, 2013, West et al., 2018). As such there are very few opportunities for natural gene flow between sub-populations. All populations of BFRW within WA are therefore at risk from genetic drift, with the smallest populations most endangered.

In addition, the highly isolated nature of each sub-population increases their risk of localized extinction as geographic or physical barriers minimize the capacity for individuals from other populations to repopulate the area should a population be lost.

This combined with the small number of populations within the larger metapopulation means the loss of one population will have substantial impacts on the species' genetic pool. Further, given the distribution of BFRW populations across multiple climatic zones implies the species retains substantial adaptive variation. Increasing the number of populations and maintaining those across climate gradients will be important for the long-term conservation of this species.

8.5 Human interactions and unstable tenure

In the Wheatbelt, many populations of BFRW are situated in close proximity to private land. Landholders adjacent to BFRW reserves have previously experienced issues with BFRW damaging crops and farm machinery (Willers, 2013, Willers et al., 2015). This has led to objections and in some instances requests for the removal of animals. This can cause conflict with adjoining private landholders. Population maintenance and re-establishment needs to consider these possible conflicts and ensure that adjoining landholders are supportive of BFRW interactions and potential tourism.

8.6 Predation

Foxes will hunt and kill large numbers of rock-wallabies in short periods of time, and they have been implicated in local extinction events (e.g. Depuch Island) (Kinnear et al., 2010, Kinnear et al., 2002). However, despite intensive management of foxes at many BFRW populations some populations of BFRW in WA continue to decline. Recent evidence has strongly implicated feral cats in the decline of many populations of rock-wallabies throughout Australia (e.g. Anderson et al 2022, Read et al, 2019, Tuft et al 2011). Implementation of integrated feral cat and fox management at several sites has shown positive population responses (e.g. Cape Range NP, Kalbarri NP, Nangeen exclosure). Both foxes and feral cats must therefore be managed simultaneously to maximise the long-term viability of BFRW populations. A key component of this management includes managing other food sources for foxes and feral cats in the surrounding landscape, including rabbits (Hayward et al., 2011, Robley et al., 2004).

8.7 Resource competition

An overabundance of native macropods and/or introduced herbivores can be detrimental for rock-wallaby habitat and contribute to their decline (Hayward et al., 2011, Pentland, 2014, White and Fleming, 2021). White and Fleming (2021) identified that roughly 56% of the diet of the western grey kangaroo (*Macropus fuliginosus*) overlapped with BFRW and (Creese et al., 2019) identified a significant competitive overlap with BFRW and the feral goat (*Capra hircus*) at Cape Range National Park. The increased competition for food from other herbivores may force rock-wallabies to forage in poorer habitats often further from their refuges, and potentially expose them to greater predation risk. Habitat and dietary competition between rock-wallaby and other herbivores may well intensify with recurrent drought and bushfire (White and Fleming, 2021).

Recent studies in the Wheatbelt, report the high consumption of Veldt grass (*Ehrharta* spp.) by BFRW in areas with limited alternatives (Chauvin, 2015, White and Fleming, 2021). This suggests that Veldt grass has likely replaced part of their natural diet. If this species is to be managed replacement native vegetation sources would need to be available to prevent a lack of food resources for BFRW (White and Fleming, 2021).

BFRW relies on access to deep caves to provide thermal and predator refuge. Thermal refuge is particularly important during summer months and during drought (Pentland, 2014). Introduced goats and feral bees can push BFRW into marginal habitat where thermal and predator refuge availability is limited. This will place them at risk from dehydration and increased risk from predators (Hayward et al., 2011).

9. BFRW populations and Decision-making context for management options

Each BFRW population will have additional objectives that will need to be considered in the broader context of population management.

Specific threat management (section 8) that does not relate to genetic management or population supplementation or re-establishment is covered under the Recovery Plan.

9.1 Avon Valley populations

Multiple translocations using animals from primarily wheatbelt sites were conducted between 2001 and 2010 in an attempt to re-establish viable BFRW populations along the Avon Valley and Walyunga National Parks, and Paruna Wildlife Sanctuary.

Although initial responses to threat management were promising, increasing feral cat and goat activity combined with only limited available habitat resulted in the functional loss of both Avon Valley and Walyunga colonies and the ongoing decline of the population at Paruna. The topography of the sites and proximity to an intensive urban development make threat management extremely difficult, particularly when managing feral cats. More intensive threat management will need to be implemented if these sites are to be considered appropriate for re-establishment/supplementation into the future.

9.1.1 The Avon Valley and Walyunga NP population is considered functionally extinct and no longer supports viable populations without intervention. Intensive management of feral species will be fundamental to re-establishing the colony.

There are three management options:

1. Improve the management of invasive species in AVNP and supplement with individuals from Wheatbelt source populations with high genetic diversity, such as Mt. Caroline and Gundaring/Sales Rock (1:1 sex ratio). *Note: Unknown carrying capacity due to uncertainty around the extent of habitat in the park, and therefore not able to define the number of individuals to supplement AVNP.*

Comprehensive habitat surveys would be beneficial to inform the future value of re-establishing this population.

2. Regular monitoring (trapping, SECR, PVA and assess genetic diversity – see Table1 and 3) with the aim of determining survival and causes of mortality
3. Relocate the remaining animal and improve the management of AVNP (Table 1 and 3) for future reintroduction.
4. Do not intervene.

9.1.2 Paruna population will require a high level of management to ensure the population is maintained.

The population estimate for 2022 at Paruna was the lowest since 2011 (Figure 14), the increase in goat numbers has likely been an additional stressor and the population is now considered to be in imminent danger of extinction.

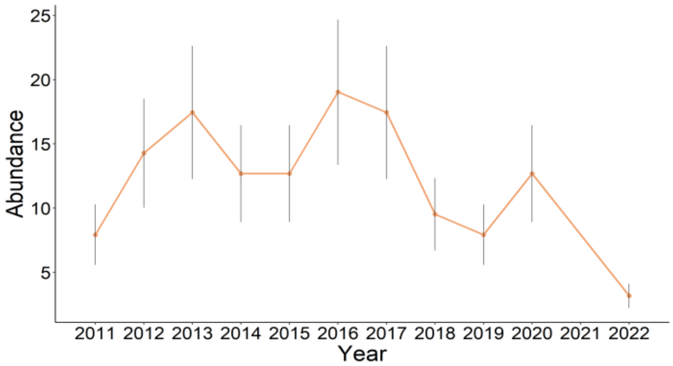

Figure 14. BFRW mark-recapture population estimates at Paruna.

There are three management options:

1. Improve the management of invasive species in Paruna and supplement with individuals from Wheatbelt source populations with high genetic diversity, such as Mt. Caroline and Gundaring/Sales Rock (1:1 sex ratio). The site could be considered within the supplementation matrix with AVNP.

2. Regular monitoring (trapping, SECR, PVA and assess genetic diversity – see versioTable1 and 3) with the aim of determining survival and causes of mortality.

3. Do not intervene

9.2 Goldfields populations

9.2.1 Calvert Ranges is an extant indigenous population which has been supported with annual aerial feral cat baiting (Eradicat) since 2003.

Management options:

1. Require ground-truthing for fire and weed management.
2. Require PVA analysis.
3. Do not intervene.

9.2.2 Durba Hills was re-established in 2013 from 26 animals sourced from the Calvert Ranges and has been subject to annual aerial feral cat management (Eradicat) from 2012 to 2022. The area is regularly monitored using cameras. In 2021, trapping was conducted to assess the population size, and identified seven new individuals (3F, 4M). Two of the females had pouch young. One subadult captured. All in good health. Traps within the Pinpi gorge were set along the top of the range, an additional five individuals were also captured.

Management option:

1. Require PVA and genetic diversity analyses.

9.3 Midwest populations

9.3.1 Cape Range NP is the largest and most stable indigenous BFRW population, that was used in 2018 to support the supplementation of BFRW at Kalbarri NP (below). Intensive fox (1996–2017) and feral cat management (2012–2022) within Cape Range and surrounding areas has seen the populations of BFRW expand along the extensive gorge systems present in the park and in the adjoining crown and defence land. The Cape Range population has unique alleles, high heterozygosity and is one of the larger extant populations in Western Australia.

The number of animals in the Pilgonomon Gorge were estimated to be around 60 animals in 2020; however, populations now exist in many of the gorges across a 100 km stretch of the area. Populations at Bungelup, Mandu, Pilogonomon (Figure 15) and Yardie Creek (Figure 16) gorges have been regularly monitored with point count methods. More recently a number of these and additional sites have been monitored with cameras to determine BFRW presence, and trapping has been conducted at some sites as part of translocation monitoring.

Foxes have rarely been recorded in the Cape Range NP since 2017. Feral cat incursions are limited and are quickly addressed through intensive trapping in the vicinity of the sighting. Intensive management of goats has resulted in a low density of goats and ground shoots are conducted when required. Weed management is ongoing within the park.

Increasing visitor numbers to the gorges and the expansion of BFRW into other gorges is negatively impacting on more recent point counts. However, estimates indicate that there are well over 200 animals currently residing across the gorge system of the Northwest Cape.

Management options:

1. Potentially considered as a source.
2. Before considering harvest, PVA modelling is advised to determine sensitivity and the harvest rate threshold.

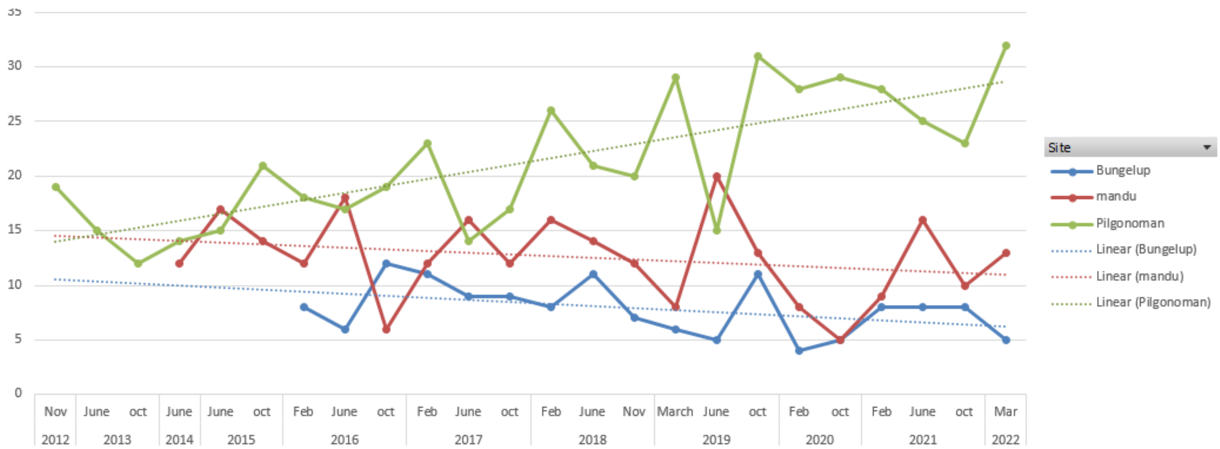

Figure 15. Population estimates at Cape Range National Park.

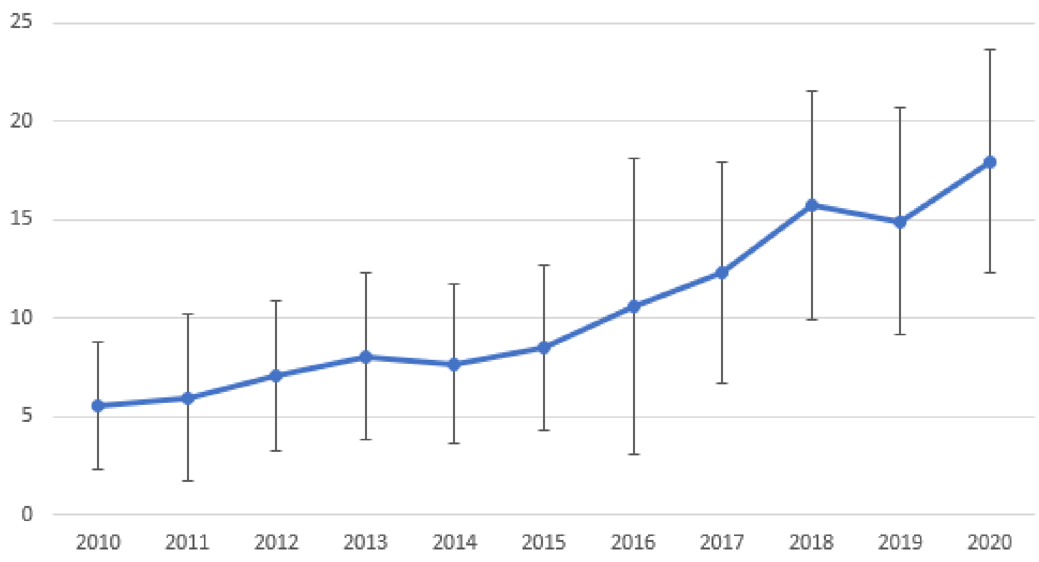

Figure 16. Mean (±S.D.) of BFRW counts at Yardie Creek.

9.3.2 Kalbarri NP

The population of BFRW at Kalbarri was until 2015 considered extinct. However, photographic evidence provided by a rock-climber identified three individuals in 2015. Between 2016 and 2018, 72 animals have been translocated from Mount Caroline (46), Nangeen (18), Sales (3) and Cape Range (5) into three primary locations with the gorge area of the National Park to supplement the extant population. Genetic analysis has indicated successful breeding of translocated animals, with several successful pairings between Kalbarri and Wheatbelt animals. Recent surveys indicate an estimated population of 100 individuals.

The NP is actively managed for goats using aerial goat shoots and the park has been regularly baited for foxes since 1996. Annual aerial and regular ground feral cat baiting was integrated into the baiting program in 2016. There is an extensive and complex gorge area within the National Park with the capacity to support 500 or more animals.

Management options:

1. Do not intervene.

9.4 Pilbara Populations

9.4.1 Barrow Island is free of introduced predators and herbivores. The BFRW on the island have been separated from the mainland for approximately 8000 years. The Barrow Island population has unprecedented low levels of genetic variation and suffers from inbreeding depression (reduced fecundity, skewed sex ratio, increased levels of fluctuating asymmetry) and a small effective population size (Eldridge et al., 1999)

Surveys have not been regular, but a recent survey in 2021 indicated that the population remains stable with a total of 55 individuals, compared to 50 in 2004 and 40 in 2005. Higher than average (277.5mm) rainfall in 2021 (385.8mm) and 2022 (428.4mm) will likely have improved conditions for animals on the island.

Management options:

1. Intervention not considered necessary at this time point9.5 Southcoast populations

9.5.1 Salisbury Island is free of introduced predators and herbivores. The BFRW on the island have been separated from the mainland for about 10,000 years and the population suffers from low genetic diversity.

The population on the island has not been monitored recently except via camera traps. Estimates suggest the population is around 500, however no systematic surveying has been completed in recent years.

Management options:

1. Require PVA and genetic diversity analyses.
2. Consider genetic reinforcement.

9.5.2 Cape Le Grand BFRW population was re-established in 2004. The recent 2022 camera trapping monitoring determined the population is in decline.

Management options:

1. Regular monitoring is recommended (trapping, SECR, PVA and genetic diversity – see Table 1 and 2) with the aim of defining the cause of the decline.
2. Once the cause of the decline is defined and the threats are ameliorated the site could be considered within the supplementation matrix.

9.6 Wheatbelt populations

There are six remaining sub-populations in the wheatbelt. Most of these sites have been used intermittently for the re-establishment or supplementation of BFRW populations around the state.

9.6.1 Nangeen Hill Nature Reserve

Nangeen Hill Nature Reserve was fenced in 2013. Current abundance estimates using a spatially explicit capture recapture (SECR: Efford, 2022) suggest the population is at around 170 individuals and is likely at carrying capacity (Figure 17). This population will require a high level of management to ensure the population is maintained appropriately as an insurance population, with particular attention needed to ensure this population is genetically diverse (see below).

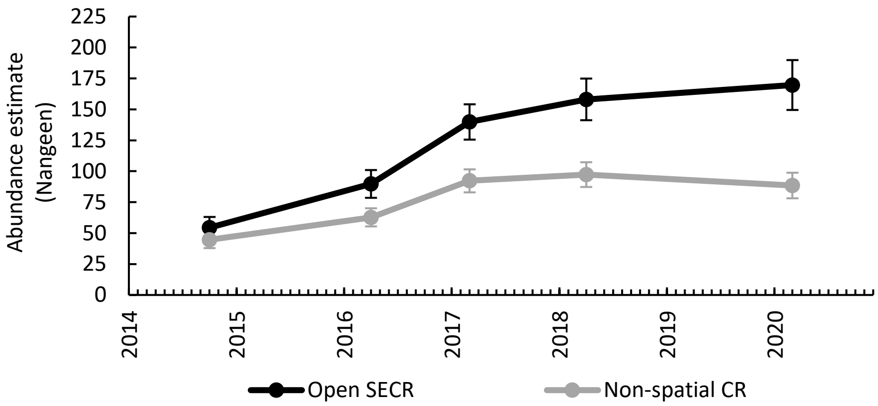

Figure 17: Abundance estimates (±SE) of BFRW at Nangeen calculated by non-spatial (grey) and spatially explicit capture recapture assuming an open (black) population.

Nangeen has previously been used as a source site for several translocations, but as identified previously has limited genetic diversity. The PVA estimated a harvest rate threshold of approximately 40 animals. Note that harvesting large numbers of animals at frequent intervals of five years had greater impacts on this population.

The extant population is likely above the carrying capacity of the current exclosure and has low genetic diversity.

Management options:

1. Based on the population genetics and PVA outlined in section 7.5 of this document, modelling suggests that the population requires at least 12 males (Figure 13a, b) added to the population to improve the overall genetics. Males can be sourced from Mount Caroline and potentially from Sales Rock at a ratio of 3:1. This will provide a boost in genetic diversity within the population to

improve its capacity to act as an insurance population. This, however, will require additional management of the overall population size to be effective.

2. A number of animals will need to be removed to minimize the risks to the resource availability within the exclosure and to facilitate improved genetic composition. PVA modelling indicates that if 30 animals are removed the population at Nangeen will likely return to the current size within 5 to 10 years (Figure 12). As an example, this could mean a total of 40 BFRW are harvested from the site for reestablishment/supplementation at other locations and a total of 6 to 12 animals are added to Nangeen from surrounding suitable populations to provide the required genetic boost within the exclosure.
3. In this case, approximately 40 animals should be relocated between 2023 and 2024 to either supplement or re-establish other populations, such as Cape Le Grand NP (supplementation) or Cape Arid (proposed translocation in 2023). With consideration given to mixing with other source populations to ensure a diverse genetic base.
4. After regular monitoring (short- to medium-term, see Table 5) Nangeen should receive a supplementation of 10 BFRW from a mixture of Mt. Caroline and Sales with a 3:1 ratio, and continue with monitoring (+5 years) to confirm the genetic diversity is maintained.

9.6.2 Mt Stirling

The population at Mt. Stirling has not been monitored regularly since 2011. In 2011 it was identified that the population was declining rapidly, and attempts were made to salvage the remaining animals to nearby reserves in 2013. However in 2018 nine animals were identified as persisting at the site. Model estimates suggest the population at the time was around 13 individuals (Figure 18).

No surveys were completed between 2019 and 2022. However, if the population remains it is likely to be very small and have limited genetic viability. The site once supported up to 15 known individuals with model estimates suggesting that in 2010 the population was likely around 45 (± 15) animals. It is likely that drought combined with increasing pressure from feral predators and the removal of animals in 2013 has limited the populations capacity to recover.

Management options:

1. Survey is recommended (update SECR, PVA and genetic diversity).
2. Salvage the remaining animals.

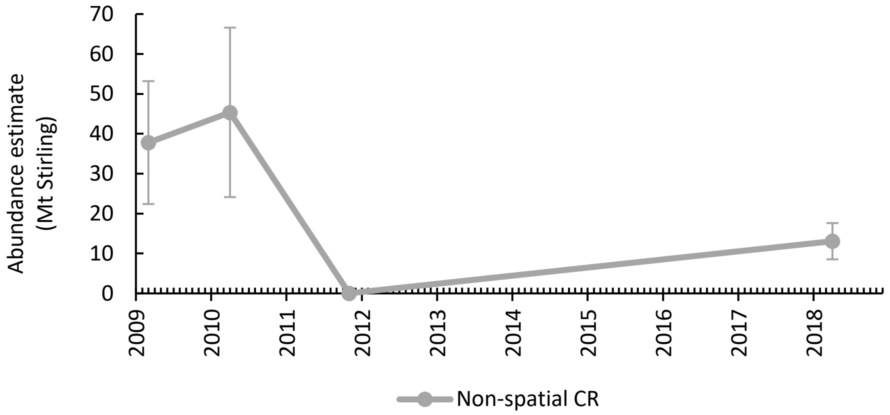

Figure 18. Abundance estimates (±SE) of BFRW at Mt. Stirling calculated by non-spatial capture recapture (grey). population (black) and a closed population (blue).

9.6.3 Mt Caroline Nature Reserve

The Mt. Caroline population has been monitored systematically since 2001. Abundance estimates suggest the population has approximately 180 individuals (Figure 19 - Nilsson, 2022). In terms of habitat area this is one of the larger rock formations that supports BFRW in the wheatbelt. It has played a critical role in the supplementation of declining populations and attempts to re-establish populations around the state.

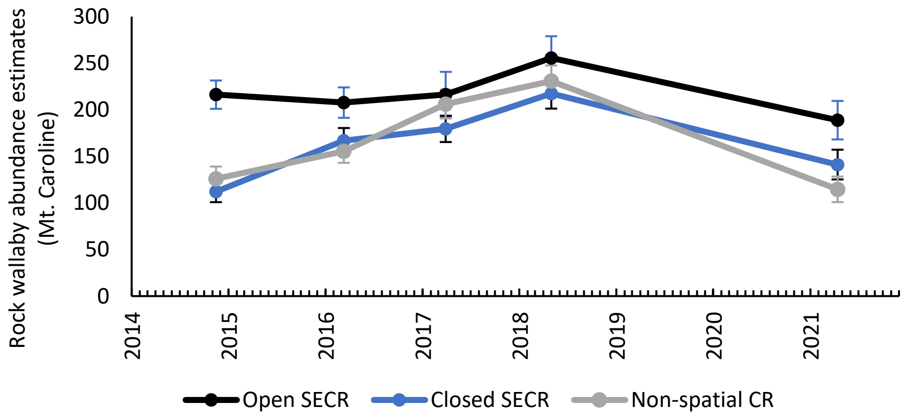

Figure 19. Abundance (±SE) of BFRW at Mt. Caroline using both non-spatial and spatial capture recapture methods. SECR was conducted assuming both an open population and a closed population,

*using a 50m buffer area around trap sites (according: Pentland, 2014) *Trapping effort was significantly reduced in 2021 and estimate for this session is lower than expected due to this bias.*

The Mt. Caroline population has been the source for many reintroductions. This sub-population has high genetic diversity, and a harvest rate of approximately 50 animals is suggested to be viable at the current population size (see section 7.5). However, there is fine-scale genetic structuring across the Mt Caroline population that should be considered in any harvest of animals. Gene flow was restricted between some parts of the reserve, even though they were separated by as little as 950m, and was largely driven by females (Willers, et al., 2014). Harvest of animals should target representative parts of the reserve in a stratified approach to ensure minimal genetic impacts.

Management options:

1. Keep monitoring for abundance and genetic diversity

9.6.4 Gundaring NR and Sales Rock

Gundaring Nature Reserve and the adjacent privately owned Sales Rock have been intermittently monitored since 2008. Monitoring indicates that the population has steadily increased from 2008 to 2018. Monitoring in 2018 identified 37 individuals, but no monitoring has occurred since then (Figure 20). Population modelling has yet to be completed on this population but based on 2018 data the population was likely to be around 50 animals in 2018.

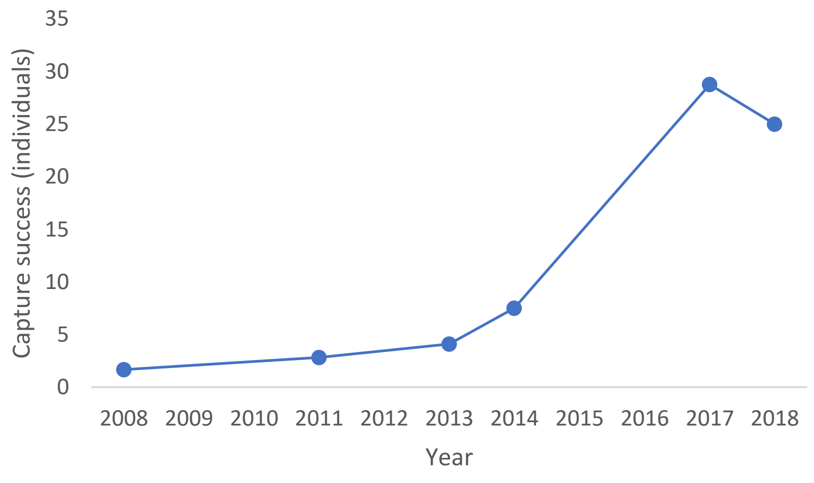

Figure 20: Relative abundance of BFRW at the Gundaring/Sales population over time.

Management options:

1. Keep monitoring for abundance and genetic diversity
2. Continue management and landholder engagement
3. Reassess reinforcement feasibility in the future

Mount Caroline NR, Mt Stirling NR, Gundaring NR and Sales Rock (private) are baited for foxes fortnightly. As Nangeen Hill NR has a predator-exclusion fence, intensive baiting is only undertaken if there has been a suspected breach. Several canid pest ejectors (CPE) are also maintained within Nangeen Hill NR. Intensive feral cat, fox and rabbit trapping was implemented by Wheatbelt NRM in the period 2016 – 2021. Some private landholders continue to manage introduced species by trapping or shooting rabbits, foxes, and feral cats around BFRW habitat.

10. Population Management Strategy and Decision Workbook

As part of the translocation process, subsequent monitoring, genetic material, and the tracking of individual fate has been routinely collected to understand the value of each population genetically and its population trajectory. This information can now be incorporated into the long-term planning process.

In an effort to facilitate the assessment and management of each BFRW population to determine their ranking as either source site for future population augmentation, re-establishment or to assess the suitability of a new site (i.e., historical sites – Table 3) we designed a decision workbook (Appendix 2).

For the purpose of the assessment and use of the workbook, ensure that the most current information is available to maximise the chances that the assessment will provide the best conservation outcomes for the species.

Within the decision-making process the assessment will be directed by the following principles:

1. Appropriate genetic knowledge and diversity of the BFRW population to ensure appropriate genetic input to apply minimal risk of outbreeding depression at the receiving site.
2. Population sufficiently large to tolerate harvest of BFRW for the life of the planned translocation (noting that multiple source sites can be considered for one receiving site).
3. Sites at risk of overpopulation (i.e. fenced reserves) must form part of the source site selection matrix with consideration of the genetic requirements at the receiving site.
4. The receiving site has secure tenure that will enable the long-term management of the population.
5. Key threatening processes have been adequately managed prior to the translocation and there is an ongoing capacity and resources to manage threatening process long-term.

6. Sufficient habitat to support a viable population, with emphasis on identifying new receiving sites that can support larger populations (e.g. 100+).
7. Logistically feasible to access for monitoring and ongoing management.

11. Definition of success

Assessment of success or failure of each population should be based on risk assessment guidelines of the IUCN SSC (2013) and further divided to short term (release to 12 months), medium term (1–5 years) and longer term (5 years) in order to better identify success or failure. An example of success/failure criteria are provided in Table 5. In the Wheatbelt context each movement of animals between sites may be to meet one or more objectives, so the criteria should relate to each specific objective, for example maintenance of genetic diversity, increase in sub-population size to reduce risk of extirpation.

Table 5. Success and failure criteria for BFRW populations, based on risk assessment guidelines of the IUCN SSC (2013).

	Success	*Failure*
Short ***(12 months)***	Survival of 75% of founder individuals. Founders established home-range (confirmed by radio-tracking) and live trapping data (body mass gain). Evidence of pouch young and young at foot produced with first 12 months (live trapping and camera trap).	Mortality of ≥50% of collared founder BFRWs within 6 months post-release. Home-range restricted to the release area and loss of body mass after translocation of ≥ 50 % of founder individuals post-release. No evidence of pouch young.
Medium ***(1-5 years)***	Evidence of recruitment, monitored by camera trap, identifying individuals by physical characteristics (i.e. natural body mark) of juveniles and their mothers (ear tagged) relative to the location of cameras should allow an estimate of the number of young born. Maintenance or increase of body weight. Population extant after 5 years.	Poor recruitment (<25%) of young to adult within three years.
Long ***(5+ years)***	Genetic diversity maintained. No skewed paternity (Pedigree analysis). Minimal intervention required.	Population size decline. No or poor recruitment. Paternity skewed.

Self-sustained population.

12. References

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Appendix 1 Strategies and Actions to Achieve Goal and Objectives (*reference to actions in the Recovery Plan, Pearson 2013)

Objective	Target	Strategies	Actions	Lead Agency/ Stakeholders	Performance Measures
Maximise the genetic diversity and resilience of Black-flanked Rock-Wallaby (Petrogale lateralis lateralis)	Develop a population model to inform genetic management of wheatbelt and associated populations.	Population monitoring to understand population trends and inform population modelling (Recovery Plan Action 6 Monitor populations and review efficacy of management actions)	• Monitor rock wallaby populations at all locations • Collection ear biopsies for DNA analyses from all BFRW individuals that have not been previously sampled • Undertake genetic analysis of ear biopsy material collected and incorporate with known genetic profiles for each population • Develop model to inform a genetic augmentation (mixing) program for Wheatbelt populations. • Identify and secure funds for genetic analysis and population modelling	Parks and Wildlife WWF	• Robust population data collected enabling population trends to be determined and inform population model • DNA samples collected from all existing BFRW populations • DNA analysed and data added to population model • Population model developed • Targeted BFRW mixing plan prepared
	Genetic diversity in all extant populations maintained or increased from 2021 levels	Genetic augmentation (Recovery Plan Action 5 Conduct translocations, captive breeding and reintroductions to establish new, or supplement existing populations)	• Develop a targeting genetic mixing plan that aims to maximise resilience of all BFRW populations • Undertake appropriate translocation of BFRW	Parks and Wildlife Australian Museum Universities	• Genetic mixing plan completed. • Genetic mixing plan enacted • No further genetic erosion detected over 5 years against 1990-2015

Objective	Target	Strategies	Actions	Lead Agency/ Stakeholders	Performance Measures
			based on targeted mixing plan • Monitor populations to assess success of mixing program and adapt if required		trends/baseline for each site • Reduction in genetic differentiation between Wheatbelt sites (increased overlap) • No unique genotypes lost from any population • Increased genetic diversity with the Nangeen insurance population
Establish at least two new genetically robust populations	At least two additional viable, healthy and genetically diverse populations established in the next 10 years.	Identify suitable locations for establishment of new or augmentation of existing populations (Recovery Plan Action 5)	• Identify and evaluate candidate sites based on habitat suitability and ability to manage possible threats (see Appendix 1) • Identify current and potential threatening processes • Develop a threat mitigation plan for each site • Identify and secure funding to establish and facilitate threat management at identified sites • Implement necessary threat management at each site • Prepare translocation plans • Communicate and liaise with non-DPaW stakeholders to facilitate establishment of new		• Two suitable sites identified • Threat mitigation plan developed for each site. • Funding secured to mitigate threats at each site • Threat management implemented at each site • Two translocation plans written and approved • Other potential sites identified for future translocations

Objective	Target	Strategies	Actions	Lead Agency/ Stakeholders	Performance Measures
			populations (including land managers, Traditional Owners, researchers, volunteers, visitors to reserves especially Kalbarri NP and the general public) • Identify and secure funds to implement translocations		
		Population monitoring (Recovery Plan Action 6)	• Monitor BFRW and threatening processes to assess the efficacy of threat abatement programs at each site. • Adjust mitigation strategies as necessary to maximise survival of BFRW. • Monitor the well-being (body condition, weight, reproductive output) of rock-wallabies to ensure that nutritional, shelter and social features of the habitat are conducive to persistence and breeding • Involve volunteers and the public in monitoring where practical via sighting reports of RW and feral herbivores (Knungagin not publicly accessible)		• Population of BFRW increasing at each site • Overall health of both populations as measured by body condition index high.
Manage the size of the fenced insurance population at		Manage population size to minimize risk of exceeding carrying capacity.	• Define likely carrying capacity of the Nangeen enclosure using population	•	• Captive populations managed in accordance with guidelines

Objective	Target	Strategies	Actions	Lead Agency/ Stakeholders	Performance Measures
Nangeen to act as and effective insurance population, providing source animals to support the improvement of existing populations and/or the establishment of new populations over the next 10 years.			modelling or other suitable measure • Define appropriate metric to be used to assess population size. • Identify appropriate trigger point to initiate removal of animals when population is reaching carrying capacity. • Define protocols for biased sex ratios • Timely execution of actions to reduce deleterious effects on animals (e.g. overcrowding leading to behavioural issues) or habitat (e.g. overgrazing).		• Maintenance of genetic diversity in all populations • Avoidance of overgrazing or other habitat degradation that leads to pronounced population fluctuations (crashes)

Appendix 2 The Decision Workbook

	Name	Mt Stirling	Site suitability score	68	
	Date of assessment				
Qu#	Premliminary Assessment	Response	Next step	score	notes
1	Do BFRW currently persist at the site?	yes	Go to Qu 2	10	
2	What is the current population size ?	below carrying capacity	Go to Q 3	5	possible augmentation
3	What is the current long-term tenure of the site ?	State reserve system	Go to Qu 4	8	
4	How well are foxes managed?	well	Go to Qu 5	7	
5	How well are cats managed?	well	Go to Qu 6	7	
6	How well are goats managed?	well	to Qu 7	7	
7	What weed management is occurring?	excluded	to Qu 7.1	5	
8	What is the risk of an unplanned fire to the site (i.e. consider historical frequency and current management, high frequency fire with little or no management = Extreme)?	well partially	to Qu 9	6	
9	What is the likely carrying capacity of the site (note - thermal shelter (complex rock areas) and access to food resources are the two primary limiting factors for a site) ?	none <50	Go to Qu 10	5	high risk and may require intensive management
10	Has genetic analysis been conducted on samples collected in the last five years	no	Conduct a population assessment to improve the priority of this site for augmentation	0	
11	What is the estimated population size?	5	Go to Qu 12	0	This may require augmentation
12	Is there conservation value in augmenting the population?	some	Go to Qu A12.1	5	High community value, historically important and/or considered genetically a valuable sub-population
	Additional threat management	Answer	Next step	score	
2.1	What is the current population trajectory?	Declining		0	
4.1	Can additional fox management be implemented within available budget/resources	possible	Go to Qu 5	1	
5.1	Can additional feral cat management be implemented within available budget/resource	possible	Go to Qu 6	1	
6.1	Can additional goat management be implemented within available budget/resources	possible	Go to Qu 7	1	
7.1	Can additional weed management be implemented within available budget/resources	unlikely	ameloratng this threat	0	
8.1	Can additional fire management be implemented within available budget/resources	unlikely	ameloratng this threat	0	
Qu#	Source Assessment	Response	Next step	score	
S15	What is the current genetic diversity at the site?		#N/A	#N/A	#N/A
S16	What is the estimated population size?		source site. Ideally it would need to be 100 or more or close to carrying capacity to be considered a source site. Transfer site suitability score to the	0	