South Island Takahē Meta-population: 2020 Modelling Report

Acknowledgements

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For further information on this project contact Glen Greaves: ggreaves@doc.govt.nz

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EXECUTIVE SUMMARY

As of November 19, 2019, there are 83 takahē occupying North Island sites, 168 birds occupying South Island sites, excluding the Murchison Mountains where there are an estimated 167 birds (128 adults plus offspring). Total estimate for the species is 418. The meta-population outside the Murchison Mountains is demographically and genetically healthy, growing at a rate of around 10% per year and with 97.07% of wild-sourced gene diversity retained. Some sites in the North are proving less suitable for takahē or more resource intensive for the Recovery Team, than initially envisaged. Meanwhile a new, large, wild site in the South Island is performing well and more of these sites may soon be available, but they will remain an uncertain prospect until more information is available on the results of 1080 bait trials. Immediate decision-making for takahē needs to strike a balance between maintaining the current labour-intensive but relatively certain outcomes of the existing meta-population and investing in new directions with potentially much larger but currently less certain benefits.

AIMS OF THIS MODELLING PROJECT

To support the Recovery Team to build a species management approach that provides a targeted level of genetic security, while considering limitations of resources (particularly site availability), medium term recovery goals, and the various tools at their disposal.

INDICATORS OF SUCCESS

Though circumstances and knowledge may change dramatically for the programme over the next five years, 25-year success indicators are used here to distinguish successful models from unsuccessful ones.

- sustaining or exceeding population growth of at least 10% per annum over the next 25 years (for combined sites outside the Murchison Mountains and Kahurangi);
- maintaining gene diversity at or above 98%[1] (for combined sites outside the Murchison Mountains);
- maintaining gene diversity at or above 92%[2] in individual sub-populations (for local health and viability);
- realistic pair number and distribution given expected site availability (i.e. no more than 90 in Secure Sites).

STRATEGIES MODELLED

Modelled management strategies were based on the potential ability to either 1) manipulate reproductive output of birds; 2) genetically optimise pairings; 3) increase, decrease or re-distribute capacity; or 4) change the rate of input of wild birds.

RESULTS

Over the next 25 years, and with the values and risks included in the models, **extinction risk was zero for all Secure Site scenarios.** Gene diversity, which began in year 1 at 99.70%, declined slowly but overall gene diversity targets were met for all scenarios except those in which large amounts of carrying capacity were removed from year one without compensation elsewhere in the programme (e.g. with no recovery sites in place).

Increasing reproductive output at Burwood to "high" and "very high" levels achieves all success criteria and increases the number of birds at recovery sites by year 25 by roughly N=20-50 individuals. Benefits can only be

[1] The actual target is 95% of wild source gene diversity. The current meta-population sits at 97.07% (calculated from pedigree data using PMx). Gene diversity is overestimated in these *VORTEX* models and so a threshold of 98% is applied in evaluating model outputs, to account for the difference.

[2] The actual target is 90% but is elevated to 92% to account for the overestimation expected in the models.

realised where the additional population growth is matched by available carrying capacity, at sites that can themselves support growth (i.e. are not population sinks). This may be met either by ongoing success at Kahurangi or by a site of equivalent size and qualities.

Increasing the intensity of genetic management at Burwood and extending this to other Secure Sites makes only a small difference to growth rates and gene diversity retention over the 25-year window. A larger difference is made to the rate of inbreeding accumulation because inbreeding accumulates rapidly in the smaller sub-populations and this has a disproportionate influence on the mean for the meta-population. With current rates of gene-flow between sites, and current intensity of genetic management even if applied only at Burwood, 25-year outcomes are good. The additional gains to overall meta-population gene diversity and population growth resulting from applying additional close management everywhere, are likely to be small. However, the value to health and welfare of individual birds, especially at the smaller sites, may still warrant its application.

Varying capacity by deleting sites showed a range of outcomes. Genetic targets are still met when Tāwharanui is removed and loss of both Tāwharanui and Motutapu takes gene diversity only slightly below the 98% target with overall meta-population growth rate slightly increased (because Burwood does not have to "top-up" these two sites). Removing the No MK Sites allowed all success criteria to be met. The loss of other individual sub-populations can be tolerated if Burwood retains its current size and productivity, though not all success criteria are met. Neither growth nor gene diversity criteria can be met without Burwood.

Increasing the rate of input of wild birds from the Murchison Mountains increases gene diversity and reduces inbreeding accumulation but only slightly compared with other interventions. Note though that this may be due to the models, which will assign new founders the same opportunities to contribute as other birds, when they would be likely to receive preferential treatment.

In summary, the greatest gains for the overall meta-population are made where Burwood females are individually highly productive and where the birds generated from this are deployed at sites that can support good population growth. Maintaining gene-flow among sites is important. Current levels of close genetic management are enough to meet success criteria and increasing this intensity makes only a slight difference. Removal of low-performing sites can increase growth rates at recovery sites provided the conditions there are favourable.

Note the low variance in mean meta-population size when either Motutapu or all MK Sites are removed. This is because of the way in which the models are constructed. The MK Sites sub-population varies a great deal in size over time due to the multiple local risks entered for those sites and the small amount of supplementation from Burwood (3 pairs every 7 years). As a result, removal of those sites, or a significant component of them (such as Motutapu), significantly reduces overall meta-population variation.

Table 1. summarises model outcomes for the population outside the Murchison Mountains and Kahurangi. The larger report gives results that include these two sites. Note that throughout the report, models take a precautionary approach to risk by including potential catastrophes of various types, at estimated rates and severities. Appendix III shows the effect of removing these catastrophes on performance in individual sub-populations and across the whole meta-population. With all catastrophes removed, the total modelled meta-population (including the Murchison Mountains and any recovery sites) reaches almost 1000 birds in 25 years (Mean N at 25 years across iterations = 983.00; SD =2.00), indicating recovery potential under closely managed and well-resourced conditions.

Table 1. Comparison of alternative management strategies on meta-population performance (excluding the Murchison Mts. and Kahurangi). Green = outcomes that meet success criteria; Orange = outcomes close to meeting success criteria; Red = outcomes that do not meet success criteria; Grey = Standard Deviation, indicating degree of variability in the mean values.

Strategies	Pairs	stoch-r	SD(r)	Nall	SD(Nall)	GeneDiv	SD(GD)	Inbr	SD(Inbr)
Varying reproductive output 1									
50% females breeding at Burwood	98	0.06	0.07	277	38	0.985	0.0021	0.0136	0.0082
75% females breeding at Burwood	94	0.07	0.07	275	39	0.984	0.0023	0.0139	0.0082
100% females breeding at Burwood	92	0.09	0.07	275	39	0.984	0.0027	0.0152	0.0087
Varying reproductive output 2									
Very Low Performance (0.75 fledged/ female/year)	94	0.06	0.07	272	41	0.9848	0.0023	0.0133	0.0088
Low Performance (1.00 fledged/ female/year)	92	0.08	0.07	274	40	0.9840	0.0027	0.0145	0.0093
Current Performance (1.12 fledged/ female/year)	92	0.09	0.07	275	39	0.9836	0.0027	0.0152	0.0087
High Performance (1.25 fledged/ female/year)	90	0.10	0.07	273	40	0.9832	0.003	0.0151	0.0091
Very High Performance (1.50 fledged per female per year)	88	0.12	0.07	276	38	0.9836	0.0027	0.0198	0.0106
Varying the intensity of genetic management (GM)									
No gene-flow between sites, no GM within sites	87	0.08	0.07	260	46	0.9822	0.0029	0.0288	0.0129
Current gene-flow between sites, no GM within sites	92	0.08	0.07	272	41	0.9817	0.0032	0.0223	0.011
No gene-flow between sites, GM within sites	88	0.09	0.07	265	43	0.9839	0.0025	0.0206	0.0108
Current gene-flow between sites, GM at Burwood only	92	0.09	0.07	274	40	0.9829	0.0026	0.0186	0.0096
Current gene-flow between sites, GM at all MK sites	92	0.09	0.07	275	39	0.9836	0.0027	0.0152	0.0087
Varying capacity									
Baseline (all current sites retained)	92	0.09	0.07	275	39	0.9836	0.0027	0.0152	0.0087
Loss of Tawharanui	85	0.09	0.06	254	30	0.9828	0.0028	0.0143	0.0089
Loss of Tawharanui and Motutapu	69	0.10	0.07	209	16	0.9796	0.0027	0.0147	0.01
Loss of Group A only (No MK Sites)	71	0.10	0.08	222	39	0.9802	0.0036	0.0138	0.0093
Loss of Group B only (MK Sites)	50	0.13	0.06	153	5	0.9729	0.0035	0.0165	0.0119
Loss of Burwood	57	0.03	0.12	164	46	0.9713	0.0084	0.0234	0.0165
Increasing wild inputs									
Baseline (two wild birds every seven years)	92	0.09	0.07	275	39	0.9836	0.0027	0.0152	0.0087
Two wild birds every five years	92	0.09	0.07	276	39	0.9839	0.0027	0.0143	0.0081
Two wild birds every two years	92	0.10	0.07	274	39	0.9850	0.0025	0.0132	0.0083

Stoch-r=mean instantaneous growth rate over 25 years; Nall=mean population size across iterations after 25 years, including populations that went extinct; GeneDiv=expected heterozygosity at 25 years; Inbr=population average inbreeding coefficient.

INTRODUCTION

The takahē is the largest living member of the rail family and endemic to New Zealand. As of November 19, 2019, an estimated 418 birds remain, 251 occupying 1 recovery site[3], 12 secure sites[4], and 7 advocacy facilities[5], with approximately 167 birds in one remaining wild site[6] in the Murchison Mountains (see Figure 1).

Sustained recovery and conservation of the species is currently supported by large-scale intensive breeding at the Burwood captive breeding centre in Te Anau, followed by strategic translocation to other sites within the wider meta-population. In 2014, the takahē Recovery Group proposed the management of remaining takahē as two distinct meta-populations; one focused on the northern islands and the other on southern areas, fostering adaptation in two contrasting bioclimatic zones and substantially reducing the need for long-distance translocation of birds. A 10-year strategy and action plan were developed for this by the Team (see Lees *et al*., 2014) and this has been actively pursued with a total of 83 birds now residing in the North.

In recent years it has become apparent that some of the secure sites in the North are less suitable for takahē or more resource intensive for the Recovery Team, than initially envisaged and new sites needed to support expansion are proving hard to find. At the same time, a large wild site has become available for takahē on the South Island potentially able to support thousands of birds and others may follow in the near future. The utility of these sites will depend firstly on whether they provide suitable conditions for takahē survival and breeding and secondly on whether takahē can co-exist with 1080-based predator control measures. So far, birds released to the first of these sites (Kahurangi) are doing well. The results of bait trials will be available within the next two years.

At present the existing North Island Meta-population, along with the Burwood breeding centre in Te Anau, provides insurance against catastrophic decline of the single remaining wild population in the Murchison Mountains and against the further erosion of genetic diversity within the Murchison's population as a result of its small size. However, maintaining this meta-population is labour intensive. Expanding the takahē meta-population into larger "recovery sites" could provide a massive leap in the long-term security of the species and, eventually, a better return on the investment of labour and resources. However, it will not be clear for several years whether these sites will realise this potential. In the meantime, Recovery Team resources are limited, and decisions will need to be made about how to invest these resources to ensure the best outcomes for the species. A balance will need to be struck between maintaining the current labour-intensive but relatively certain outcomes of the existing meta-population and investing in new directions with potentially much larger but less certain benefits.

The purpose of the population viability analysis modelling exercise described here was to test scenarios for the redistribution of effort and to compare their impacts on species abundance, viability and genetic diversity. The PVA outputs are interpreted here for clarity but management recommendations are not included; this will be done by the Recovery Team once further information about recovery sites and the bait trials is available and can be incorporated into decision making.

[3] Large, wild, mainland areas within the former range of the South Island Takahē.

[4] Predator-free islands and fenced sites.

[5] Zoological gardens open to the public.

[6] Sites with a continuous history of Takahē presence.

REVIEW OF CURRENT STATUS

All remaining takahē originate from the South Island population in the Murchison Mountains. The species is currently listed as Endangered by the IUCN in its *Red-List of Threatened Species* (IUCN, 2019).

Figure 1. 2019 distribution of Takahē

Each site name is followed by the estimated adult capacity with the estimated total capacity in brackets.

In total, as of November 19, 2019, there are 83 birds occupying North Island sites and facilities and 168 birds occupying South Island sites and facilities (excluding the Murchison Mountains). Within the Murchison Mountains there is an estimated 167 birds (70 pairs plus offspring). This brings the total estimate for the species to 418. This is an increase of 132 birds since the 2014 report (Lees, et al., 2014).

META-POPULATION COMPONENTS

Supporting the species to thrive as a single meta-population currently requires management of and movement between the following components (see Table 2 for details):

WILD & RECOVERY SITES

Description: genetically and demographically resilient populations under wild conditions and natural selection pressures. Genetic and demographic management limited to determining the number and selection of birds to be released to or removed from, those sites. Long-term these sites should require little or no genetic or demographic management (there may be a need to engineer gene-flow, depending on site sizes and connectivity).

Purpose: multiple, self-sustaining recovery sites is a conservation endpoint.

Challenges: The only remaining wild site is in the Murchison Mountains. The population there is estimated to be declining at 3% per year due to predation and requires ongoing supplementation. Kahurangi is new and is currently the only "recovery site". It is showing promise, but its long-term security cannot be assessed until the completion of 1080 bait trials.

BURWOOD BREEDING CENTRE

Description: highly successful captive facility, productive and genetically efficient and protected from predator incursion. Birds produced here are fit for wild translocation. Demographic and genetic management is highly intensive with direct control of pairing combinations and reproductive outputs.

Purpose: a source of birds for wild and recovery sites and insurance against catastrophic loss at those sites.

Challenges: single site with a relatively small resident population – not sufficient to be the sole source of both insurance and of birds for release.

META-POPULATION OF SECURE SITES

Description: predator-managed islands and mainland sanctuary areas with some captive facilities, distributed mainly in the North Island, providing additional, secure space for birds outside wild and recovery sites and outside Burwood. Depending on the specific site, demographic and genetic management ranges from highly intensive (management of pairing combinations to minimise average mean kinship and reduce inbreeding accumulation, and control of reproductive outputs) to limited intervention. For analysis these are distinguished as MK Sites and No MK Sites. Some Secure Sites may be designated "Retirement Sites" and allocated only birds older than 14 years. At present Auckland Zoo is the only designated Retirement Site.

Purpose: spreads risk of loss across several sites; builds numbers to increase resilience to environmental risks; slows the rate of genetic deterioration in the insurance population and operates as an additional source of birds for release and for advocacy.

Challenges: the species does not favour northern sites (too warm). As a result, some sites are not performing well (breeding rates are low). At present, birds bred at these sites need pre-release conditioning at Burwood (though in future tussock habitat will be de-emphasised in release site choice, potentially making it easier for northern birds to adapt). At some sites the management burden is high for several reasons. In short, for a number of these sites and in terms of recovery goals, return on investment is low.

Table 2. Individual site characteristics and allocation to sub-populations for subsequent modelling.

Model sub-populations	Sites	N	In pairs by 2022	K
Wild	Murchison Mts	200	128	N/A
Recovery Site	Kahurangi	31	N/A	N/A
Burwood	Burwood	100	50	100
Group A Secure Sites (NoMK)				
Breeding sites, without MK management.	Mana	18	16	24
	Raratoka	22	14	30
Group B Secure Sites (MK)				
Breeding sites with MK management.	Rotoroa	6	6	9
	Maungatautari	5	4	6
	Tiritiri Matangi	6	4	6
	Cape Sanctuary	2	8	12
	Orokonui	2	4	6
	Puangiangi	7	6	9
	Mt. Bruce	2	2	2
	Kapiti Island	2	2	2
	Te Anau	4	4	6
	Wairakei Sanctuary	6	6	7
	Willowbank	2	2	2
	Zealandia	2	2	2
	Tāwharanui	10	20	30
	Motutapu	22	40	60
Group C				
Retirement sites	Auckland Zoo	2	-	2

N= current number of birds (including juveniles); Paired by 2022 = number of adult birds expected to be in established pairs by 2022; K=total capacity including juveniles; Mean Kinship (MK) Management = preferential pairing of birds with similar and low levels of relatedness to the wider meta-population.

DEMOGRAPHIC PROFILE OF TAKAHĒ OUTSIDE THE MURCHISON MTS

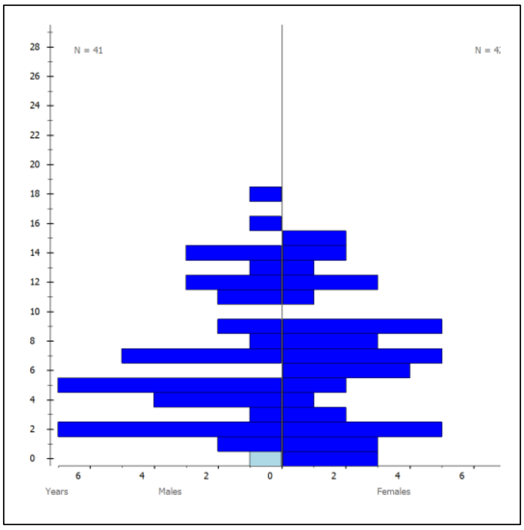
This section provides a snapshot of the demographic profile and potential of the current takahē meta-population excluding the Murchison Mountains. The summaries provided were generated from the Takahē Studbook (Greaves & Joustra, 2019) using the small population analysis program PMx (Ballou, et al., 2018). Separate summaries are provided for the North Island Meta-population and for all takahē living outside the Murchison Mountains and Kahurangi.

As can be seen from Figure 2a the North Island population (as of November 2019) stood at 83 individuals spread across 12 sites in the North Island. It has an even sex-ratio (41 males to 42 females) and a balanced age-structure. Figure 2b is a summary of the managed takahē population outside the Recovery and Wild sites. As at November 2019, the wider insurance meta-population (at 20 sites distributed New Zealand-wide) stood at 220 individuals. The population has a roughly even sex-ratio (102 males and 118 females) and a balanced age-structure.

Estimates of annual population growth rate (lambda), generation length and life expectancy were calculated from life-table data (see Appendix II) gathered and treated by PMx from studbook-derived age-specific mortality and reproduction values. Lambda values of less than 1.0 indicate a declining population; those above 1.0 indicate growth. Vital rates to date in the population predict growth and this is illustrated in the 20-year projections in Figure 3b.

Figure 2a. Demography overview of the takahē population in the North Island showing age pyramid (Nov 2019). (Note: excludes any additional birds hatched in 2019/20 season).

	Total	Males	Females
Totals	83	41	42
Pre-Reproductive	1	1	0
Breeding Age	82	40	42
Post Reproductive	0	0	0
Proven Breeder	49	23	26
Retired birds	14	7	7
# Sites (including zoos) [1]	12		
Generation length (T)	6.9yrs		
Expected annual growth (Λ)	1.047		
Life expectancy from hatch[7]	10.8yrs		



[7] **Note:** at Burwood chicks are counted from hatch, but at other sites they are added to the studbook only after banding at 3-5 months of age. Any deaths prior to this are therefore not included in the studbook. Overall then, PMx analyses of studbook data will underestimate first year mortality and as a result overestimate life expectancy from hatch. As a precaution the value presented can be interpreted as life expectancy from 3-5 months.

Figure 2b. Demography overview of the total managed takahē population in New Zealand (i.e. outside the Murchison Mts.) showing age pyramid (Nov 2019). (Note: excludes Kahurangi (Recovery Site) and any additional birds hatched in 2019/20 season).

	Total	Males	Females
Totals	220	102	118
Pre-Reproductive	15	15	0
Breeding Age	205	87	118
Post Reproductive	0	0	0
Proven Breeder	101	50	51
Retired birds	20	10	10
# Sites (including zoos) [1]	18		
Generation length (T)	6.9yrs		
Expected annual growth (λ)	1.047		
Life expectancy from hatch	10.8yrs		

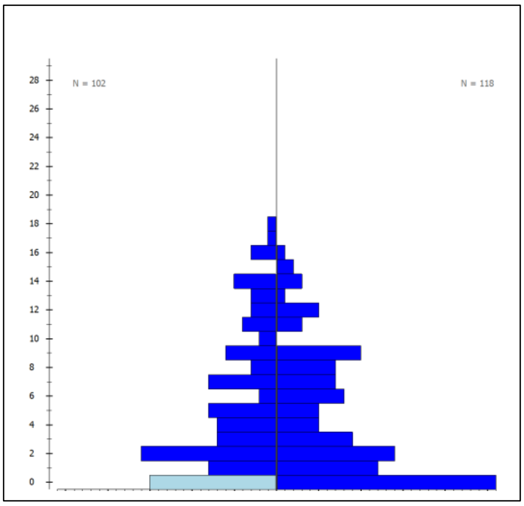


Figure 3a. Projections for the North Island population based on mortality and reproductive parameters observed up until 2014 assuming no further imports from Burwood. Black dotted line shows deterministic projection; blue dotted lines show 95% confidence intervals for stochastic projections; red solid line shows mean of stochastic projections.

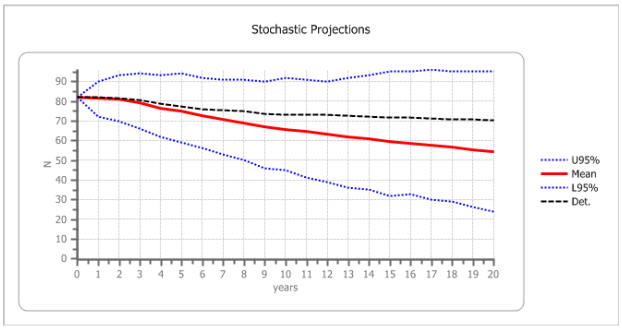


Figure 3b. Projections for the North Island population based on mortality and reproductive parameters observed up until 2019 assuming no further imports from Burwood. Black dotted line shows deterministic projection; blue dotted lines show 95% confidence intervals for stochastic projections; red solid line shows mean of stochastic projections.

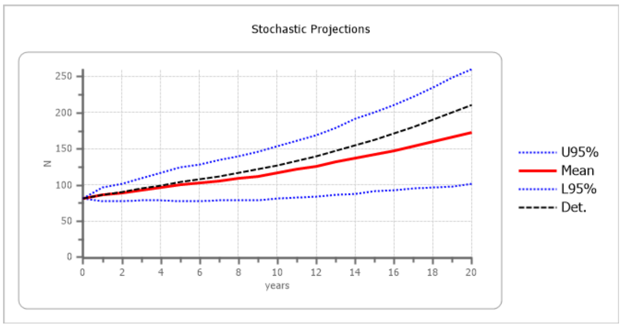
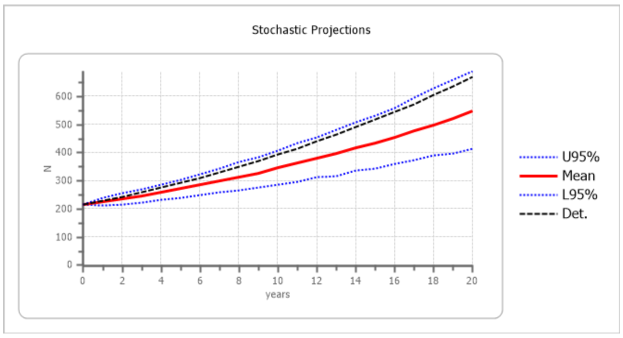


Figure 3c. Projections for the combined North Island and South Island sites (excluding Murchison Mts and Kahurangi). Black dotted line shows deterministic projection; blue dotted lines show 95% confidence intervals for stochastic projections; red solid line shows mean of stochastic projections.



As illustrated in graphs 3a and 3b, the prognosis for a demographically self-sustaining North Island meta-population has improved since 2014, with sustained positive growth now predicted even in absence of further imports from Burwood.

However, vital rates at the Burwood breeding centre continue to out-perform those elsewhere such that adding Burwood and the other South Island sites (excluding Murchison Mts and Kahurangi) produces an even more optimistic and more certain picture of growth into the future (see Figure 3c).

GENETIC PROFILE OF TAKAHĒ OUTSIDE THE MURCHISON MTS

Gene diversity is of recognised importance to short-term population health and to long-term adaptability in the face of environmental change (Frankham, et al., 2010; Frankham, et al., 2013; Jamieson & Allendorf, 2012). The status of gene diversity can be inferred from analyses of pedigree information from the population or populations of interest. The Department of Conservation (DOC) currently maintains full pedigree data for birds held outside the Murchison Mountains (which as the only remaining wild site is too inaccessible for this to be achievable). These data have been transferred to the studbook records keeping and analysis program SPARKS (Species360, 2012) and the resulting dataset (Greaves & Joustra, 2019) analysed using the small population analysis program PMx (Ballou, et al., 2018). Note that in the absence of information to the contrary the analysis calibrates the relatedness of founder individuals to zero; that is, it assumes that those wild-caught birds sampled from the Murchison Mountains which form the basis of the North and South Island pedigreed populations, were sampled randomly and representatively from the wild and were not unusually close relatives (where "close relatives" is judged relative to the population average). A summary of measures is shown in Table 3. below

Table 3. Genetic characteristics of the managed population in the North Island, the combined population outside the Murchison Mountains (wild) and the Kahurangi recovery site (Nov 2019).

Characteristics	All managed sites in the North Island	All managed sites outside of the wild	Kahurangi recovery site	Definitions and notes
Number of birds	83	220	31	Number of living birds.
Founder number	44	44	30	Number of birds sampled from the wild population who have no known relationship to any other birds in the population except for their own descendants.
% Ancestry certain	92 %	90.5 %	90.3 %	% of the birds' pedigree that can be traced back to known founders.
Current Gene Diversity	95.98 %	97.07 %	91.53 %	The heterozygosity expected in the progeny under random breeding.
Potential Gene Diversity	98.00 %	98.43 %	96.64 %	The GD that could theoretically be achieved by adjusting the relative contributions of founders by optimising pairing.
Founder Genome Equivalents	12.44	17.09	5.90	The number of wild caught founders that would contain the same amount of gene diversity as the population.
Potential Founder Genome Equivalents	25.12	31.80	14.88	The FGE's that could be achieved by adjusting the relative contributions of founders.
Population Average Inbreeding Coefficient	0.0323	0.0230	0.0525	The average inbreeding coefficients of all individuals in the population. A common rule of thumb threshold for captive populations is F=0.1250
Inbreeding Range	0 – 0.3438	0 – 0.3438	0 – 0.1532	F = 0.3438 in 2 individuals in the population (both at Tiritiri Matangi Island), F= 0.2813 in 2 individuals (both at Mana Island). Remainder of the population falls under F= 0.250.

Characteristics	All managed sites in the North Island	All managed sites outside of the wild	Kahurangi recovery site	Definitions and notes
Population Average Mean Kinship	0.0402	0.0293	0.0847	The average of the MK values of all individuals in the population (and the expected average inbreeding coefficient of the progeny under random breeding).
Ratio of Genetically Effective Pop. Size to Actual Pop. Size (Ne/N)	0.5283	0.4304	0.3896	Indicates how efficiently the population will retain GD from one generation to the next. 0.2 – 0.4 is common for well-managed captive populations (Frankham *et al.* 2002).
Note: Living founder birds are included.				

The analyses show that both the North Island population and the wider population outside the Murchison Mountains, are well-founded, have been well-managed and can be expected to have retained high levels of wild source gene diversity; the standard gene diversity retention target for conservation breeding programs is 90% for the duration of the program and both subsets considered here sit comfortably above this. Note though that these figures estimate the amount of wild source gene diversity retained; they make no judgement about the gene diversity of the wild source population at the time of sampling, which may have been low following many multiple generations of small size and isolation.

FUTURE DIRECTIONS FOR TAKAHĒ MANAGEMENT

Over the next 10-15 years, advances in predator control capability and capacity are expected to increase significantly. This has the potential to mobilise multiple large tracts of natural habitat on the South Island where takahē could eventually persist safely and in numbers of several thousands. Once multiple sites of sufficient size and capacity are in place, the species should: require minimal ongoing management; be demographically and genetically secure; and no longer require close management of a separate insurance meta-population. In the meantime, management decisions need to be made which, over the next five to ten years, will effectively bridge the gap between current and likely future approaches to takahē conservation, taking into account the status and challenges of the current programme, the uncertainty relating to some elements of it and the resources available to the Recovery Team. To support these decisions, Population Viability Analysis (PVA) tools were applied using inputs from the takahē Recovery Team, to compare the impact on insurance meta-population performance of feasible alternative management strategies.

THE 5-10 YEAR SITUATION AND AIMS OF THIS STUDY

The following points describe the challenges relevant to planning over the next 5-10 years of this programme:

1. The programme currently targets 90 pairs in Secure Sites, calculated from PMx to meet genetic targets over 25 years, but it is proving difficult to achieve this with the sites available and there are no new secure sites on the horizon.
2. Some secure sites are particularly management-intensive and as a result, return on investment is low.
3. The new recovery site (Kahurangi) is outperforming some of the Secure Sites but will remain an uncertain prospect until more information is available on the results of the 1080 bait trials.
4. The takahē population is growing rapidly and founder representation is evening out.
5. Available space will be filled by 2022 and a new recovery site will be mobilised by then.
6. We will soon have the takahē genome sequenced, with ~80% of the current population sampled, allowing for targeted sampling of new, high-value founders from the Murchison Mts.

AIMS OF THIS MODELLING PROJECT

To support the Recovery Team to build a species management approach that provides a targeted level of genetic security, while considering limitations of resources (particularly site availability), medium term recovery goals, and the various tools at their disposal.

INDICATORS OF SUCCESS

Though circumstances and knowledge may change dramatically for the programme over the next five years, 25-year success indicators are used here to distinguish successful models from unsuccessful ones.

- sustaining or exceeding population growth of at least 10% per annum over the next 25 years(for combined sites outside the Murchison Mountains);
- maintaining gene diversity at or above 98%[8] (for combined sites outside the Murchison Mountains);
- maintaining gene diversity at or above 92%[9] in individual sub-populations (for local health and viability);

[8] The actual target is 95% of wild source gene diversity. The current meta-population sits at 97.07% (calculated from pedigree data using PMx). Gene diversity is overestimated in these *VORTEX* models and so a threshold of 98% is applied in evaluating model outputs, to account for the difference.

[9] The actual target is 90% but is elevated to 92% to account for the overestimation expected in the models.

- realistic pair number and distribution given expected site availability (i.e. no more than 90 in Secure Sites).

The modelling exercise simulates the management options available and measures the performance of each against these success indicators.

MANAGEMENT STRATEGIES AND SCENARIOS MODELLED

Modelled management strategies are based on the potential ability to either 1) manipulate reproductive output of birds; 2) genetically optimise pairings; 3) increase, decrease or re-distribute capacity; or 4) change the rate of input of wild birds. The most successful scenarios will be those that deliver sufficient benefits to growth and gene diversity with realistic and achievable application of resources. Additional scenarios were also modelled to explore relationships between variables that while not directly related to current management decisions, may be relevant to future ones. Table 4. describes the strategies and scenarios tested using PVA models. Not all are meant to describe real-life management strategies. For example, ceasing inter-site transfers is not a strategy under consideration, but models of this are run to illustrate the importance of this "business-as-usual" management and the impact of not doing it on meta-population health and viability. **Note that advocacy roles and aims are not considered in this analysis.**

Table 4: Alternative management strategies and scenarios tested, and an outline of the model manipulation required. Note that outputs from these models refer to the whole meta-population, not just the birds outside the Murchison Mountains and Kahurangi.

Management strategy	Scenarios tested	Model manipulation
Varying reproductive output		
Females breeding rates at Burwood	Low rate	Annual % females breeding =50%
	Medium rate	Annual % females breeding =75%
	High rate	Annual % females breeding =100%
Individual female outputs at Burwood	Very low	0.75 fledged /female/year
	Low	1.00 fledged /female/year
	Current	1.12 fledged /female/year
	High	1.25 fledged /female/year
	Very high	1.50 fledged /female/year
Varying genetic management intensity (starting kinships meta-population-wide = 0.0261 (current pedigree average))		
Vary rates of inter-site movement	Current rates of dispersal between sites	Rates as described in Figure 2.
	No dispersal between sites.	No dispersal from Year 1 onwards.
Close genetic management at selected sites	Optimise pairings and slow inbreeding at Burwood only.	Select pairings to minimise average MK and avoid mean Inbreeding ≥ 0.125 at Burwood.
	Optimise pairings and slow inbreeding at Burwood AND at MK Sites.	As above but with extended to Secure Sites with MK management capability.
Varying capacity		
Include, exclude or re-purpose sites	Remove Tāwharanui and repurpose Motutapu as a retirement site.	K is removed for Tāwharanui. No change required for Motutapu as repurposing does not impact K or vital rates.
	Remove Tāwharanui and Motutapu	Total K for these two sites is removed and 15 birds (the excess created) is transferred to Kahurangi.

Remove sub-populations	Remove MK Sites	K=0 for MK SItes, resident birds are removed from the metapopulation.
	Remove No MK Sites	K=0 for No MK Sites, resident birds are removed.
	Remove Burwood	K=0 for Burwood, resident birds are removed.
Vary wild inputs		
	Lower recruitment rate	Four birds every 7 years from the wild.
	Current recruitment rate	Two birds every 7 years from the wild.
	Increased recruitment rate	Two birds every 14 years from the wild.
Additional models 1		
Impact of 1080 at Kahurangi	Current modelled impact	Both predation and 1080 negatively impact survival and reproduction
	1080 removed	Negative impacts of predation increase, 1080 impacts stay the same.
	1080 poisoning increases	Negative impacts of 1080 increase, predation stays the same.
Additional models 2		
Establishing new sites	Impact of dispersal and starting size on extinction risk	Initial population sizes of 5; 10; 15; 20; 25; 30; 40 and 50 birds were used and pairs of birds were transferred every 10; 7; 5; 2 or 1 year
	Impact of dispersal and starting size on gene diversity retention	

Building *Vortex* models

The simulation software programme *Vortex* (v10.3.6.0) (Lacy and Pollak 2017) was used to model alternative Takahē management strategies using data from previous PVA models (see Lees et al., 2014) updated with recent data from the studbook (Greaves & Joustra, 2019) and additional expert opinion from the Recovery Team. *Vortex* is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on populations of wildlife. *Vortex* models population dynamics as discrete sequential events that occur according to defined probabilities. The programme begins by creating individuals to form the starting population and then steps through life cycle events (e.g., births, deaths, dispersal, catastrophic events), typically on an annual basis. Events such as breeding success, sex at birth, and survival are determined based upon designated probabilities. 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 (2000) and Lacy *et al*. (2017).

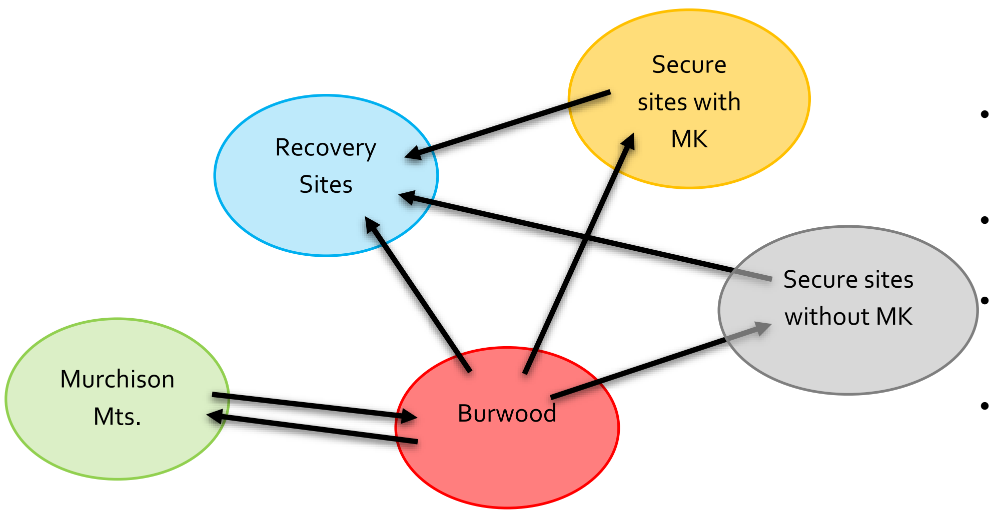
Limitations of the models

PVA models were built to emulate the composition of the takahē meta-population, the roles and intensity of management of the different sites and, roughly, the direction and scale of movements between sites. However, some aspects of dynamics and management were hard to capture because decisions about movements and management are not directed by a single and constant set of rules. Instead, decisions are in part actively driven towards project goals and in part reactively driven in response to unexpected events and trends in the meta-population, to changes in resourcing and to new opportunities. However, given that this reactive feature is constant across all scenarios the models should still provide a useful tool for comparison between different strategies.

Model structure

For the purpose of modelling, the meta-population structure was broken down into a number of "sub-populations". Sub-populations are either single sites or facilities or are groups of sites that share characteristics such as intensity of management, degree of risk, or patterns of movement to and from other sub-populations. The pattern of flow of birds between sub-populations is illustrated in Figure 4. and Table 2. shows the allocation of individual sites to the different sub-populations (see Figure 1. for geographic locations).

Figure 4: PVA sub-populations and rules for movements of birds



- **MURCHISON MOUNTAINS: 1 PAIR PER GENERATION TO BURWOOD. RECEIVES SIX 1-YEAR-OLD BIRDS PER YEAR FROM BURWOOD.**
- **BURWOOD TOPS UP OTHER SITES: MURCHISON MTS. > SECURE SITES > KAHURANGI.**
- **MK SITES: TOP UP NO MK SITES BEFORE BURWOOD IS CALLED ON.**
- **ONCE ALL SECURE SITES ARE FILLED, ALL SURPLUS JUVENILES ARE MOVED TO KAHURANGI.**
- **ONCE KAHURANGI IS FULL, A SECOND, HYPOTHETICAL SITE IS MOBILIZED.**

INCORPORATING RISK

Risks are incorporated into the *VORTEX* model in several different ways. Risks to reproduction and survival that are a year-round or regular feature of the takahē's environment or biology are factored into annual, age-specific mortality and fecundity rates. The extent of year-to-year variation in these rates is added by the user as an additional modifier, and any additional variation resulting from "sampling error" (i.e. small population size) is included by the programme itself. There is also an opportunity for the user to include occasional, extreme fluctuations (catastrophes) in mortality or fecundity resulting from, for example, fires, floods or disease outbreaks. These were included or excluded on advice from the Recovery Team (see Appendix I. for details).

At Secure Sites, incidental risks are standard across all sites (e.g. firearm misuse, bait station risks, dog attacks) and so are included in annual rates. No disease issues have been observed to date, though it was noted that this has been a problem for other bird species. Some protection from disease outbreak is provided by the fragmented nature of the meta-population, though depending on the disease, the current rates of inter-site movements may reduce or remove this protection. Disease is included in annual mortality and reproductive rates however disease outbreaks (extreme disease events) are not included in this round of modelling.

Localised flooding could be a risk at wild or recovery sites but would only be expected to affect one or two pairs and so is not included in the models. Though none have occurred in 30 years, fire is considered a potential risk at Burwood and one likely to be increasing with climate change and site visitor numbers.

Predation is an ongoing risk in the Murchison Mountains causing approximately 10% additional mortality every four years. In Kahurangi, where aerial baiting with 1080 keeps predation down to acceptable levels, 1080 poisoning is a risk. This risk is not yet able to be measured, but a threshold of acceptable risk is set here at 10% additional mortality once every four years and this is the level of risk included in the Kahurangi model. It is assumed that if this threshold is exceeded, Kahurangi birds would be moved elsewhere or alternative predator-mitigation would be used to keep mortality rates at or below this threshold.

THE BASELINE MODEL

A Baseline Model was constructed based on updated parameters from previous analyses (see Lees et al., 2014). For uncertain parameters a range of values was tested representing pessimistic, best guess and optimistic estimates. Across the range of values tested and as for previous analyses, growth in the current model is especially sensitive to the percentage of females breeding annually, the mortality rate of adult females and the mortality rate of juveniles. Table 7. Shows the values tested and the annual growth rates (λ) generated by each. As shown, annual growth varies between 4.7 and 13.2% per annum but the Best Guess scenarios sit at 9.7%, which accords well with the rates recently observed in the living population (Greaves, pers. comm.).

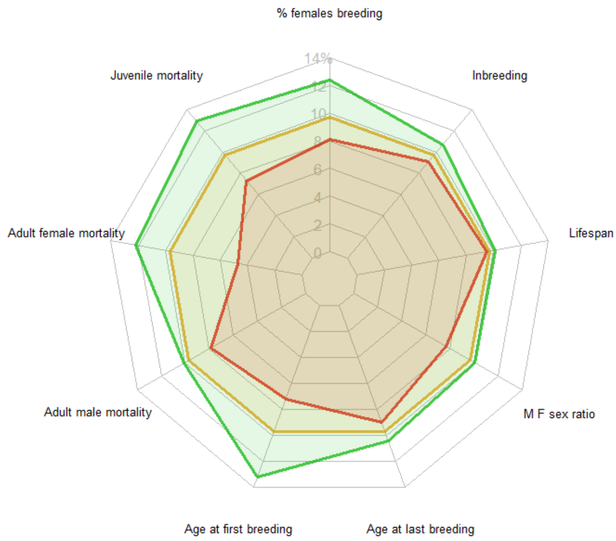


Figure 5. Radial plot comparing the impact on modelled population growth of optimistic (green), best guess (orange) and pessimistic (red) values for seven different takahē model parameters.

Table 5. Pessimistic, Best Guess and Optimistic values tested in the Baseline Model, with the stochastic growth rates (r) that these variations produced.

	Percentage of Breeding females	Juvenile mortality	Female mortality	Male mortality	Age at first breeding	Age at last breeding	Sex-Ratio	Lifespan	Inbreeding depression
Growth rate									
Pessimistic	0.081	0.073	0.047	0.079	0.072	0.090	0.077	0.095	0.091
Best Guess	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
Optimistic	0.124	0.129	0.122	0.101	0.132	0.104	0.101	0.101	0.107
Values									
Pessimistic	70	45	10	10	4	13	0.6	17	4.7
Best guess	60	30	6	6	3	15	0.5	19	2.35
Optimistic	50	20	2	2	2	17	0.4	21	0

RESULTS

Models were built for each of the scenarios described in Table 4. Each model was run 500 times, for a period of 25 years. The following pages consider each model in turn, reporting the following information:

- Expected change in population number over time, for different sub-populations, illustrated as graphs showing mean population size across iterations for each year of the simulation with shading to show the variation in this (as +/- 1 standard deviations from the mean).
- A summary table showing:
    - stochastic growth rate (r), mean and standard deviation;
    - probability extinct after 25 years (P_{Ex});
    - mean population size at 25 years (N) and standard deviation;
    - gene diversity at 25 years (GD), mean and standard deviation;
    - mean population inbreeding coefficient at 25 years.
- For a subset of scenarios, accumulation of inbreeding and loss of genetic diversity over time are presented as graphs.

BASELINE MODEL.

In the Baseline model, all populations are connected as described earlier. This represents "business as usual" in the meta-population and is used to evaluate the impact of alternative strategies.

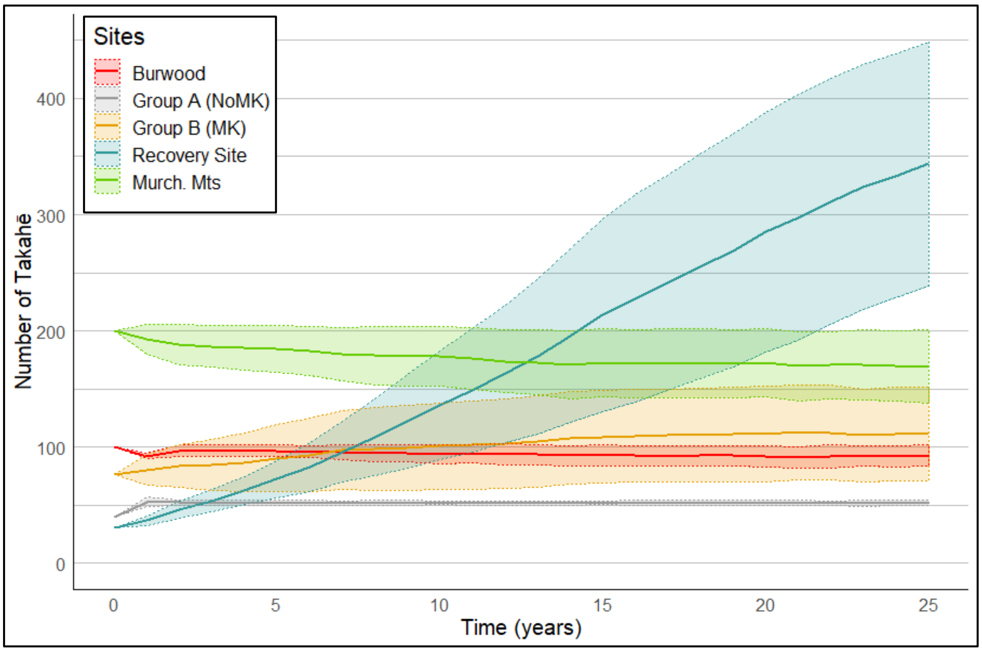


Figure 6. Baseline sub-population growth projections over 25 years (graph) and associated metrics (table).

Population	r	SD(r)	P_{Ex}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
Sites MK	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
Sites No MK	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
Kahurangi	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00

As can be seen, the meta-population performs well under "business as usual" management. Gene diversity remains above the 98% threshold in the meta-population and at or above 96% in all sub-populations. The lower value at Sites No MK is due to the small size of this sub-population and consequent rapid loss of gene diversity through drift. **Overall this is a high-performing strategy which meets the genetic target and sees good growth at Kahurangi with no detriment to the wider insurance meta-population.**

VARYING REPRODUCTIVE OUTPUT

The first set of scenarios in this section tests the impact of varying the annual percentage of adult females breeding at Burwood on meta-population performance. The second set tests the impact of varying the average individual outputs of the birds that breed, in terms of average number of birds fledged per year.

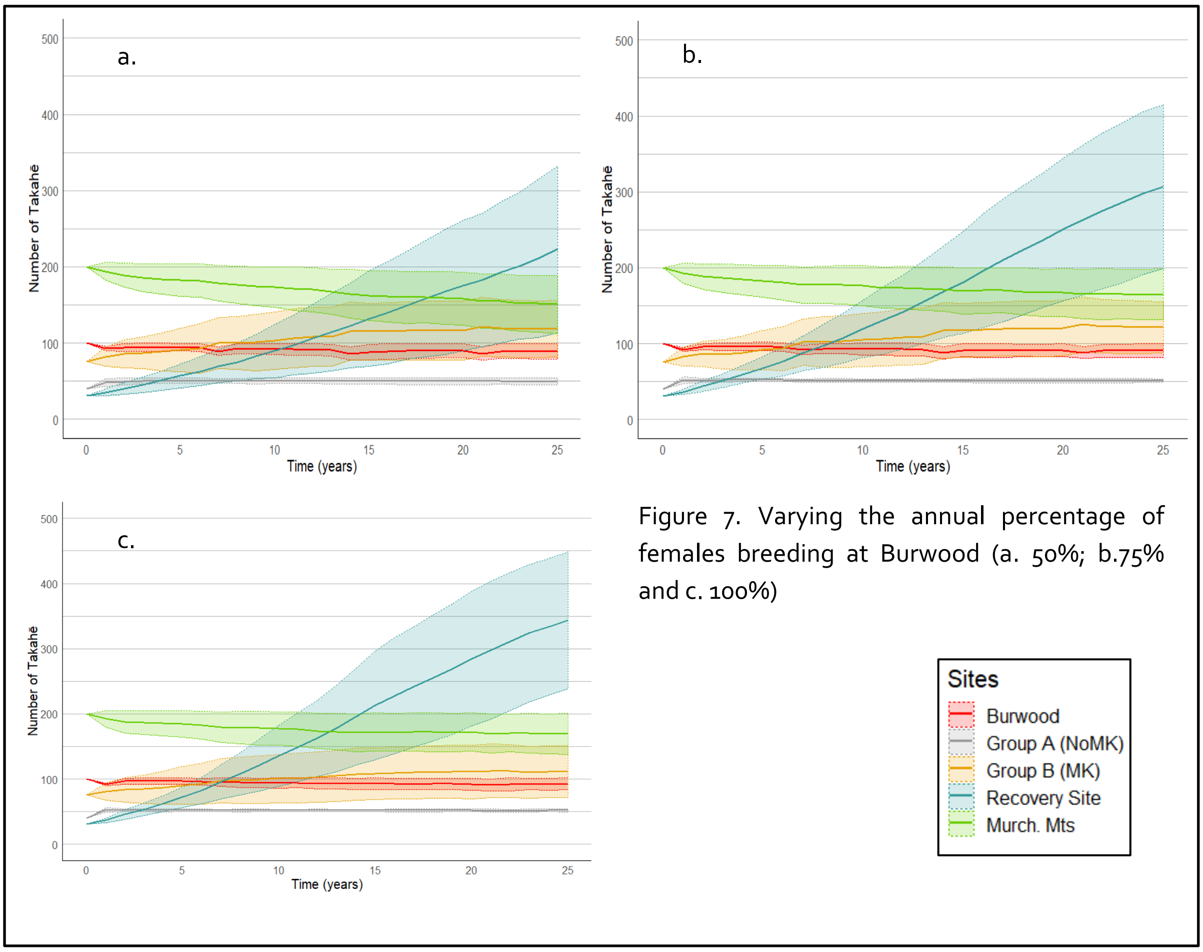


Figure 7. Varying the annual percentage of females breeding at Burwood (a. 50%; b.75% and c. 100%)

Varying the percentage of females breeding at Burwood alters the expected meta-population size at 25 years from a low of N=631 birds (50%), to a high of N=770 (100%). At 75% females breeding N= 736. Extinction risk is zero for all sub-populations and gene diversity remains above the threshold for success over the 25-year period. The difference made to individual sites is relatively small.

Table 6. Summary statistics for meta-population performance at 25 years when varying the annual percentage of females breeding at Burwood (a. 50%; b.75% and c. 100%)

	Sub-population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
a.	Burwood	0.00	0.10	0.00	88.93	9.80	0.97	0.00	0.0049	0.01
	Murch Mts	0.00	0.12	0.00	150.73	37.88	0.98	0.00	0.0074	0.01
	MK Sites	0.00	0.14	0.00	118.70	37.11	0.97	0.01	0.0119	0.01
	No MK Sites	0.01	0.08	0.00	49.87	4.44	0.95	0.01	0.0203	0.02
	Recovery Site	0.05	0.11	0.00	223.10	109.57	0.98	0.01	0.0109	0.01
	Meta-population	0.02	0.05	0.00	631.33	137.55	0.99	0.00	0.0101	0.01
b.	Burwood	0.01	0.12	0.00	90.99	8.85	0.97	0.00	0.0064	0.01
	Murch Mts	0.02	0.10	0.00	165.04	33.46	0.98	0.00	0.0081	0.01
	MK Sites	0.00	0.14	0.00	121.70	33.83	0.97	0.01	0.0117	0.01
	No MK Sites	0.01	0.07	0.00	51.46	2.30	0.96	0.01	0.0163	0.02
	Recovery Site	0.04	0.09	0.00	306.96	108.31	0.99	0.00	0.0092	0.01
	Meta-population	0.02	0.05	0.00	736.15	125.81	0.99	0.00	0.0095	0.00
c.	Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
	Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
	MK Sites	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
	No MK Sites	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
	Recovery Site	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00

Increasing reproductive output of individual females has a significant impact on population size at year 25. At the lowest rates modelled, expected N at 25 years is 689 but moves to N=825 at the highest rates modelled. Gene diversity and inbreeding outcomes are good in all cases. This is the highest-performing intervention of those tested.

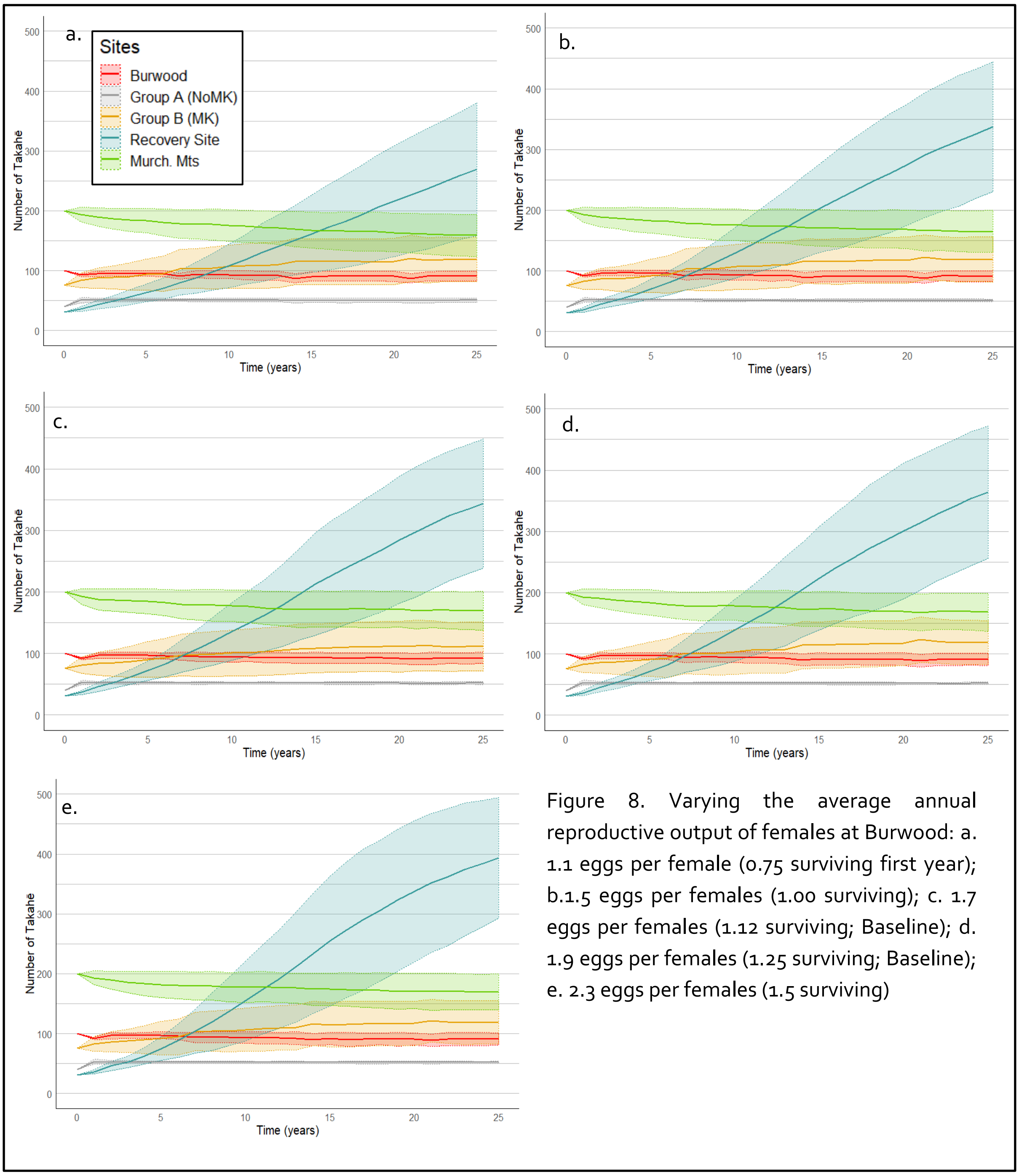


Figure 8. Varying the average annual reproductive output of females at Burwood: a. 1.1 eggs per female (0.75 surviving first year); b.1.5 eggs per females (1.00 surviving); c. 1.7 eggs per females (1.12 surviving; Baseline); d. 1.9 eggs per females (1.25 surviving; Baseline); e. 2.3 eggs per females (1.5 surviving)

Table 7. Varying the average annual reproductive output of females at Burwood: a. 1.1 eggs per female (0.75 surviving first year); b.1.5 eggs per females (1.00 surviving); c. 1.7 eggs per females (1.12 surviving; Baseline); d. 1.9 eggs per females (1.25 surviving; Baseline); e. 2.3 eggs per females (1.5 surviving)

	Sub-population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
a.	Burwood	0.00	0.11	0.00	91.37	8.14	0.97	0.00	0.0056	0.01
	Murch Mts	0.01	0.11	0.00	158.81	34.90	0.98	0.00	0.0071	0.01
	MK Sites	0.00	0.13	0.00	118.78	37.29	0.97	0.01	0.0115	0.01
	No MK Sites	0.01	0.07	0.00	51.01	3.29	0.96	0.01	0.0178	0.02
	Recovery Site	0.04	0.10	0.00	269.06	110.67	0.99	0.00	0.0090	0.01
	Meta-population	0.02	0.05	0.00	689.03	128.82	0.99	0.00	0.0091	0.00
b.	Burwood	0.01	0.13	0.00	91.37	8.95	0.97	0.00	0.0068	0.01
	Murch Mts	0.02	0.10	0.00	165.12	34.38	0.98	0.00	0.0075	0.01
	MK Sites	-0.01	0.15	0.00	118.94	36.77	0.97	0.01	0.0124	0.01
	No MK Sites	0.02	0.09	0.00	51.68	2.15	0.96	0.01	0.0126	0.02
	Recovery Site	0.04	0.09	0.00	337.30	107.13	0.99	0.00	0.0086	0.01
	Meta-population	0.03	0.05	0.00	764.41	122.86	0.99	0.00	0.0091	0.00
c.	Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
	Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
	MK Sites	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
	No MK Sites	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
	Recovery Site	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00
d.	Burwood	0.02	0.16	0.00	90.96	10.06	0.97	0.00	0.0070	0.01
	Murch Mts	0.01	0.11	0.00	168.36	31.01	0.98	0.00	0.0072	0.01
	MK Sites	0.00	0.14	0.00	118.76	35.90	0.97	0.01	0.0110	0.01
	No MK Sites	0.02	0.10	0.00	51.97	2.13	0.97	0.01	0.0119	0.02
	Recovery Site	0.05	0.09	0.00	363.90	107.94	0.99	0.00	0.0090	0.01
	Meta-population	0.03	0.05	0.00	793.96	126.76	0.99	0.00	0.0089	0.00
e.	Burwood	0.04	0.17	0.00	90.84	10.44	0.97	0.00	0.0094	0.01
	Murch Mts	0.02	0.10	0.00	169.96	29.83	0.98	0.00	0.0089	0.01
	MK Sites	-0.01	0.14	0.00	118.97	36.37	0.97	0.01	0.0115	0.01
	No MK Sites	0.03	0.11	0.00	52.10	1.97	0.97	0.01	0.0134	0.02
	Recovery Site	0.05	0.09	0.00	393.43	101.03	0.99	0.00	0.0101	0.01
	Meta-population	0.03	0.05	0.00	825.29	120.88	0.99	0.00	0.0101	0.00

VARYING THE INTENSITY OF GENETIC MANAGEMENT (GM)

Close genetic management can slow the rate of inbreeding accumulation and increase gene diversity retention in a population. This is important to very small populations for which these factors can be significant contributors to population declines. As populations become larger, they become less vulnerable to these factors. As genetic management can require increased investment of resources it is important to have a sense of when it adds value and how much. In these models, genetic management has two components: 1) managing rates of gene-flow between sites; 2) optimising pairings within sites (to retain gene diversity while keeping average inbreeding below 0.125).

MANAGING GENE-FLOW BETWEEN SITES

In the following model there is no movement of birds between sub-populations. This allows us to look at the resilience of each sub-population to 25 years of isolation, starting in year 1. This is unlikely ever to occur across the whole meta-population, though it is conceivable that some sub-populations could be isolated for periods of time due to resource constraints or disease issues.

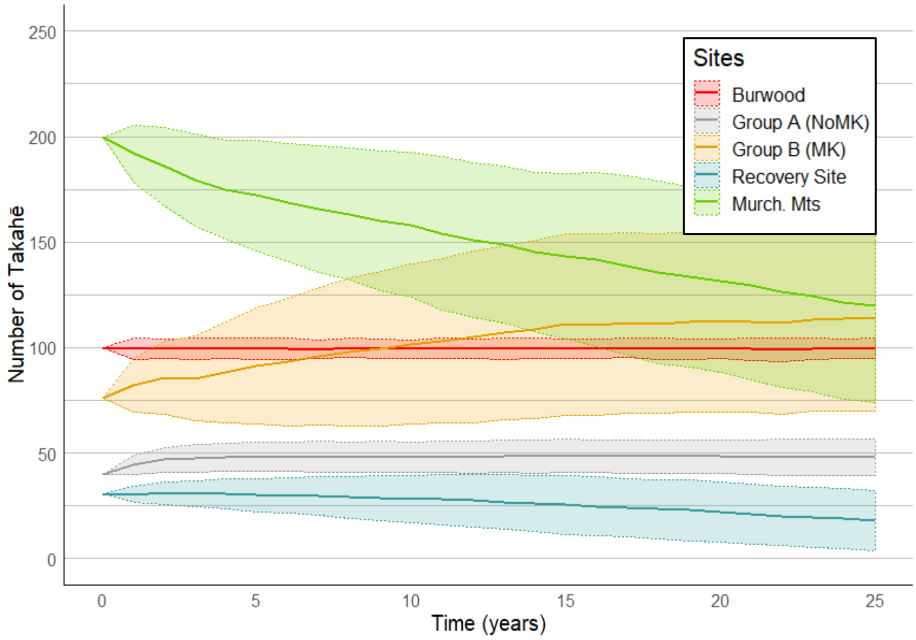


Figure 9. Sub-population growth projections over 25 years with no inter-site transfers (graph) and associated summary statistics (table below).

Population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
Burwood	0.16	0.08	0.00	99.56	4.83	0.96	0.01	0.0171	0.02
Murch Mts	-0.01	0.11	0.00	120.09	46.20	0.97	0.01	0.0113	0.01
MK Sites	0.02	0.16	0.01	114.03	44.08	0.96	0.02	0.0174	0.02
No MK Sites	0.03	0.10	0.00	48.09	8.71	0.92	0.02	0.0387	0.03
Recovery Site	-0.06	0.17	0.09	18.20	14.24	0.85	0.08	0.0662	0.09
Meta-population	0.05	0.06	0.00	399.97	69.48	0.99	0.00	0.0193	0.01

In this scenario. the Murchison Mts and Kahurangi sub-populations average negative growth over the period. For the Murchison Mts this is attributable to the ongoing losses due to predators which are not being compensated for. Despite this, the sub-population showed no risk of extinction over 25 years at the predation rates modelled, though mean population size had decreased by the end of the period to N=121 (S.D=46) from a starting size of 200 birds. At Kahurangi the declining growth is due to the current small size of the population. which for the next few years and in absence of further supplementation will leave it vulnerable to small population effects. The Kahurangi model showed a 9% chance of extinction over the period. The only other non-zero extinction risk (1%) was for the MK Sites. The stochastic risks allocated to sites within this sub-population make its performance highly variable and vulnerable to declines. However due to its size (mean N=114.03 at 25 years) gene diversity at 25 years is still 96%. The No MK sites sub-population grows positively and at a slightly faster rate than the MK Sites sub-population, though its smaller size retains less gene diversity over the period (GD at 25 years = 92%)). Burwood exhibits strong growth (r=0.17) throughout because it is not required to supplement either the Murchison Mountains, Kahurangi or the lower-performing sub-populations. It loses some gene diversity due to its size but remains above detrimental levels (GD at 25 years=96%). Figure 10. illustrates the 25-year impacts on inbreeding accumulation (a) and gene diversity loss (b). Overall the meta-population numbers move from a starting size of 447.00 to a mean of roughly 399.97 birds (SD= 69.48). Despite declines in some sub-populations **this strategy meets the overall genetic target but does not advance conservation of the species; overall growth is low and inbreeding higher than in the baseline.**

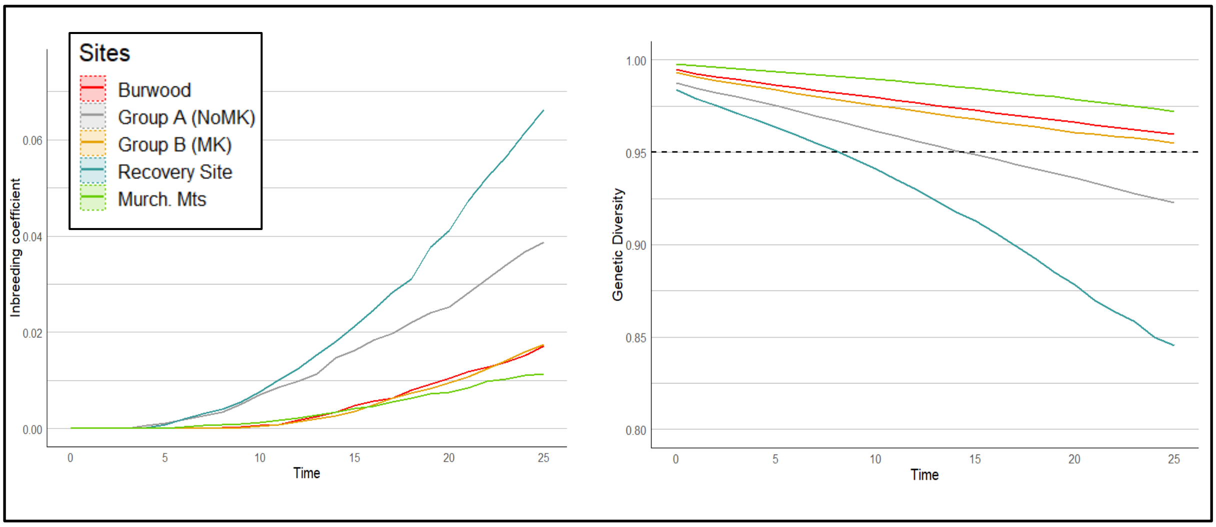


Figure 10. Impact of shutting off gene-flow between sub-populations for 25 years, on inbreeding accumulation (a) and gene diversity retention (b).

OPTIMISING PAIRINGS

In the following three scenarios, gene-flow is switched on at Baseline model levels. In the first scenario (a), pairings are selected at random from the adult birds available for breeding within each site. In the second scenario (b), pairings are optimised to connect under-represented founder lines with each other and at the same time avoid mating between close relatives, but only at Burwood. In the third scenario, close genetic management is also extended to the MK Sites sub-population.

As shown in Table 8., the overall meta-population goal (retention of 98% GD) is met in all three cases (i.e. even without close management), as is the goal of maintaining more than 92% gene diversity in individual sub-populations. Inbreeding accumulation remains below detrimental levels in all sub-populations for the period considered. Close management has no apparent effect on gene diversity outcomes at Burwood but elevates diversity at the MK Sites sub-population from 95% to 96%.

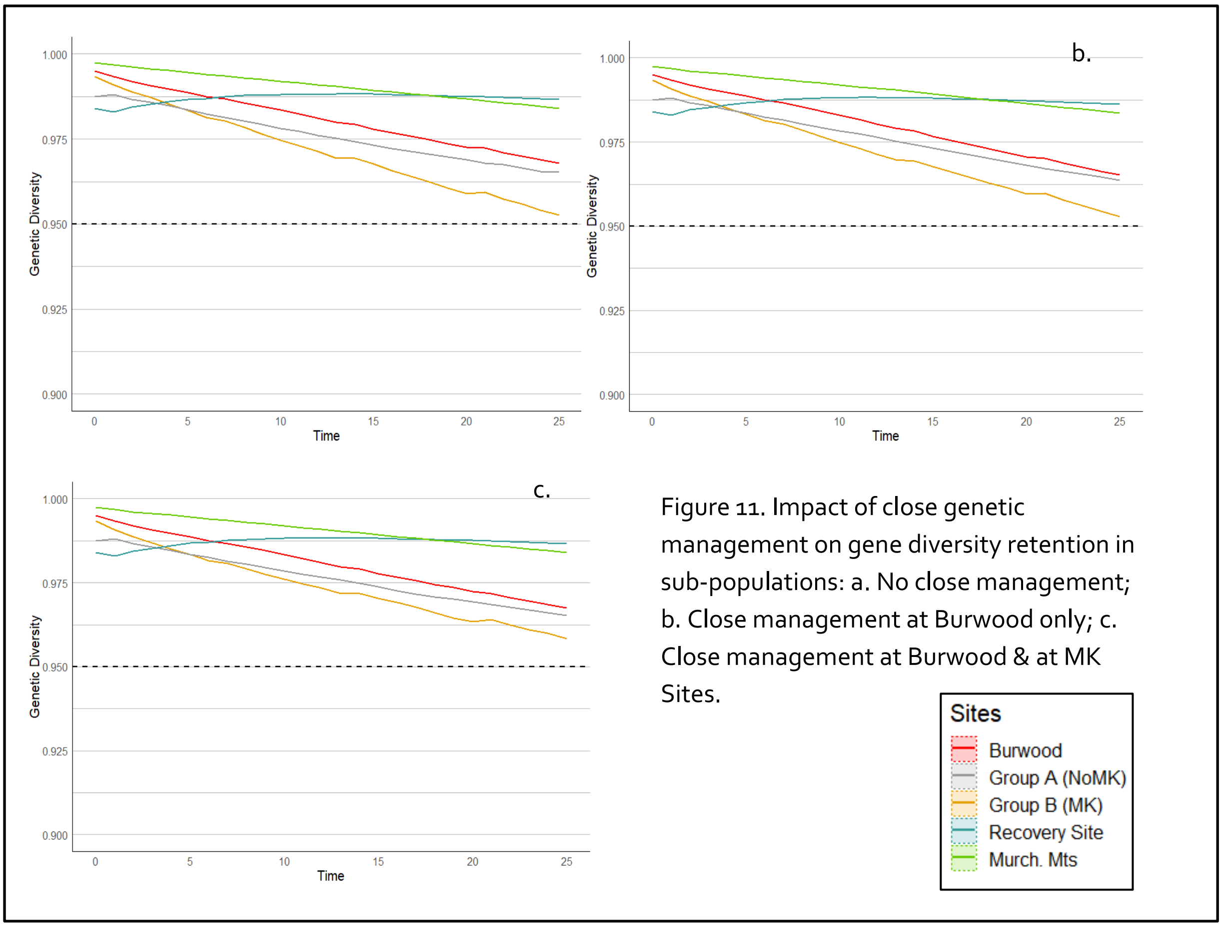


Figure 11. Impact of close genetic management on gene diversity retention in sub-populations: a. No close management; b. Close management at Burwood only; c. Close management at Burwood & at MK Sites.

Table 8. Summary statistics for the meta-population showing the impact of close genetic management on 25-year performance: a. No close management; b. Close management at Burwood only; c. Close management at Burwood & at MK Sites.

a.	Burwood	0.02	0.14	0.00	92.41	9.02	0.97	0.00	0.0064	0.01
	Murch Mts	0.02	0.10	0.00	171.24	29.89	0.98	0.00	0.0076	0.01
	MK Sites	0.00	0.15	0.00	110.38	40.41	0.95	0.02	0.0261	0.02
	No MK Sites	0.03	0.10	0.00	51.87	2.29	0.97	0.01	0.0140	0.02
	Recovery Site	0.05	0.09	0.00	342.68	111.39	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	768.57	132.45	0.99	0.00	0.0111	0.00
b.	Burwood	0.03	0.14	0.00	92.76	8.83	0.97	0.00	0.0166	0.02
	Murch Mts	0.02	0.10	0.00	168.78	32.64	0.98	0.00	0.0091	0.01
	MK Sites	0.00	0.14	0.00	111.40	39.51	0.95	0.02	0.0289	0.03
	No MK Sites	0.03	0.11	0.00	51.77	2.41	0.96	0.01	0.0178	0.02
	Recovery Site	0.04	0.09	0.00	346.54	105.63	0.99	0.00	0.0118	0.01
	Meta-population	0.03	0.05	0.00	771.25	127.14	0.99	0.00	0.0144	0.01
c.	Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
	Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
	MK Sites	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
	No MK Sites	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
	Recovery Site	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00

Varying capacity

In these models, various sections of the managed meta-population are removed to explore the impact on overall meta-population performance.

Tāwharanui and Motutapu

Scenarios in this section consider the removal or repurposing of two sites that are proving challenging to manage effectively: Tāwharanui and Motutapu. The following scenarios are considered:

- removal of Tāwharanui and the repurposing of Motutapu as a retirement site;
- removal of both Tāwharanui and Motutapu from the meta-population.

Removing Tāwharanui and/or Motutapu consists of reducing K in the No MK Sites sub-population and re-distributing the birds previously at those sites among the remaining sites in that sub-population.

Repurposing Motutapu as a retirement site requires no action as though the redistribution of birds has practical and logistical implications it does not have an impact on the overall numbers of births and deaths within the sub-population, or on overall carrying capacity. Using the Baseline model for comparison, Figures 12 & 13 below illustrate the demographic and genetic impacts of these changes.

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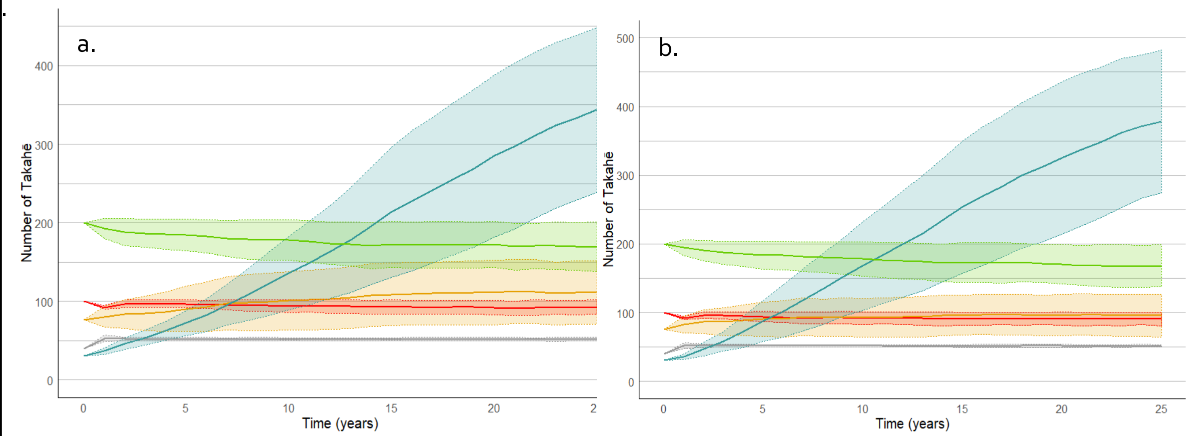


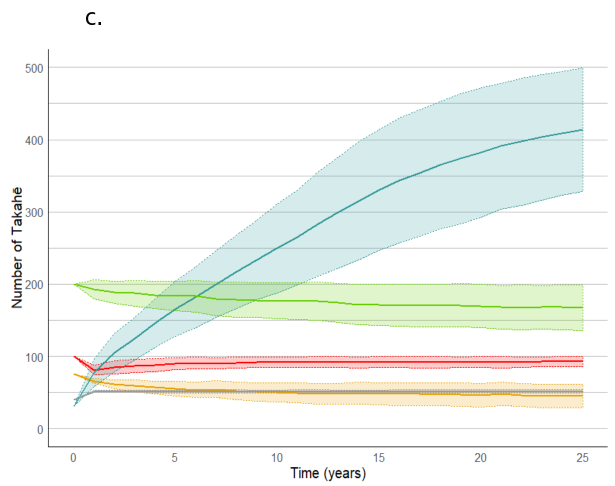
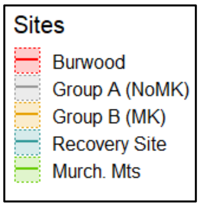


Figure 12. Impact on sub-population growth of removing Tāwharanui (K=30) and either removing (b) or repurposing (c) Motutapu (K=60). Baseline models are shown for comparison (a).



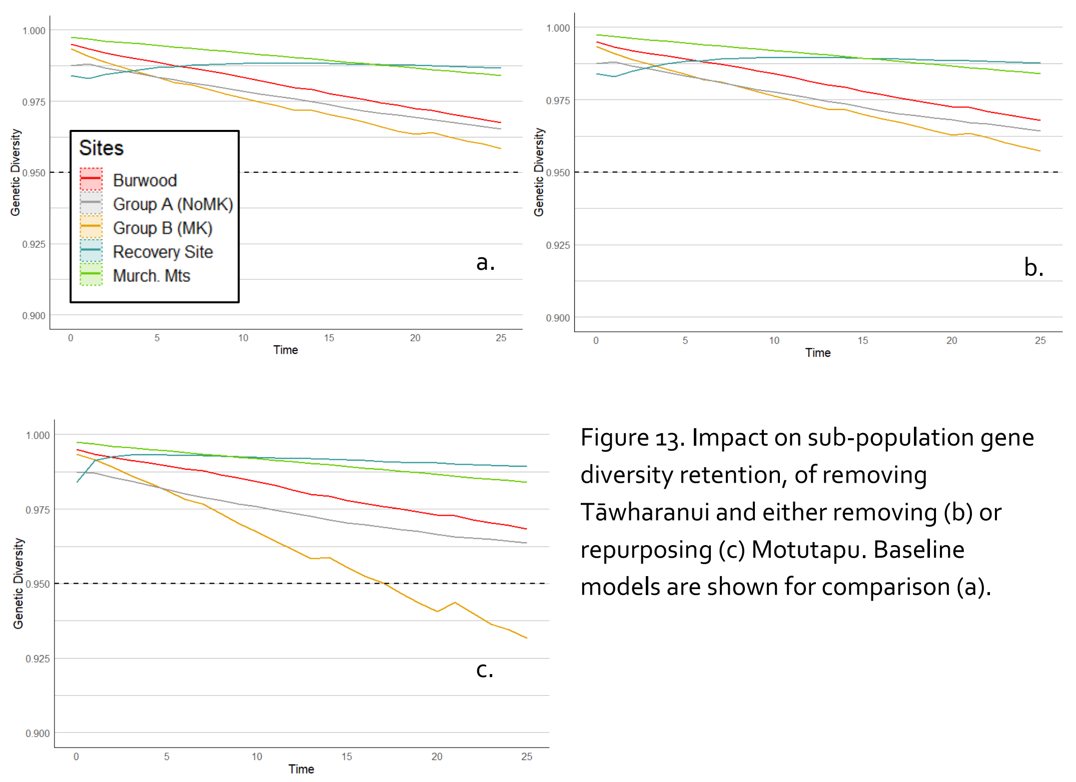


Figure 13. Impact on sub-population gene diversity retention, of removing Tāwharanui and either removing (b) or repurposing (c) Motutapu. Baseline models are shown for comparison (a).

Tāwharanui and Motutapu are two of the larger MK Sites. However, because growth rates in that sub-population are relatively low and there is still some unused capacity at the start of the simulations, the loss of these sites does not make a dramatic difference over the period modelled, as long as Burwood remains strong and Kahurangi continues to perform well. Gene diversity remains high enough to exceed the target threshold in both scenarios (see Table 9) though it falls to 93% in the MK Sites sub-population due to the decrease in K. When only removing Tāwharanui there is very little change in performance. Figure 14 below illustrates the impact on inbreeding accumulation of removing or re-purposing Tāwharanui and Motutapu. Though there is some escalation of inbreeding it remains below detrimental levels. Loss of carrying capacity in the MK sites reduces the number of birds that need to be sent there from Burwood, making more birds available for supplementation at Kahurangi. As a result, population size at Kahurangi increases from N=769.20 in the Baseline to N=784.68 with both Tāwharanui and Motutapu removed.

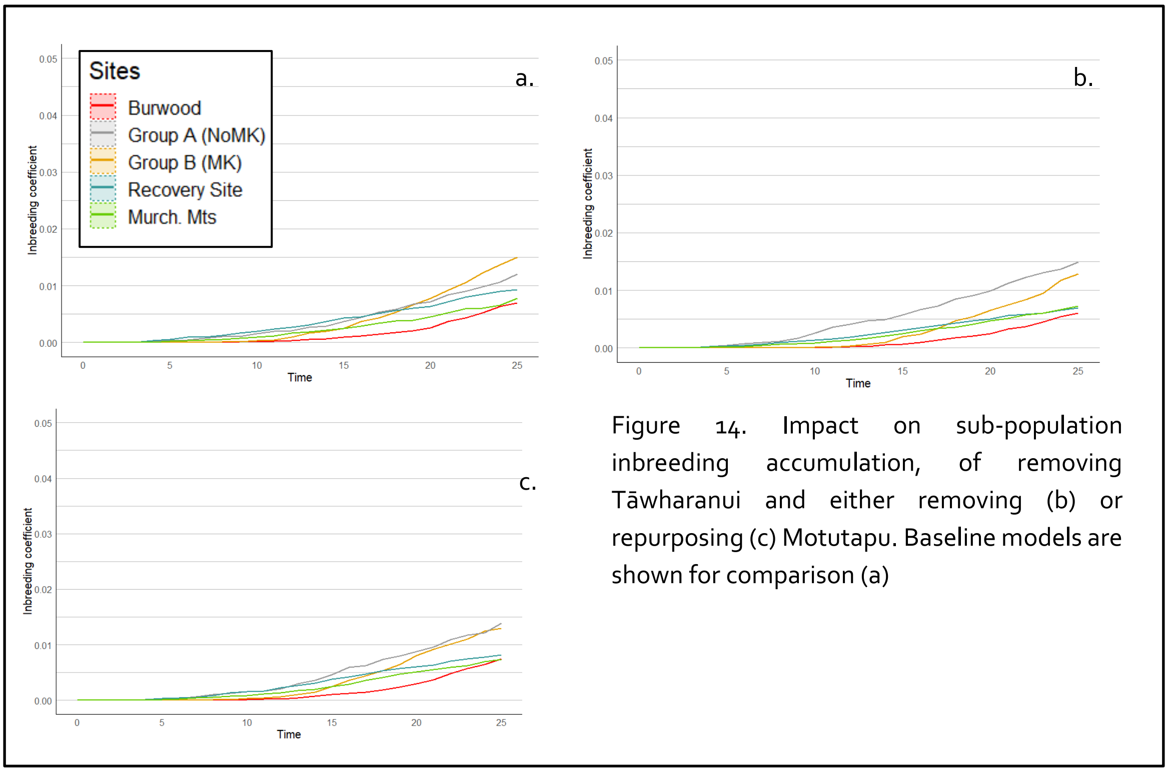


Figure 14. Impact on sub-population inbreeding accumulation, of removing Tāwharanui and either removing (b) or repurposing (c) Motutapu. Baseline models are shown for comparison (a)

Table 9. Summary statistics showing impact on meta-population, of removing Tāwharanui and either removing (b) or repurposing (c) Motutapu. Baseline models are shown for comparison (a)

	Sub-population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
a.	Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
	Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
	MK Sites	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
	No MK Sites	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
	Recovery Site	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00
b.	Burwood	0.01	0.14	0.00	90.98	9.69	0.97	0.00	0.0075	0.01
	Murch Mts	0.02	0.10	0.00	168.02	30.57	0.98	0.00	0.0074	0.01
	MK Sites	0.00	0.15	0.00	95.71	30.84	0.96	0.02	0.0130	0.02
	No MK Sites	0.01	0.09	0.00	51.80	1.96	0.96	0.01	0.0139	0.02
	Recovery Site	0.04	0.09	0.00	378.18	104.20	0.99	0.00	0.0082	0.01
	Meta-population	0.03	0.05	0.00	784.68	121.69	0.99	0.00	0.0089	0.00
c.	Burwood	0.02	0.11	0.00	93.16	7.15	0.97	0.00	0.0061	0.01
	Murch Mts	0.01	0.11	0.00	167.44	31.50	0.98	0.00	0.0073	0.01
	MK Sites	0.00	0.15	0.00	44.79	16.34	0.93	0.03	0.0129	0.02
	No MK Sites	0.02	0.09	0.00	51.84	2.18	0.96	0.01	0.0149	0.02
	Recovery Site	0.03	0.08	0.00	413.70	85.30	0.99	0.00	0.0070	0.00
	Meta-population	0.02	0.05	0.00	770.93	96.72	0.99	0.00	0.0079	0.00

REMOVAL OF SUB-POPULATIONS

Scenarios in this section consider the hypothetical removal of each sub-population in turn. The models shown here explore the response of the meta-population to the loss of entire sub-populations. This is not likely to be a deliberate management strategy, but the purpose is to illustrate the extent to which meta-population viability relies on one or more of its component sub-populations. With a. showing the Baseline, we removed from the system: b. Burwood; c. MK Sites; and d. No MK Sites. Deleted sub-populations are removed at the start of year 1.

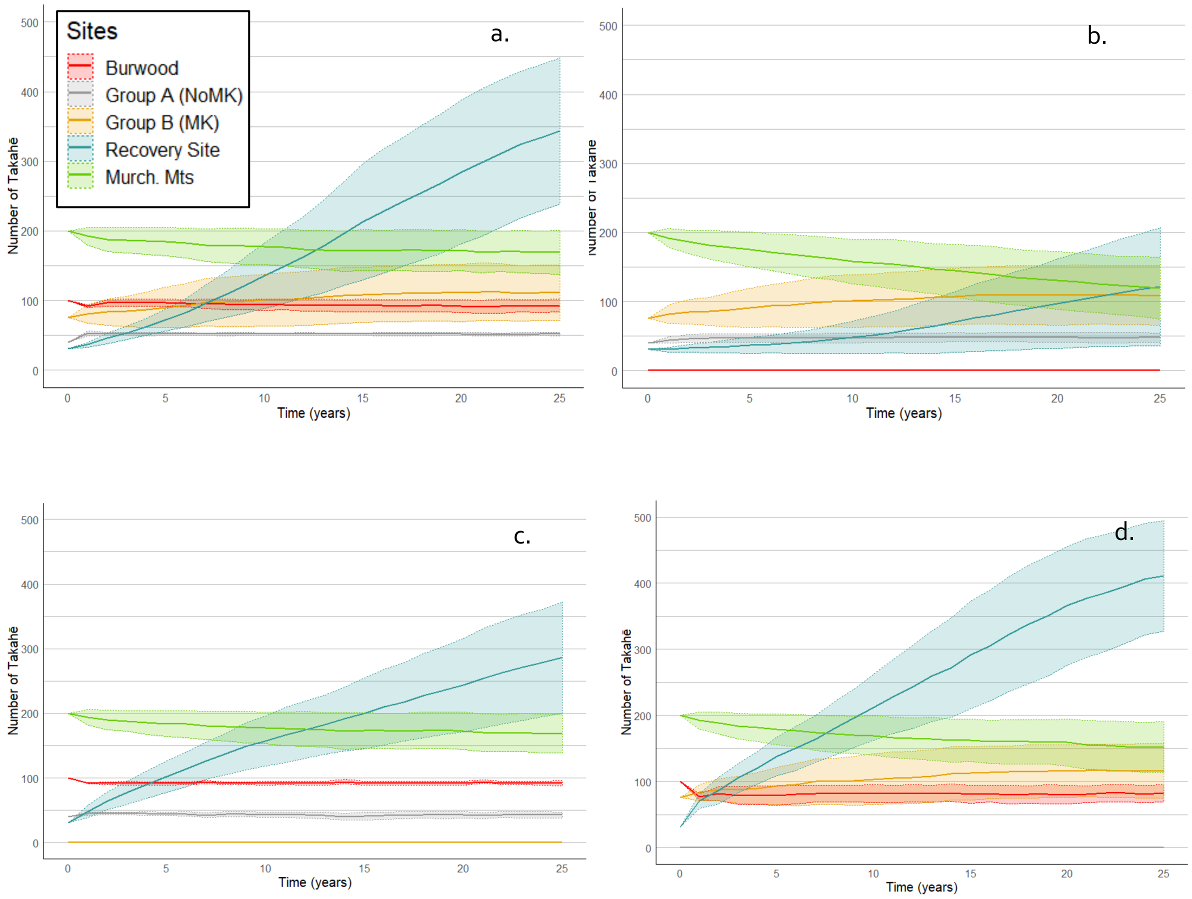


Figure 15. Impact on the meta-population of removing specific sub-populations: Baseline (a); Burwood (b); MK Sites (c); and No MK Sites (d)

As shown. removing Burwood has the greatest impact on the meta-population, leading to ongoing declines in the Murchison Mountains and poor performance at Kahurangi. Growth of the MK Sites sub-population is also slowed.

Removal of the MK Sites sub-population results in poorer performance than the baseline, with slower growth at Kahurangi. Removal of the No MK Sites results in birds that would otherwise be used to top-up sites there being sent instead to Kahurangi, resulting in more growth there.

Though the loss of any of these sub-populations depresses overall growth and genetic retention. the loss of Burwood has the greatest negative impact.

Table 10. Summary statistics showing impact on meta-population, of removing different sub-populations: Baseline (a); Burwood (b); MK Sites (c) and No MK Sites (d).

	Sub-population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
a.	Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
	Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
	MK Sites	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
	No MK Sites	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
	Recovery Site	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00
b.	Burwood	-	-	-	-	-	-	-	-	-
	Murch Mts	-0.02	0.12	0.00	119.94	44.69	0.97	0.01	0.0108	0.01
	MK Sites	-0.01	0.16	0.00	108.57	43.12	0.95	0.03	0.0150	0.02
	No MK Sites	0.00	0.08	0.00	48.11	6.74	0.93	0.02	0.0322	0.03
	Recovery Site	0.04	0.14	0.00	121.98	85.53	0.96	0.04	0.0270	0.04
	Meta-population	0.00	0.06	0.00	398.60	121.46	0.99	0.00	0.0180	0.01
c.	Burwood	0.00	0.05	0.00	92.13	3.73	0.97	0.00	0.0049	0.01
	Murch Mts	0.02	0.10	0.00	168.81	29.83	0.98	0.00	0.0067	0.01
	MK Sites	-	-	-	-	-	-	-	-	-
	No MK Sites	-0.01	0.11	0.00	43.01	4.61	0.97	0.00	0.0045	0.01
	Recovery Site	0.03	0.08	0.00	286.28	86.29	0.98	0.00	0.0095	0.01
	Meta-population	0.02	0.05	0.00	590.22	91.88	0.99	0.00	0.0076	0.00
d.	Burwood	0.02	0.23	0.00	82.37	12.98	0.97	0.01	0.0053	0.01
	Murch Mts	0.01	0.10	0.00	152.07	38.21	0.98	0.00	0.0081	0.01
	MK Sites	0.00	0.15	0.00	116.10	41.02	0.96	0.02	0.0143	0.02
	No MK Sites	-	-	-	-	-	-	-	-	-
	Recovery Site	0.03	0.09	0.00	411.29	83.77	0.99	0.00	0.0083	0.01
	Meta-population	0.02	0.06	0.00	761.83	109.38	0.99	0.00	0.0088	0.00

VARYING WILD INPUTS

The following scenarios consider the impact of varying the number and frequency with which birds are currently recruited from the Murchison Mountains from a. 4 birds every generation (7 years); to b. 2 birds every generation (Baseline)) to c. 2 birds every second generation (14 years). Figure 16 shows the impact on gene diversity retention and on inbreeding accumulation of these alternatives.

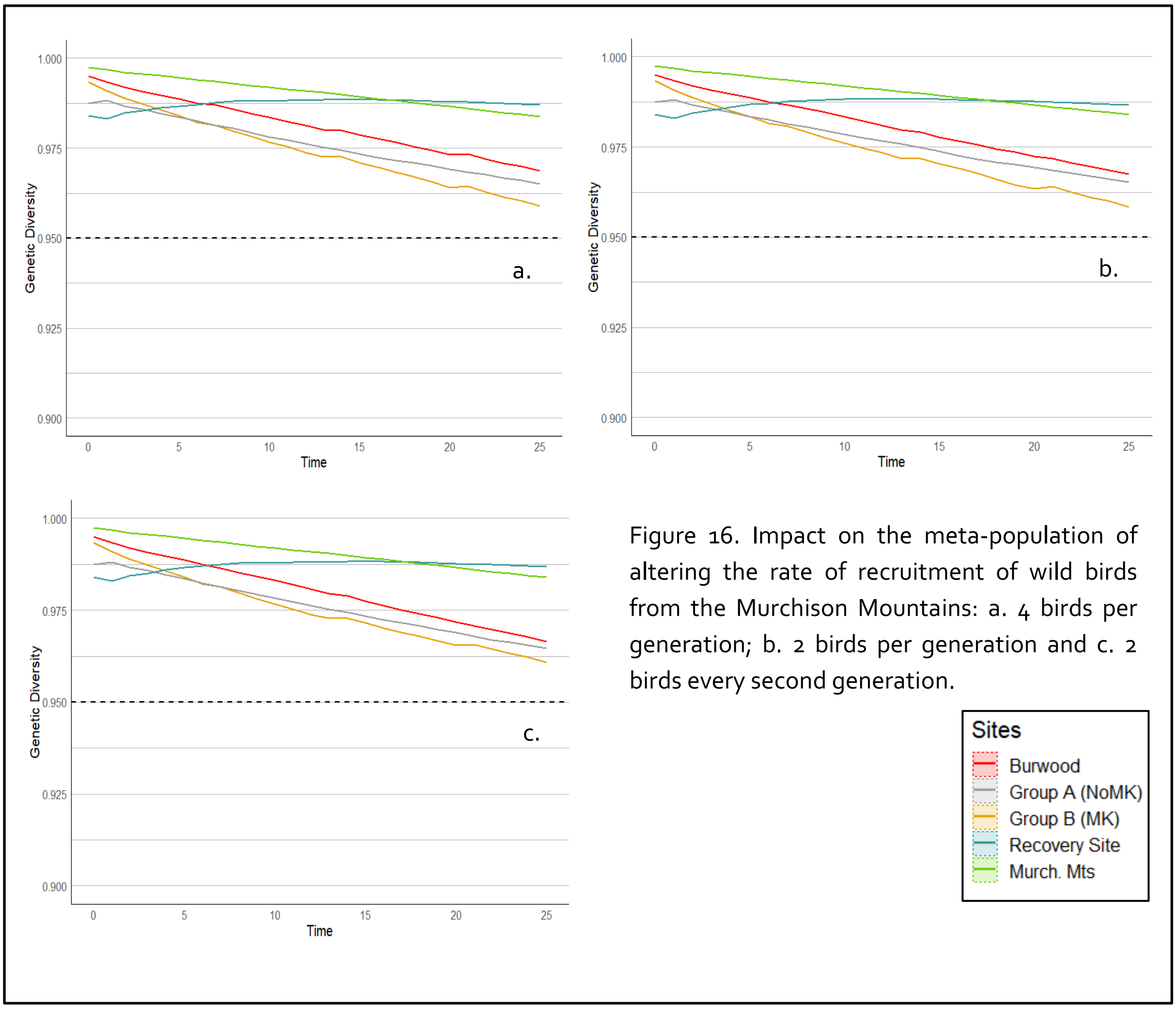


Figure 16. Impact on the meta-population of altering the rate of recruitment of wild birds from the Murchison Mountains: a. 4 birds per generation; b. 2 birds per generation and c. 2 birds every second generation.

As illustrated, even doubling the Baseline rates of input from the wild makes little difference to gene diversity outcomes. In practice, outcomes may be slightly improved because in the models, new founders are given the same chance of breeding and rearing young as other birds, whereas newly acquired founders would be likely to receive preferential treatment. However, given the high rates of success at Burwood included in the Baseline Model this would be expected to make only a slight difference.

Table 11. Summary statistics for impact on the meta-population of altering the rate of recruitment of wild birds from the Murchison Mountains: a. 4 birds per generation; b. 2 birds per generation and c. 2 birds every second generation.

	Population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
a.	Burwood	0.02	0.14	0.00	91.28	9.80	0.97	0.00	0.0076	0.01
	Murch Mts	0.01	0.11	0.00	169.24	29.36	0.98	0.00	0.0074	0.01
	MK Sites	-0.01	0.15	0.00	114.03	40.00	0.96	0.01	0.0124	0.01
	No MK Sites	0.02	0.09	0.00	51.82	2.02	0.96	0.01	0.0123	0.02
	Recovery Site	0.04	0.09	0.00	351.19	108.88	0.99	0.00	0.0091	0.01
	Meta-population	0.03	0.05	0.00	777.56	131.70	0.99	0.00	0.0093	0.00
b.	Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
	Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
	MK Sites	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
	No MK Sites	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
	Recovery Site	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00
c.	Burwood	0.01	0.15	0.00	91.28	10.22	0.96	0.00	0.0074	0.01
	Murch Mts	0.02	0.10	0.00	168.87	30.61	0.98	0.00	0.0079	0.01
	MK Sites	-0.01	0.16	0.00	111.17	42.52	0.95	0.02	0.0145	0.01
	No MK Sites	0.01	0.09	0.00	51.88	2.27	0.96	0.01	0.0126	0.02
	Recovery Site	0.04	0.10	0.00	340.18	108.64	0.98	0.00	0.0090	0.01
	Meta-population	0.03	0.05	0.00	763.38	131.22	0.99	0.00	0.0095	0.00

Additional Models 1. Impact of 1080 on Kahurangi

The following models explore the potential impacts on the meta-population of different 1080 results at Kahurangi. In the Baseline model, 1080 increases mortality of the birds by 10% and reduces overall reproduction by 20%. Predation is present but operates at a reduced rate (5% extra mortality and 10% reduction in reproduction).

Two additional scenarios were run. In the first (a) 1080 is removed, predation increases mortality by 20% and reduces reproduction by 25%. In the second (c), the effect of 1080 on the birds is to reduce survival by 20% (instead of 10%) and to reduce reproduction by 30% (instead of 20%), without changing the effect on predation. The Baseline model is provided for comparison (b).

As illustrated, the Kahurangi sub-population performs best with the Baseline values. Growth is still positive but decreases when either predation increases (due to lack of 1080) or poisoning increases (due to more severe effects of 1080). It is important to note that the Kahurangi population is continually supplemented by Burwood. In absence of this ongoing support it would be expected to decline.

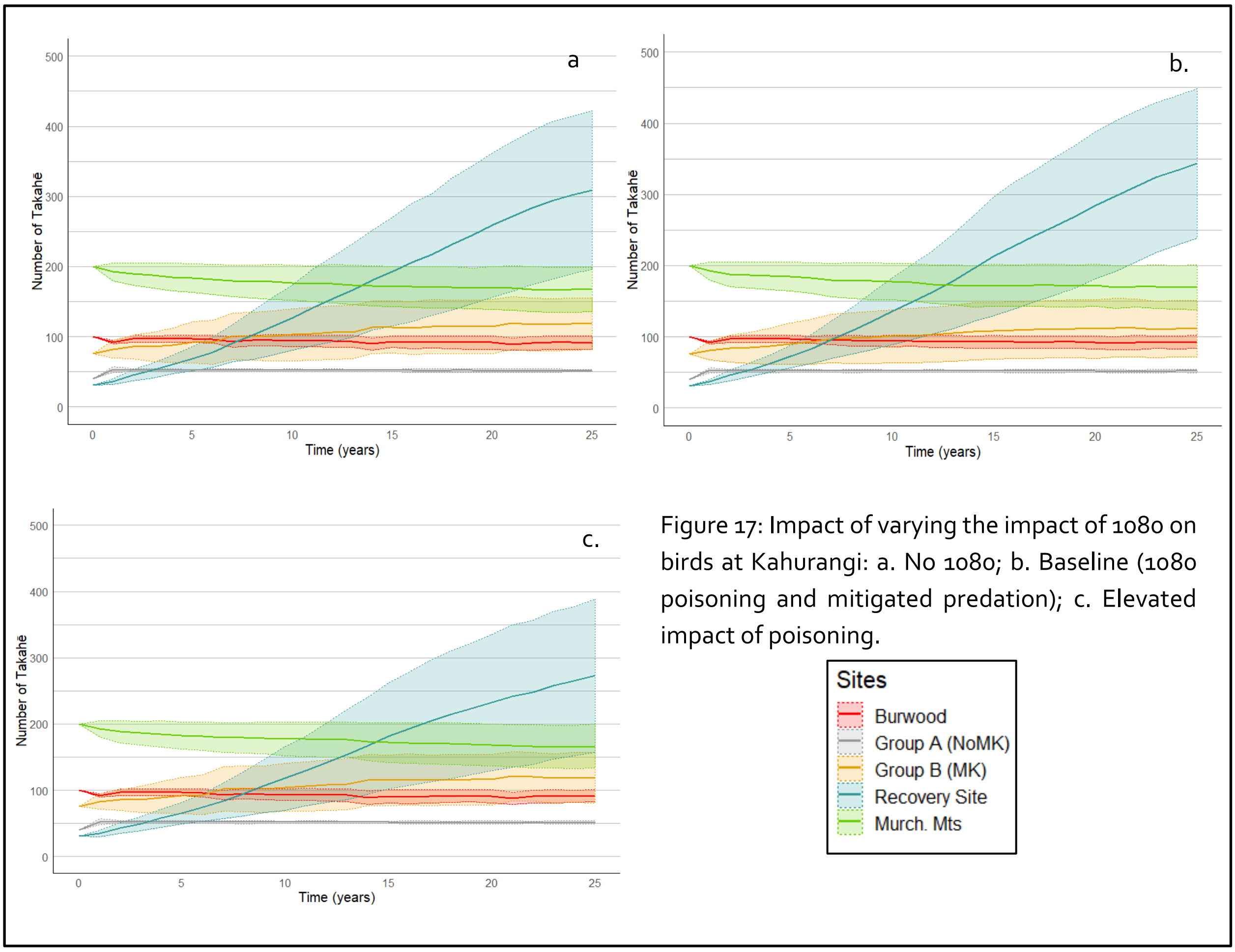


Figure 17: Impact of varying the impact of 1080 on birds at Kahurangi: a. No 1080; b. Baseline (1080 poisoning and mitigated predation); c. Elevated impact of poisoning.

Table 12: Impact of varying the impact of 1080 on birds at Kahurangi: a. No 1080; b. Baseline (1080 poisoning and mitigated predation); c. Elevated impact of poisoning.

	Sub-population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
a.	Burwood	0.01	0.14	0.00	91.29	9.74	0.97	0.00	0.0079	0.01
	Murch Mts	0.02	0.10	0.00	167.69	31.58	0.98	0.00	0.0073	0.01
	MK Sites	0.01	0.13	0.00	118.64	36.84	0.97	0.01	0.0115	0.01
	No MK Sites	0.03	0.09	0.00	52.00	1.79	0.96	0.01	0.0137	0.02
	Recovery Site	0.03	0.12	0.00	309.05	113.02	0.99	0.00	0.0097	0.01
	Meta-population	0.02	0.06	0.00	738.68	130.11	0.99	0.00	0.0095	0.00
b.	Burwood	0.03	0.13	0.00	92.79	9.12	0.97	0.00	0.0070	0.01
	Murch Mts	0.02	0.10	0.00	169.38	31.34	0.98	0.00	0.0078	0.01
	MK Sites	0.00	0.15	0.00	111.39	40.05	0.96	0.02	0.0150	0.02
	No MK Sites	0.02	0.10	0.00	51.92	2.14	0.97	0.01	0.0121	0.02
	Recovery Site	0.04	0.09	0.00	343.73	104.69	0.99	0.00	0.0093	0.01
	Meta-population	0.03	0.05	0.00	769.20	126.91	0.99	0.00	0.0096	0.00
c.	Burwood	0.02	0.14	0.00	91.77	9.22	0.97	0.00	0.0061	0.01
	Murch Mts	0.02	0.10	0.00	166.71	32.85	0.98	0.00	0.0072	0.01
	MK Sites	-0.01	0.14	0.00	118.89	37.84	0.97	0.01	0.0109	0.01
	No MK Sites	0.02	0.10	0.00	51.82	2.53	0.96	0.01	0.0125	0.02
	Recovery Site	0.03	0.14	0.00	273.10	115.46	0.99	0.00	0.0098	0.01
	Meta-population	0.03	0.06	0.00	702.27	131.44	0.99	0.00	0.0090	0.00

ADDITIONAL MODELS 2. INITIATING NEW POPULATIONS

Extinction risk for newly founded sites will vary depending on the initial population size and the rate of further supplementation. Larger starting sizes confer lower extinction risk than smaller starting sizes, and more supplementation is less risky than less supplementation. The following graphs (Figures 18. and 19.) illustrate the relationship between these variables, for takahē.

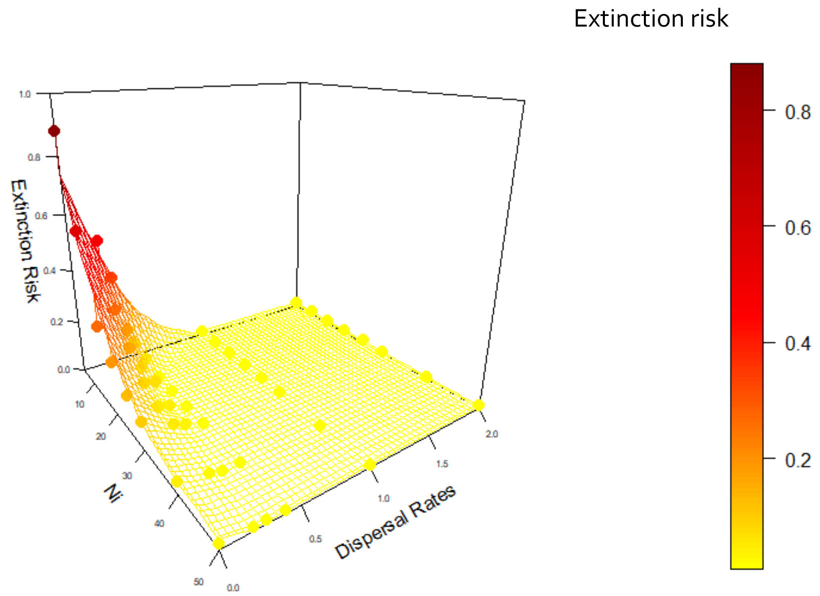


Figure 18. Impact on extinction risk of starting population size versus supplementation rate.

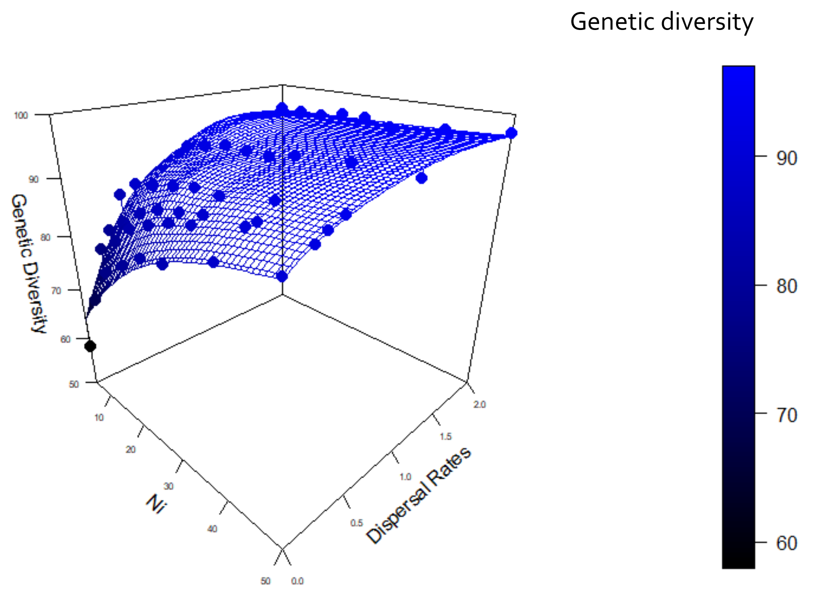


Figure 19. Impact on gene diversity of starting population size versus supplementation rate.

Initial population sizes of 5; 10; 15; 20; 25; 30; 40 and 50 birds were used and pairs of birds were transferred every 10; 7; 5; 2 or 1 year (representing annual transfer rates of 0.2; 0.28; 0.4; 1 or 2 birds a year respectively). One simulation was sun for each pair of parameters described to model the "landscape" of extinction risk and genetic diversity retention over the entire range of parameters studied.

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APPENDIX I: *VORTEX* MODEL DETAILS

VORTEX (Lacy, et al., 2003) provides a generic life-history framework into which species-specific values and life-history anomalies can be incorporated and projected forwards at the population level. For the analyses described in this report, a baseline model was constructed which was designed to emulate a meta-population under "normal" conditions with respect to local risks, typical inter-site transfer rates and within-site birth and death rates. The parameters used to construct this baseline are described in more detail in the following tables. For a more detailed explanation of *VORTEX* models for this species, see Lees et al., (2014).

Table 13. Summary of VORTEX parameters

Vortex Parameter	Best Guess	NOTES
# of populations	3 to 5 depending on scenario	In total the species is spread across 1 captive breeding facility. 6 non-breeding retirement sites; 9 existing managed islands. 3 new managed islands. 1 wild population (Murchison Mts). See previous diagram.
Inbreeding depression included?	Yes (2.35LEs to first year survival; 13.68LEs to female reproduction)	Entered in the model as lethal equivalents imposing additional mortality on juveniles though we can also include it as reduced female reproduction. Default for captive populations is 3.14LEs calculated from a study of 40 captive mammalian species (Ralls et al. 1988). O'Grady et al recommend incorporating a higher number of LEs in wild population models to allow for the impact of a more stressful environment - 12.00Les spread across survival and reproduction. Managed island populations may sit somewhere between. A takahē-specific analysis described in Grueber et al. (2010) records 16.0 LEs spread inter-generationally across life-stages. After some additional testing and discussion (see associated report) 2.35 lethal equivalents were allocated to first-year survival and 13.68 allocated to female reproduction in the Best Guess. The default of 50% allocation of LEs to recessive lethals was retained.
Concordance of environmental variation (EV) and reproduction	0.5	Mortality events mainly related to old age and aggression. These are not coupled to good years for reproduction.
EV correlation among populations	0.5	Not much year-to-year variation in conditions on islands. but what variation there is island-specific.
Breeding system	Long-term Monogamous	In general pairs remain together unless experiencing breeding difficulties. which is unusual.
Age of first reproduction (♂ / ♀)	3yrs/3yrs	Females have been known to breed at 2 years but this is rare.
Maximum age of reproduction	15 years	Birds may breed beyond this but it becomes increasingly unlikely and birds are not expected to exceed 20 years. 15 year old birds are removed to "retirement homes" so should have no detrimental impact on capacity in the immediate future. Impact of not removing them may be considered as part of scenario testing but will require discussion of appropriate density dependent parameters.

Vortex Parameter	Best Guess	NOTES
Annual % adult females breeding	80%	Based on real data. Vary between sites (From 100% in Burwood to 50% in Group A).
EV in breeding (measured as standard deviation of % of breeding females)	5%	Ranges between around 75-85% breeding - i.e. relatively little year-to-year variation.
% males in breeding pool	100%	Sex-ratio on islands is maintained at 50:50. Only when there is a male surplus will some males lose access to the breeding pool.
Clutch size	Max size 3. Distribution 1=68%; 2=28%; 3=4%	Hatch rate is 65%. mortality rates are measures from hatch. In the model maximum number of progeny per brood is set to 1. This may be slightly conservative. Glen re-checked data (March 19. 2014) and data support setting a maximum clutch size of 2 with a distribution of 1=70% and 2 = 30%. Baseline changed to reflect this.
Offspring Dependent	Yes. Over 1 year.	Offspring are considered as dependent on their dam for 1 year.
Offspring sex ratio	0.5	Birds are sexed at 3-4 months of age - at that point sex-ratio is 50:50
% annual mortality (♂ / ♀)	Age 0 to 1: mean= 25% Age 1 to 2: mean= 9% Age 2 to 3: mean= 7% Age 3 to 14: 5% > Age 14: 50%	Vary between populations, based on Burwood's record. Relatively little year-to-year variation observed.
0-1 years	28 (2.8)	
1-15 years	5 (0.5)	
15-20 years	50 (5)	At 50% annual mortality only 1% of animals remain at age 21.
Initial population size	Expected to vary with management	This will be varied according to the management scenario being examined. To inform deliberations data have been gathered on current numbers and also capacities at each site. Various sizes given for existing and planned populations. Carrying capacities given below as Adults (Total).
Rarotoka	12 (20)	K= 16 (26)
Murchison Mts	40 (70)	K=70 (120)
Burwood (captive)	36 (60) (currently 6 spare females)	K= 36 (70)

Vortex Parameter	Best Guess	NOTES
Maud (likely to cease as a breeding site)	8 (8)	K= 8 (8)
Kapiti	6 (11)	K=0 (in 2 years)
Mana	22 (33)	K=22 (33)
Cape Sanctuary	2 (2)	K=50 (75)
Maungatautari	6(7)	K=8(12)
Motutapu	10 (17)	K=50 (75)
Tiritiri Matangi	8 (9)	K=8 (12)
Tawharanui	0	K=24 (36)
Te Kopi	0	K=30 (45)
Clinton Valley	0	K=6 (6)
Total Initial Size (excludes Murchisons) given as total ADULTS.	Varied according to scenario	
Carrying Capacity (K) (excludes Murchisons) given as total number of animals aged >1yr	This will be varied according to the management scenario being examined. For the purpose of sensitivity testing the following value. which is the sum of all available site carrying capacities at present. was used. 328 (rounded to 330)	ST only to the point where intrinsic growth rather than K is limiting population expansion.
% transfer rates	Appendix X	To be determined with respect to individual management scenarios.
Breeding pair selection	random	Other genetic management strategies also tested but random included in baseline.
Catastrophe	See table 15	Suggest at the very least using the rule of thumb from Reed et al (2003) generated from study of 88 vertebrate species (i.e. 15% per generation probability of a severe catastrophe where severe = at least 50% loss). Suggest applying at the island-level rather than population-wide? (Can convert generational rate of 15% to an annual rate of 1.8% (rounded to 2) for takahē generation time of 8.3 years) See Table 15 for other specific catastrophes
Timeframe	25 Years	?

For verification that the key source population at Burwood is maintaining realistic characteristics during the simulation, the age-structure at 25 years was checked and was sitting at roughly that currently in place (see Table 14 below).

Table 14. Age structure of Burwood after 25 years

Age	1	2	Adult
Females	8	4	37
Males	8	4	37

Table 15. Site-specific risks (estimated by the Recovery Team): the following table describes site-specific risks to Takahē, either existing or potential, with estimated likelihood of occurrence and expected impact on reproduction and survival. For modelled sub-populations, risks are averaged across the sites included in that sub-population.

SITE TYPE	SITE NAME	RISK	FREQUENCY	IMPACT REPROD	IMPACT SURVIVAL
Wild	Murchison Mts	Disease	01:50	0.1	0.05
Wild	Murchison Mts	Drought	01:10	0.25	0
Wild	Murchison Mts	Extreme winter	01:20	0.25	0.15
Wild	Murchison Mts	Fire	01:50	0.05	0.05
Wild	Murchison Mts	Stoat induced predation	01:04	0.25	0.15
Recovery	Kahurangi	1080 induced predation	01:04	0.2	0.1
Recovery	Kahurangi	Disease	01:50	0.1	0.05
Recovery	Kahurangi	Fire	01:50	0.1	0.05
Recovery	Kahurangi	Flood	01:25	0.1	0.025
Recovery	Kahurangi	Stoat induced predation	01:04	0.1	0.05
Burwood	Burwood	Disease	01:25	0.1	0.1
Burwood	Burwood	Drought	01:10	0.1	0
Burwood	Burwood	Extreme winter	01:20	0.1	0.025
Burwood	Burwood	Fire	01:50	0.35	0.2
Burwood	Burwood	Incursion	01:10	0.1	0.05
GroupA	Mana	Disease	01:25	0.2	0.1
GroupA	Mana	Fire	01:40	0.1	0.2
GroupA	Mana	Incursion	01:20	0.2	0.1
GroupA	Rarotoka	Disease	01:25	0.1	0.05
GroupA	Rarotoka	Fire	01:50	0.5	0.25
GroupA	Rarotoka	Incursion	01:10	0.02	0.01
GroupB	Cape Sanctuary	Disease	01:25	0.2	0.1
GroupB	Cape Sanctuary	Drought	01:10	0.25	0

SITE TYPE	SITE NAME	RISK	FREQUENCY	IMPACT REPROD	IMPACT SURVIVAL
GroupB	Cape Sanctuary	Fire	01:25	0.1	0.05
GroupB	Cape Sanctuary	Incursion	1.1	0.02	0.01
GroupB	Kapiti	Disease	01:25	0.1	0.2
GroupB	Kapiti	Fire	01:50	0.1	0.2
GroupB	Kapiti	Incursion	01:10	0.1	0.2
GroupB	Maungatautari	Disease	01:25	0.5	0.5
GroupB	Maungatautari	Fire	01:50	0.5	0.5
GroupB	Maungatautari	Incursion	01:20	0.25	0.25
GroupB	Motutapu	Disease	01:25	0.2	0.1
GroupB	Motutapu	Drought	01:10	0.25	0
GroupB	Motutapu	Fire	01:25	0.1	0.05
GroupB	Motutapu	Incursion	01:10	0.1	0.05
GroupB	Orokonui	Disease	01:50	0.5	0.5
GroupB	Orokonui	Fire	01:50	0.1	0.1
GroupB	Orokonui	Incursion	01:05	0.02	0.01
GroupB	Puangiangi	Disease	01:25	0.2	0.1
GroupB	Puangiangi	Drought	01:10	0.5	0
GroupB	Puangiangi	Fire	01:25	0.1	0.05
GroupB	Puangiangi	Incursion	01:10	0.2	0.1
GroupB	Rotoroa	Disease	01:25	0.5	0.25
GroupB	Rotoroa	Drought	01:10	0.5	0.1
GroupB	Rotoroa	Fire	01:25	0.2	0.1
GroupB	Rotoroa	Incursion	01:20	0.2	0.1
GroupB	Tawharanui	Disease	01:25	0.2	0.1
GroupB	Tawharanui	Drought	01:10	0.25	0
GroupB	Tawharanui	Fire	01:25	0.2	0.1
GroupB	Tawharanui	Incursion	01:01	0.02	0.01
GroupB	Te Anau Bird Sanctuary	Disease	01:50	0.5	0.5
GroupB	Te Anau Bird Sanctuary	Fire	01:50	0.5	0.5
GroupB	Te Anau Bird Sanctuary	Incursion	01:10	0.25	0.5
GroupB	Tiritiri	Disease	01:25	0.5	0.25
GroupB	Tiritiri	Drought	01:10	0.5	0.1
GroupB	Tiritiri	Fire	01:25	0.2	0.1
GroupB	Tiritiri	Incursion	01:20	0.2	0.1
GroupB	Wairakei	Disease	01:15	0.25	0.5
GroupB	Wairakei	Fire	01:25	0.1	0.1
GroupB	Wairakei	Incursion	01:10	0.25	0.5

APPENDIX II: DISPERSAL BETWEEN POPULATIONS

		To				
		Burwood	Murchison	HV sites	LV Sites	Kahurangi
From	Burwood	-	6 * (1yo)/A (ii)	2/G (i)	Maintain K (v)	Transfert the rest (vii)
	Murchison	2/G (i)	-			
	HV sites			-	Maintain K (iv)	All surplus (vi)
	LV Sites				-	All surplus (iii)
	Kahurangi	2/G (i)				-

(i)	**(((Y%7)=0)*2)+0**
(ii)	**IF(NN1>(KK1+6));6;MAX(NN1-98;0))**
(iii)	**IF(NN4>KK4;NN4-KK4;0)**
(iv)	**IF((NN4<KK4)&&(NN3>KK3); MIN((NN3-KK3);(KK4-NN4));0)**
(v)	**IF((NN4<KK4) && ((NN4 + (NN3-KK3))<KK4) && ((NN1-KK1)>0) ; MAX(MIN((KK4-(NN4 + (NN3-KK3)));(NN1-KK1))-(6+(((Y%7)=0)*2)+0);0);0)**
(vi)	**IF(NN3-(MIN((NN3-KK3);(KK4-NN4)))>KK3 && (NN3>KK3); (NN3-KK3)-(MIN((NN3-KK3);(KK4-NN4)));0)**
(vii)	**IF((NN1-KK1)>6) ; MAX((NN1-KK1) – MIN((KK4-(NN4 + (NN3-KK3)));(NN1-KK1))+(6+(((Y%7)=0)*2)+0);0) ; 0)**

Equations were adjusted if some population were removed from the model.

APPENDIX III: META-POPULATION PERFORMANCE IN ABSENCE OF CATASTROPHES

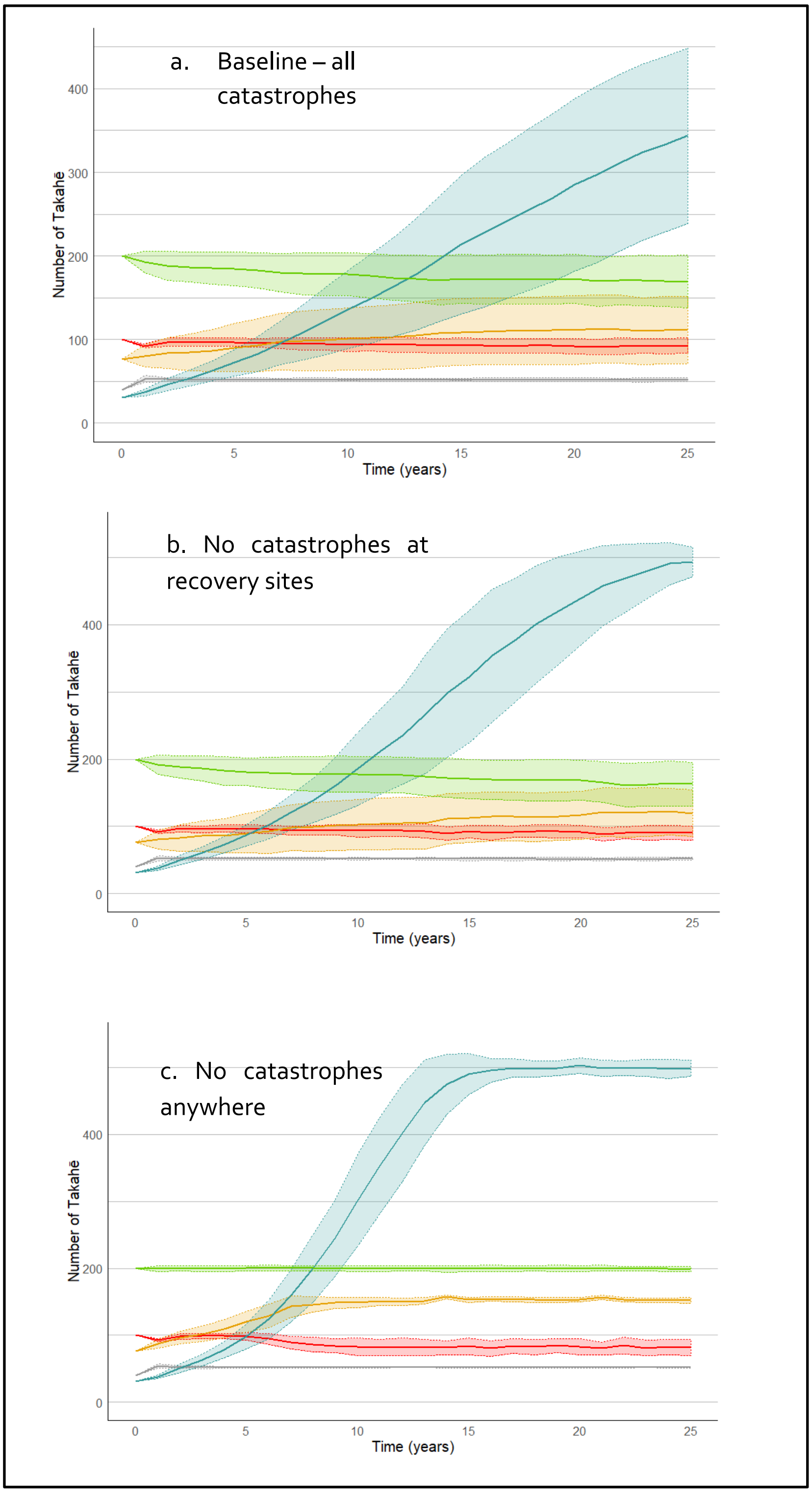

Table 16. Comparison Meta-population and sub-population performances with and without catastrophes: a) Baseline – all catastrophes included; b) Catastrophes excluded from recovery sites only; c) All catastrophes removed from the models.

	Sub-population	r	SD(r)	P_{EX}	N	SD(N)	GD	SD(GD)	Inb	SD(Inb)
a.	Burwood	0.01	0.14	0.00	91.29	9.74	0.97	0.00	0.0079	0.01
	Murch Mts	0.02	0.10	0.00	167.69	31.58	0.98	0.00	0.0073	0.01
	MK Sites	0.01	0.13	0.00	118.64	36.84	0.97	0.01	0.0115	0.01
	No MK Sites	0.03	0.09	0.00	52.00	1.79	0.96	0.01	0.0137	0.02
	Recovery Site	0.03	0.12	0.00	309.05	113.02	0.99	0.00	0.0097	0.01
	Meta-population	0.02	0.06	0.00	738.68	130.11	0.99	0.00	0.0095	0.00
b.	Burwood	0.02	0.1	0	90	10	0.968	0.004	0.006	0.009
	Murch Mts	0.01	0.01	0	16	33	0.984	0.002	0.008	0.008
	MK Sites	0	0.02	0	119	35	0.965	0.014	0.012	0.012
	No MK Sites	0.01	0.01	0	52	2	0.965	0.008	0.012	0.017
	Recovery Site	0.01	0	0	493	22.5	0.998	0.002	0.009	0.005
	Meta-population	0.05	0	0	917.00	52	0.992	0.001	0.009	0.004
c.	Burwood	0.01	0.02	0	82	1	0.968	0.004	0.005	0.008
	Murch Mts	0.06	0.004	0	198	0.3	0.985	0.001	0.007	0.007
	MK Sites	0.12	0.003	0	152	0.4	0.975	0.03	0.01	0.009
	No MK Sites	0.10	0.001	0	51	0	0.954	0.001	0.017	0.02
	Recovery Site	0.06	0.006	0	498	1	0.992	0	0.007	0.004
	Meta-population	0.07	0.003	0	983.00	2	0.993	0.001	0.007	0.003