2014 Plan for a North Island Meta-population of Takahë

A Takahë Recovery Group initiative

Caroline Lees, Glen Greaves, Tineke Joustra, Daryl Eason, Ian Jamieson

Acknowledgements
The development of this plan was supported by Auckland Zoo, CBSG Australasia and the Takahë Recovery Group. Helpful comments on the text were provided by Andrew Digby.

A contribution of the IUCN SSC Conservation Breeding Specialist Group

Citation: Lees, C.M., Greaves, G., Joustra, T., Eason, D., and Jamieson, I (2014) 2014 Plan for a North Island Meta-population of Takahë: A Takahë Recovery Group Initiative. IUCN SSC Conservation Breeding Specialist Group, Apple Valley, MN.

CONTENTS

CONTENTS

EXECUTIVE SUMMARY

INTRODUCTION

The takahë is the largest living member of the rail family and endemic to New Zealand. The species is currently listed as Endangered by the IUCN in its *Red-List of Threatened Species* (IUCN, 2013). As of June 5, 2014 an estimated 286 birds remain: 166 occupying 8 protected release sites and 7 captive facilities; and approximately 120 birds in one remaining wild site in the Murchison Mountains from which all birds originate.

The Takahë Recovery Group has proposed the management of remaining takahë 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. This document proposes a plan for the management of the North Island component of this overarching scheme over the next **10 years**. Implementation of this plan would be coordinated through the Takahë Recovery Group and enacted by the Department of Conservation and its partners.

PROPOSED LONG-TERM AIM

To build a self-sustaining, locally adapted meta-population of takahë in the North Island of New Zealand

10-YEAR STRATEGY

The following strategy is proposed to progress the population towards this aim over the next 10 years:

PHASE I. 3-5 YEARS

- Establish the means to run an effective program of intensive population management towards agreed genetic and demographic targets.
- Secure as a base for the North Island Meta-population, a representative sample of wild source gene diversity, through supplementation from the Burwood breeding centre.
- Using small population biology theory and associated software tools, direct transfers and breeding within the North Island Meta-population to slow inbreeding accumulation and maximise gene diversity retention as the population is growing.
- When the population is sufficiently robust both genetically and demographically, move to Phase II.

PHASE II. 5 – 10 YEARS

- Accelerate adaptation to North Island conditions by isolating the North Island Meta-population from further supplementation from the south.
- Continue close management of transfers and breeding within the meta-population to slow inbreeding accumulation and maximise gene diversity retention.
- Continue expansion into currently secured capacity.
- Avoid curtailing population growth by anticipating the need for new capacity and mobilising new sites of the required size.
- For sites housing 50 birds or more and where maintenance of individual monitoring and management becomes onerous, transition to lower-intensity management.
- Review and revise strategy, targets and activities.

Objectives

To support the 10-year strategy, the following objectives are proposed, each of which has associated targets and activities:

1. Establish immediately an operational framework for running an effective program of intensive population management towards agreed genetic and demographic targets.
2. Secure as a base for the North Island Meta-population, a representative sample of wild source gene diversity, through supplementation from the Burwood breeding centre.
3. Manage transfers and breeding within the meta-population to slow inbreeding accumulation and maximise gene diversity retention.
4. Move to Phase II when the North Island Meta-population has captured sufficient initial gene diversity, carries a genetically effective population size of at least 50, and where vital rates are expected to support sufficient positive growth.
5. Isolate the North Island Meta-population from further supplementation from the south.
6. Identify and secure additional sites to allow growth to continue unconstrained.
7. Monitor and evaluate progress, and review regularly the relevance of Objectives, Targets and activities. Adapt accordingly.

[Note that for the purpose of evaluation, baseline values for gene diversity retention and mean inbreeding will be the 2012 values: Gene Diversity = 92.6%; Mean Inbreeding Coefficient = 0.0523]

Tools, protocols and data management

Over the next 10 years intensive genetic and demographic management will be important to success. Three software applications will support this:

- Single Population Animal Records Keeping System (SPARKS) (ISIS, 2012) – houses individual demographic and pedigree information in a format that enables analysis by PMx.
- PMx (Ballou et al., 2013): for demographic and genetic analysis and management of small populations.
- VORTEX (Lacy et al., 2003): for population simulation to evaluate risks, project trends and compare strategies

Effective application of these tools relies on accurate, current information on all living takahë and their ancestors, on updated estimates of carrying capacity and on site-specific species management issues. Ongoing collection and collation of this information across multiple sites, in time for the annual analysis required to generate transfer and breeding recommendations, is a challenge. Draft protocols for this are provided which take account of available resources.

2014-2015 Transfer and Breeding Recommendations

Transfer and breeding recommendations will be generated and implemented annually, in line with the strategy and targets proposed. Each annual analysis will begin with a review of the previous year's successes and failures.

Transfer and breeding recommendations for 2014-2015 are provided here, based on the strategy and targets proposed. The process of generating and implementing these recommendations should be considered a pilot for the new management approach. This approach will be reviewed and refined in 2015 in advance of the 2015-2016 breeding season.

INTRODUCTION

The takahë is the largest living member of the rail family and endemic to New Zealand. Once widespread in the North and South Islands a combination of hunting, habitat destruction and introduced predators reduced its range to such an extent that by the early part of the twentieth century it was considered extinct.

Two different species existed historically: one in the South Island, *Porphyrio hochstetteri* (Meyer, 1883) and a second in the North Island, *P. mantelli* (Owen, 1848), possibly established by separate founding events from Australia (Trewick 1996, 1997). These two species were not only distinct genetically but also morphologically, with fossil evidence indicating that the North Island *P. mantelli* had a smaller beak, longer and more slender leg bones and was lighter in weight than the South Island's *P. hochstetteri.*

Though extinction of the North Island form is confirmed, in 1948 a small population of 250 – 300 South Island takahë was discovered, confined to the Murchison Mountains in Fiordland (Heather & Robertson 1997). Since then that population has suffered further declines and in 1985 a captive-rearing programme was established with the aim of raising birds for translocation to predator-free islands to reduce risk of extinction.

Due to the scarcity of preferred grassland habitat on pest-free islands, birds have been translocated to sites not only within their previous South Island bioclimatic zone but also within the North Island region previously occupied by *Porphyrio mantelli*. To date, populations in the north have increased only slowly and a number of contributing factors have been suggested: low hatching and fledging rates related to inbreeding (Bunin *et al.* 1997, Jamieson *et al*. 2003); some island sites being at or close to carrying capacity (Baber & Craig 2003; Gruber *et al*. 2012); and low adaptability of the South Island form to North Island conditions (Jamieson & Ryan, 1999).

At present, all remaining takahë are managed as a single unit with appropriate controls to reduce infection transfer to the Murchison birds. South Island birds are regularly moved to the North Island to reduce inbreeding there and birds are moved in the opposite direction to relieve pressure on well-populated sites. This is logistically costly and poses acclimatisation challenges for the birds involved. Further, the regular influx of South Island adapted birds could be preventing the emergence of a population better adapted to the warmer climatic conditions, local plant foods and different disease vectors of the North Island sites.

With these considerations in mind, the Takahë Recovery Group has proposed the management of remaining takahë 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. Over the long-term this could facilitate ecological replacement of the extinct *P. mantelli.*

This document lays out a plan for the management of the North Island component of this overarching scheme, over the next **10 years**. It considers the founding, growth and capacity phases of the proposed North Island meta-population, the requirements for demographic and genetic viability, and allows for ongoing support to the South Island population as needed. Transfer and breeding recommendations are provided for the 2014-2015 season in line with genetic and demographic targets. Protocols for data management, annual program review and revision are proposed which can be refined as the program develops.

Review of current status

All remaining takahë 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, 2013). At the time of listing the total population was estimated to be 227 adult birds, roughly equivalent to a census size of 340-350 (IUCN, 2013).

Distribution and abundance

For the purpose of management, North Island takahë are considered to be the subset of birds occupying sites in and to the north of the Marlborough Sounds. The size and distribution of this population as of June 5, 2014 is shown in Figure 1.

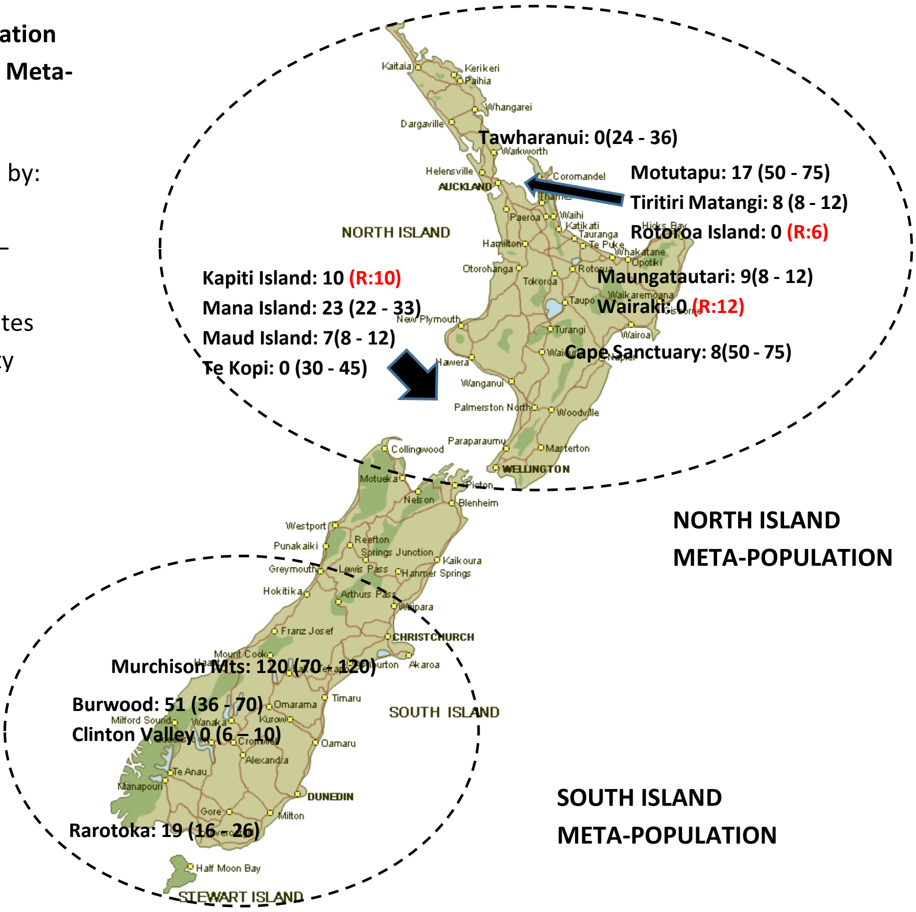
Figure 1. Proposed designation of North and South Island Meta-populations.

Each site name is followed by:
Current total pop. size
(estimated adult capacity – estimated total capacity)
R: # refers to retirement sites and their expected capacity

Supporting zoo space:

North Island:
Auckland Zoo: R:2
Willowbank: R:2
Mt. Bruce: R:2
Zealandia: R:2

South Island:
Te Anau: R:4
Orokonui: R:2



In total, as of June 5, 2014, there are 90 birds occupying North Island sites and facilities and 76 birds occupying South Island sites and facilities (excluding the Murchison Mountains). Within the Murchisons there is an estimated 120 birds (70 adults plus offspring). This brings the total estimate for the species to 286.

DEMOGRAPHIC PROFILE

This section provides a snapshot of the demographic potential of the current North Island Meta-population. The summaries provided were generated from takahë studbook data (Joustra & Greaves, 2014) using the small population analysis program PMx (Ballou *et al.* 2013)

As can be seen from Figure 2. the population (as of February 2014) stood at 82 individuals spread across 11 sites including zoos. It has a roughly even sex-ratio (43 males to 39 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 this population predict a decline and this is illustrated in the 20-year projections in Figure 3a.

Figure 2. Demography overview of the North Island Meta-population showing age pyramid (Feb. 2014). (Note: excludes 18-20 additional 1-2 year-old birds accessioned in March-April 2014).

	Total	Males	Females
Totals	82	43	39
Pre Reproductive	0	0	0
Breeding Age	77	39	38
Post Reproductive	5	4	1
Proven Breeder	44	23	21
Of breeding age	41	21	20
# Sites (including zoos)	11		
Generation length (T)	7 yrs		
Expected annual growth (Λ)	0.977		
Life expectancy from hatch	9 yrs		

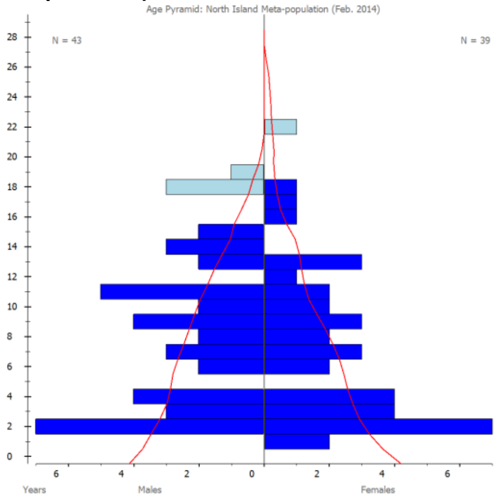
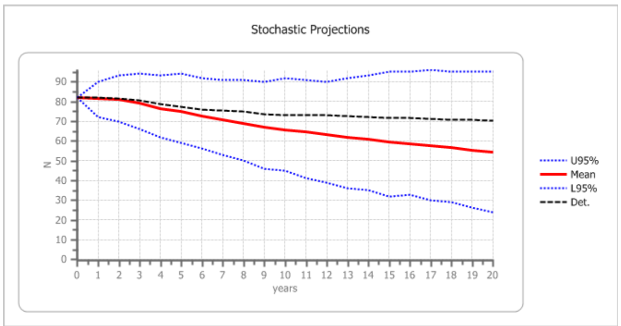


Figure 3a. Projections for the North Island Meta-population under current vital rates and with no further imports from Burwood (animals >15 years are excluded). Black dotted line shows deterministic projection; blue dotted lines show 95% confidence intervals for stochastic projections; red solid line shows mean of stochastic projections.



Vital rates at the Burwood breeding centre have been better than those observed in the north to date. Combining the rates observed at these sites with those of the North Island Meta-population produces a more optimistic picture of growth into the future (see Figure 3b.).

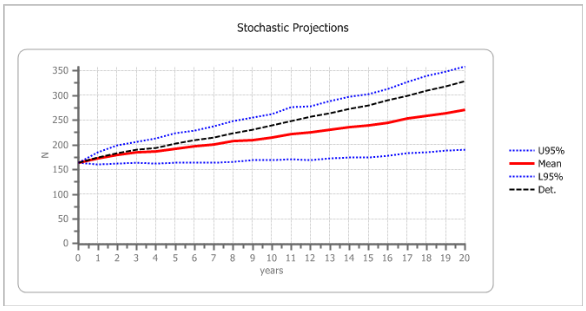


Figure 3b. Projections for the combined North Island Meta-population plus Burwood and Rarotoka. Black dotted line shows deterministic projection; blue dotted lines show 95% confidence intervals for stochastic projections; red solid line shows mean of stochastic projections.

Until vital rates improve, the North Island Meta-population will need to be supplemented periodically to ensure continued growth. Burwood has the capacity to provide birds for that purpose, though this will require careful planning to ensure that this does not interfere with its role in supporting the Murchison Mountains population.

GENETIC PROFILE

Gene diversity is of recognised importance to short-term population health and to long-term adaptability in the face of environmental change (e.g. Frankham *et al*. 2002). 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 (ISIS, 2012) and the resulting dataset (Joustra & Greaves, 2014) analysed using the small population analysis program PMx (Ballou *et al*. 2013). 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 close relatives (where "close relatives" is judged relative to the population average).

Table 1. Genetic characteristics of the North Island Meta-population and of the combined population outside the Murchison Mountains (June 2014).

Characteristic	North Island Meta-population only	All sites outside the Murchison Mountains	Definitions and notes
Number of birds	82	154	Number of living birds aged 14 years or less.
Founder number	44	48	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. Four extra founders are present in the wider population: #472 (Tumbles), #585 (Blaze), #676 (Larrivee) and #717 (Kuini)
% Ancestry certain	97%	95%	% of the bird's pedigree that can be traced back to known founders.
Current Gene Diversity	95.5%	96.7%	The heterozygosity expected in the progeny under random breeding.
Potential Gene Diversity	98.2%	98.6%	The gene diversity that could be achieved by adjusting the relative contributions of founders.
Founder Genome Equivalents	11.19	15.13	The number of wild caught founders that would contain the same amount of gene diversity as the population.

Characteristic	North Island Meta-population only	All sites outside the Murchison Mountains	Definitions and notes
Potential Founder Genome Equivalents	26.88	35.31	The FGEs that could be achieved by adjusting the relative contributions of founders.
Population Average Inbreeding Coefficient	0.043	0.034	The average of the inbreeding coefficients of all individuals in the population.
Inbreeding Range	0 – 0.250	0 – 0.250	F=0.250 found in both N.I. and S.I. populations but rarely. One bird aged >15 years on Tiri carries an F=0.344
Population Average Mean Kinship	0.045	0.033	The average of the mean kinship values of all individuals in the population (and the average inbreeding coefficient of the progeny under random breeding).
Ratio of Genetically Effective Population Size to Actual Population Size (Ne/N)	0.47	0.41	Indicates how efficiently the population will retain gene diversity 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. Living birds aged 15 years or more are treated as post-reproductive and are excluded from analyses.			

The analyses show that both the North Island Meta-population and the wider population outside the Murchison Mountains, are well-founded 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 genetic quality of the wild source population at the time of sampling].

Gene diversity as it is measured here is an indication both the number of alleles captured and of how evenly they are represented in the population. Where founder representation becomes uneven, the chance of losing less well-represented lines, and therefore any unique alleles they may contain, increases. In populations as small as these this risk can become high as rarer alleles may be carried by only one or two individuals. Chance loss of alleles in this way is referred to as genetic drift. The best way to minimise the ongoing impact of genetic drift is to increase population size and to do this as swiftly as the species' biology will allow. While the population remains small, prioritising breeding from rarer genetic lines, encouraging pairings between birds of high and similar genetic "value", and ensuring that a high proportion of birds are participating in breeding, can help reduce the rate of drift and maximise gene diversity retention. This is practised for many zoo populations and is referred to here as intensive genetic management.

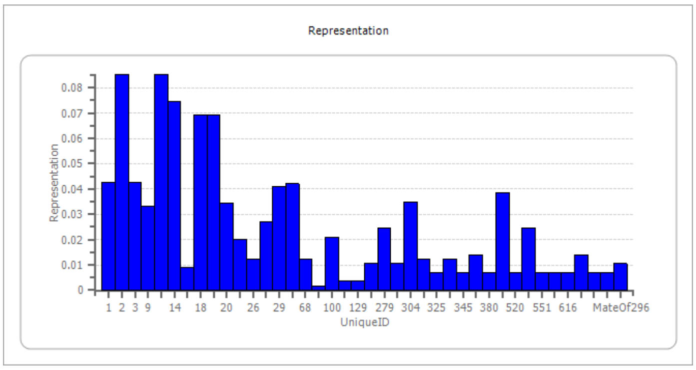


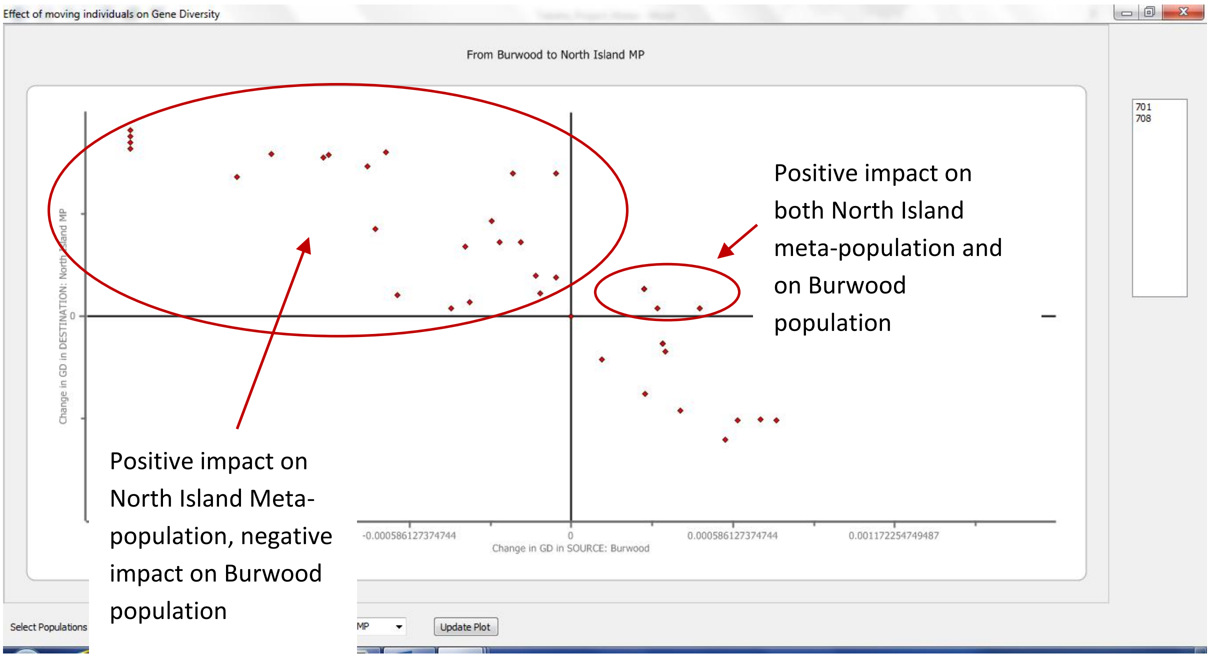
Figure 4. Founder representation in the North Island Meta-population.

[Each "Unique ID" is the studbook number of a founder]

The founder representation graph (Figure 4.) illustrates the large differences in representation between founder lines in the North Island Meta-population which, in an ideal situation would be relatively even. Gene diversity in this population can be improved by re-distributing founder representation towards parity, allowing for differences in founder retention (that is, some founder lines will have undergone genetic bottlenecks, reducing their "value". Their target representation needs to be reduced to reflect this). PMx software tools can be used to support this approach to management.

Analyses also show that at this point the wider population carries more gene diversity than the North Island Meta-population alone. Strategic breeding and transfers of currently unrepresented or under-represented lines from Burwood and Rarotoka to the north could improve the genetic prospects of the North Island Meta-population without detriment to the South Island one. The PMx *Management Sets* function allows analysis of the impact of moving individual birds from one site to another, on gene diversity at the source and destination sites and this will be useful in optimally allocating birds. Results can be illustrated graphically as in Figure 5.

Figure 5. Expected impact on gene diversity of source and destination sites, of transferring individuals from Burwood to the North Island Meta-population (each red dot represents the status of gene diversity following the transfer of one or more Burwood individuals to the North Island Meta-population).



The difference between actual and potential gene diversity (Table 1.) provides a rough guide to how much can be gained through the kind of intensive genetic management described above. Both population subsets show a considerable potential improvement[1] which is most clearly illustrated by the Founder Genome Equivalent values. Founder Genome Equivalents indicate the number of randomly sampled wild founders that would be expected to carry the same gene diversity as the current living population. For the North Island Meta-population there is potential to improve gene diversity from 11.19 – 26.88 FGEs and for the wider population from 15.13 to 35.31 FGEs.

Though some individuals in both subsets carry high inbreeding coefficients (F=0.25; equivalent to the offspring of a full-sibling pairing) the average level of inbreeding remains low in both (Mean F=0.034-0.043) and the average mean kinship value, which measures expected inbreeding in the next generation under random mating, indicates that average inbreeding will remain low in the near future (though achieving this outcome at very small sites will require careful management).

[1] It should be noted that not all of this difference will be able to be realised due to the linkage in some instances, or rarer with more common lines such that the representation of one cannot be increased without also increasing the other.

The number of wild-caught founders represented in the population is 48 for the wider population and 44 for the current North Island Meta-population. These figures fall above the n ≥ 30 threshold recommended by Marshall and Brown (1975) for capturing a reasonable sample of allelic diversity from a wild population (i.e.for capturing with 95% certainty those alleles occurring with a frequency of ≥ 5%. 2002) and should be sufficient here, particularly as periodic movements of birds from the wild population in the Murchison Mountains remains a possibility.

Capacity projections

Tables 2 and 3 summarise the estimated carrying capacity that will become available to the North Island Meta-population between 2014 and 2020. The estimates are for total numbers including pre- and post-reproductive birds (rather than just for breeding birds). A crude assessment of site-specific risk is also included.

Table 2. Capacity projections for the North Island Meta-population including a crude risk assessment.

	2014	2015	2016	2017	2018	2019	2020	K	Risk of predator incursion	Required mgmt
Rarotoka	19	21	24	26	26	26	26	26	Low	Mod
Burwood (captive)	51	70	70	70	70	70	70	70	Low	High
Maud	7	8	8	8	8	10	12	12	Low	Mod
Mana	23	24	24	24	26	26	33	33	Low	Mod
Cape Sanctuary	8	8	8	8	40	60	75	75	Mod	Low
Maungatautari	9	10	12	12	12	12	12	12	Low	Mod
Motutapu	17	20	24	30	40	60	75	75	Low	Low
Tiritiri Matangi	8	10	10	12	12	12	12	12	Low	Mod
Tawharanui	0	14	26	30	36	36	36	36	Mod	Low
Te Kopi	0	0	12	20	28	36	45	45	Mod	Low
Clinton Valley	0	6	6	6	6	6	10	10	High	Low
TOTALS:										
Range-wide (outside Murchison Mts):	142	191	224	246	354	354	406	460		
Range-wide Retirement Sites:	24	20	22	26	28	28	32	54		
North Island only (excl. retired birds):	72	100	130	150	208	258	310	310		
North Island, Low Risk:	64	72	78	86	96	120	144	144		
North Island, Low Risk, Low Mgmt:	17	20	24	30	40	60	75	75		

Post-reproductive birds

Reproductive output decreases in later life. Where good breeding sites are limited, the continued occupation of breeding territories by these birds could reduce productivity. To moderate the impact of this, birds aged 15 years or more are to be transferred to retirement either in zoo enclosures or to island sites where habitat is suitable for takahë but not conducive to breeding. VORTEX models (Lacy *et al*. 2003) were used to estimate requirements for retirement capacity over the next 50 years and the results are shown in Figure 6.

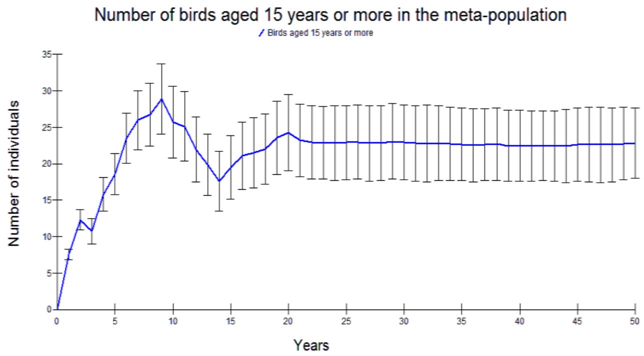


Figure 6: Expected numbers of retired birds over time from stochastic projections in VORTEX (showing standard error bars).

As can be seen, the requirement for "retirement spaces" is set to increase in the short-term due to the population's age-structure but beyond that it should fall and stabilise at around 20-25 birds. The program's current access to approximately 30 spaces for retired birds by 2020 should be sufficient for this (see Table 3).

Table 3. Projections of space for birds retired from the North Island Meta-population.

Retirement	2014	2015	2016	2017	2018	2019	2020	K
Auckland	2	2	2	2	2	2	2	2
Kapiti	10	6	6	6	6	6	6	6
Mt Bruce	2	2	2	2	2	2	2	2
Orokonui	2	2	4	4	4	4	4	4
Wairaki	0	0	0	2	4	4	6	6
Rotoroa	0	0	0	2	2	2	4	4
Te Anau	4	4	4	4	4	4	4	4
Willowbank	2	2	2	2	2	2	2	2
Zealandia	2	2	2	2	2	2	2	2
Total	24	20	22	26	28	28	32	

THE PROPOSED NORTH ISLAND META-POPULATION: VULNERABILITIES AND IMPLICATIONS FOR MANAGEMENT

The Recovery Group has determined that the North Island Meta-population will be distributed across well-protected, predator-free islands and sites assessed and managed to include sufficient food and shelter for this species. Though this will reduce significantly the risk of predation by introduced species the meta-population may remain vulnerable to factors such as its small size and fragmented structure, potentially limited space for growth, and differences in security between sites. These are explored here and the implications for management are discussed.

SMALL POPULATION SIZE AND ABUNDANCE MILESTONES

Small population size exacerbates a species' vulnerability to the variation in environmental conditions and in population qualities, arising from chance or random events. When populations are very small these chance factors can continue to drive a population to extinction even after threats such as predation and habitat loss, have been removed.

Schaffer (1981) described four broad categories of uncertainty: demographic uncertainty arising from chance fluctuations in survival, reproduction and sex-ratio; environmental uncertainty arising from unpredictable year-to-year changes in weather, food supply and competitors; natural catastrophes that bring about extreme shifts in birth or death rate (good or bad) such as fires, floods, and droughts; and genetic uncertainty or shifts in a population's genetic composition arising from founder effect, genetic drift and inbreeding, that impact on individual survival and reproductive rates. Maintaining growth of the North Island Meta-population to a sustained level of abundance at which these risks become minimal will be important to its long-term viability. A combination of generalised rules of thumb and takahë-specific population models has been used here, to develop an understanding of what might constitute sufficient abundance in this case.

VORTEX MODELS FOR TAKAHË

VORTEX simulation models were built to compare the relative impact of the different forces of uncertainty on a hypothetical takahë population founded with five pairs and allowed to grow to a total capacity of 300 individuals. Details of the models are provided in Appendix 1 and the results, illustrated as expected population size over time, are shown in Figure 7. As can be seen, current knowledge of takahë biology and of North Island conditions predict that of the four forces considered, inbreeding depression is likely to pose the biggest risk to growth and viability for the foreseeable future. By default inbreeding is included in the models in the form of additional mortality imposed on inbred offspring in their first year. In the absence of population-specific data a default impact of 3.14 lethal equivalent alleles[2] is imposed, based on a multi-species study of captive populations (Ralls *et al*. 1988). In the takahë models, the effects of 16.00 lethal equivalents are distributed between juvenile mortality and inbred female reproduction in an attempt to emulate the pattern of inter-generational inbreeding impact described in Grueber *et al*. (2010). The relatively high number of lethal equivalents reported in that study suggests that takahë may be particularly sensitive to this risk factor and this is supported by other work on the species (Jamieson & Ryan, 1999; Jamieson *et al*. 2003).

Environmental uncertainty including catastrophes has less impact than inbreeding but still makes an observable difference to the ability of the modelled populations to grow over the period considered. Demographic uncertainty shows the lowest impact for the scenarios considered.

Though currently planned to occupy a capacity of more than 300 spaces, the proposed North Island Meta-population will have a fragmented structure. Models were also used to explore the potential impact of these

[2] alleles whose summed effect is that of lethality for example, four alleles each of which would be lethal 25% of the time (or to 25% of their bearers), are equivalent to one lethal allele.

four forces of uncertainty on population fragments of varied size (K=10, 30, 50, 75, 150 and 300) in the absence of inter-site exchanges; that is, where each fragment is seeded with 5 pairs and allowed to grow only to the carrying capacity of that fragment. The impact of these scenarios on fragment extinction risk is illustrated in Figure 8.

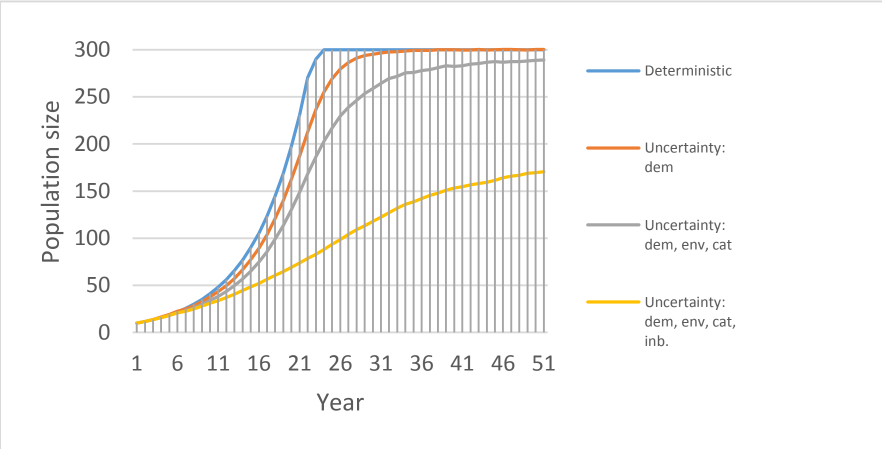
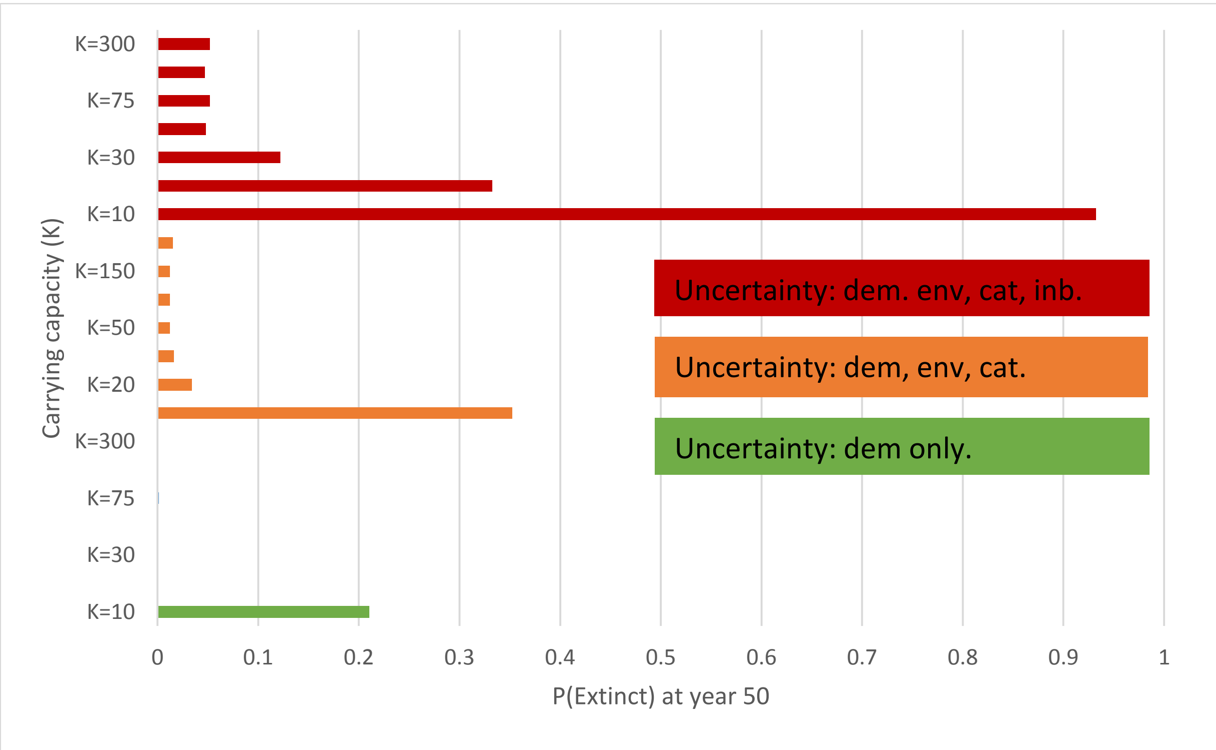


Figure 7: **The relative impact of different forces of uncertainty on population growth in modelled takahë populations.** (dem = demographic uncertainty; env = environmental uncertainty; cat = catastrophes; inb = inbreeding.

Figure 8. Probability of extinction at 50 years for population fragments of different sizes seeded with 5 unrelated pairs of takahë, in the absence of management (i.e. with no movement into or out of the population beyond the founding event) and in the presence of difference forces of uncertainty.



As illustrated, as a result of demographic uncertainty populations of around 10 individuals show a high risk of extinction (P(Ex) at 50 years > 20%) even in the absence of environmental uncertainty, catastrophes and inbreeding. The addition of environmental uncertainty and catastrophes at the levels estimated in the models increases extinction risk for fragments larger than N=10, but the risk remains low (P(Ex) at 50 years < 4%). With inbreeding depression added the risk increases to 93%, 33% and 12% for fragments of 10, 20 and 30 birds respectively, settling to around 5% or less for fragments ≥ 50.

Close management of populations to slow the rate of inbreeding accumulation and to moderate the impact of demographic and environmental extremes should reduce the susceptibility of populations to these risks. All sites are likely to benefit from this kind of management during the growth stage when numbers are low, and based on current information a precautionary approach would see ongoing intensive management for sites with a capacity of 50 birds or fewer.

RULES OF THUMB FOR GENETIC RISKS

Some rules of thumb have been established to guide consideration of minimum viable population sizes aimed at withstanding genetic risks. Two effects are of interest: inbreeding depression – the increased expression of deleterious inherited traits or general reduction in fitness of the population resulting from regular pairings between close relatives; and ongoing loss of allelic diversity resulting in reduced evolutionary adaptability. A widely used rule of thumb applied in relation to these threats is the 50/500 rule (Franklin, 1980). This proposes that a genetically effective size[3] of 50 should confer ongoing resilience to inbreeding depression (due to the observed ability of populations to cope with the resulting low rate of accumulation); and that a genetically effective size of 500 should enable long-term evolutionary adaptability by conferring drift-mutation balance – that is, the population should gain new gene diversity through mutation at around the same rate it is losing it through genetic drift. Though these figures are a guide only and are periodically the focus of debate (e.g. Jamieson & Allendorf, 2012; Frankham *et al*. 2013), to date they have not been replaced with a working alternative and so are used here as an aid to thinking about the orders of magnitude that might be required to offset these genetic risks.

From analysis using PMx software, the takahë population has been operating at a genetically effective size (Ne) which is 41-47% of the census size (N); that is, at an Ne/N ratio of 0.41-0.47 (see Table 1.), which is within the range expected for a pair-wise breeding bird (Jamieson, pers. comm). Applying the 50/500 rule in this case would give minimum abundance (and therefore minimum capacity) requirements of **106 – 122** for inbreeding resilience and **1063 -1219** for maintenance of long-term evolutionary potential.

TARGETS FROM PMX GOAL SETTING

Clearly there is a large gap between the population size required to moderate the impact of inbreeding depression and that proposed for retention of long-term adaptive potential. The latter is often beyond the immediate or even the foreseeable reach of available population potential and resources and so can be less useful in directing short or medium-term planning. Zoos deal with this challenge regularly and take an approach to setting genetics-based population targets which is directed towards retaining the genetic qualities of the wild source population for a finite period of time after which some new program development is envisaged. Standardly applied targets are the retention of 90% wild source gene diversity for 100 years, though more ambitious genetic targets (95%) are sometimes applied for shorter periods (10, 25 or 50 years) in Australasian recovery programs.

Table 4a. Values used in PMx gene diversity retention analysis.

Parameter	Baseline Value	Sensitivity Tests	Notes
Generation Length (average age of breeding)	7 years	-	Calculated from the studbook
Maximum potential growth rate (lambda)	1.12	1.05, 1.10	Baseline from *VORTEX* models based on assessment of potential rather than past performance. Other values sit between past and projected performance.
Current N	90	-	Current census size
Ne/N	0.41	0.47	Ratio of effective to actual population size – calculated by PMx. Other value calculated for combined population outside Murchison Mts and represents potential.

[3] Genetically effective population size is a measure of how efficiently a population conserves gene diversity from one generation to the next and is based on the extent to which it conforms to a set of "ideal" characteristics (see Frankham et al., 2002).

Parameter	Baseline Value	Sensitivity Tests	Notes
Current Gene Diversity	95.48	96.00	Inferred by PMx from studbook pedigree. "Other value" accounts for further supplements from Burwood plus internal manipulation of founder representation.
Maximum Allowable N	364	150, 450, 1000, 1500	Estimated Meta-population carrying capacity. Other values for illustration only.
New founders added	0	-	Unlikely to be available.

Table 4b. Estimating the population characteristics that would enable retention of at least 90% wild source gene diversity for 10, 20 and 50 years: results of PMx analysis.

Scenarios	Gene diversity at 10 years	Gene diversity at 20 years	Gene diversity at 50 years
Baseline (see Table 4a. for values used)	94.3%	93.8%	92.5%
Scenario 1. varied growth rate			
Lambda = 1.01	93.7%	92.1%	88.4%
Lambda = 1.06	94.0%	93.1%	91.6%
Scenario 2. improved Ne/N ratio			
Ne/N = 0.47	94.5%	94.0%	92.9%
Scenario 3. increased gene diversity			
Starting GD = 96.00	94.8%	94.3%	93.0%
Scenario 4. varied carrying capacity			
K=150	94.2%	93.1%	89.9%
K=450	94.3%	93.9%	92.8%
K=1000	94.3%	93.9%	93.4%
K=1500	94.3%	93.9%	93.6%
Scenario 5. optimistic across parameters			
Ne/N (0.47), increased GD (96.0%) increased capacity (500), starting population supplemented with 45 additional animals (N=135)	95.3%	95.1%	94.2%

Projecting the expected loss of gene diversity (due to genetic drift) in a population over time requires quantification of the following: starting gene diversity; starting population size; rate of growth; generation length; Ne/N ratio and supplementation regime (if applicable). The PMx Goal Setting function combines these values and reports on gene diversity over time relative to imposed targets. Table 4b shows results for takahë, for targeted retention of 90% gene diversity over 10, 20 and 50 years. As shown, for the range of values tested, growth rate and carrying capacity were the two factors that most constrained gene diversity retention. Even so, at the lowest growth rate tested (lambda=1.01) the modelled population retained in excess of 90% wild source gene diversity for more than 20 years, dropping below this threshold before 50 years. Carrying capacity of K=150 also prevented the population from exceeding the 90% threshold at 50 years. The optimistic scenario allowed the population to retain more than 95% gene diversity. This would require input of 45 additional animals from the Burwood breeding centre, a shift in growth rate and Ne/N ratio towards those observed at Burwood and an increase in available carrying capacity from around 350 to around 500.

Abundance and viability: proposed milestones for takahë

As illustrated in the paragraphs above, abundance is the single most important contributor to population viability. With increasing abundance comes increasing resilience to the threats that face small populations. Table 5 provides a rough guide to the viability gains made as population size increases. The milestones shown are specific to the North Island takahë meta-population and are drawn from the analyses presented in this report and from rules of thumb described in the literature. The proposed milestones are a guide only, aimed at providing managers with a sense of what to expect from populations at specific sites, and from the meta-population as it grows over time and under management.

Table 5. Proposed viability milestones for North Island takahë and their implications for management. Applicable to individual sites, also to multiple sites where these are inter-connected through management. The benefits indicated are expected to accrue only where the population grows from year 1 and from the 2014 genetic base reported (colours provide a visual guide to the resilience of different populations sizes).

Expected resilience to:	**n<30**	**n>30**	**n>60**	**n>120**	**n>350**	**n>1219**	**n>5000**
Environmental catastrophes (extreme mortality events)[4]							
Long-term loss of evolutionary potential (>50 years)[5]							
Short-term loss of evolutionary potential (<50 years)[6]							
Inbreeding depression[7]							
"Chance" shaping the gene pool (over natural selection)[8]							
Year-to-year environmental variation[9]							
Chance variation in sex-ratios, birth & death rates[10]							
Populations affected (retirement sites excluded)	b, c, e, f, h, i, l, m	d, j, k	a, g	Meta-population only		Meta-population beyond 15 years	
Management implications	At the lower end of the range expect some extremes in birth and death rates, occasional sex-ratio skews and a tendency for rapid inbreeding accumulation. Ongoing stability and health will require individual-based monitoring, plus ongoing genetic and demographic management.			Expect benefits only where multiple sites are managed as a single unit. This will require centralised planning and coordination of data, of pairings and of inter-site transfers.		Requires identification and preparation of new sites.	

a-Cape Sanctuary; b-Clinton Valley; c-Kapiti; d-Mana; e-Maud; f-Maungatautari; g-Motutapu; h-Rarotoka i-Rotoroa; j-Tawharanui; k-Te Kopi; l-Tiritiri Matangi; m-Wairaki

[4] Traill et al. (2010): generalised target for securing long-term viability in the face of both demographic and genetic risk factors based on the broad convergence in conclusions of several multi-species MVP studies (Reed, 2003; Thomas, 1990; Traill et al., 2007).

[5] Franklin (1980): Ne=500 proposed as theoretical threshold for sustaining adaptive potential (Ne/N for takahë estimated from models as 0.41-0.47).

[6] *PMx analysis:* maintains ≥ 90% wild source gene diversity for 50 years (starting from current GD=95.48% and with growth of $\lambda \geq 1.06$)

[7] Franklin (1980): observations of commercial breeders suggest rate of inbreeding accumulation at Ne/N ≈ 50 can be accommodated

[8] (J. Ballou, pers. comm: based on current knowledge of selection coefficients, at Ne/N ≈ 25 natural selection should begin to override chance as the dominant influence shaping the gene pool

[9] *VORTEX analyses:* using input values described in this report, simulated populations showed reduced susceptibility to demographic uncertainty (chance variation in birth and death rates, and sex-ratio).

[10] *VORTEX analyses:* reduced susceptibility to short-term (year to year) environmental variation, and to occasional "expected" catastrophes, based on current estimates of this.

Security from predators

The meta-population is to be distributed across a range of site types with different qualities and management requirements. Island sites are expected to be more reliable in terms of containment and predator-free status than proposed mainland sites but this remains untested and uncertain. Ideally, most of the meta-population would be located at sites known to be at low risk of predator incursion. A qualitative assessment was used to help gauge this, based on two aspects of site vulnerability: the inherent vulnerability of the site to predator incursion (such that island sites are considered less risky than fenced mainland sites); and the vulnerability of the site due to the level of monitoring/management required and the incumbent risk of human error or a decline in resources. Ideal sites are those both inherently less at risk to predator incursions and which require relatively little ongoing monitoring or maintenance. Table 2 shows the results of this assessment. As can be seen, in the North Island, sites considered both inherently low risk and requiring little management comprise 75 (24%) of the estimated 310 adult bird capacity so far secured for the meta-population. Sites considered inherently low risk but with moderate or high management needs comprised 144 (46%) adult spaces. Remaining capacity has some built-in resilience as a result of its degree of fragmentation which should ensure that no single catastrophe will affect more than a small proportion of the population before it can be identified and addressed. The heavy reliance of overall population security on the Motutapu site makes this a priority for ongoing monitoring.

Capacity constraints

At present the total capacity estimated to have been secured for the North Island Meta-population is approximately 364 spaces (all age-classes), which includes 54 spaces for retired birds, some in South Island facilities. These spaces are expected to be fully mobilised in approximately 8 years. VORTEX models were used to project likely growth of the North Island Meta-population over the next 20 years to compare the numbers expected to the carrying capacity secured. The vital rates used are more optimistic than those derived from PMx analysis of performance to date and are derived from averaged values calculated across the wider population outside the Murchison Mountains (see Appendix I for details). These more optimistic values are thought to be a more likely reflection of future potential. Three scenarios were considered in the models: 1) population growth from the current population (N=82 birds of breeding age; 8 post-reproductive birds); 2) growth of the current population supplemented with 15 birds each year for 3 years; 3) growth of the current population supplemented with 15 birds each year for 5 years. The results are illustrated in Figure 9.

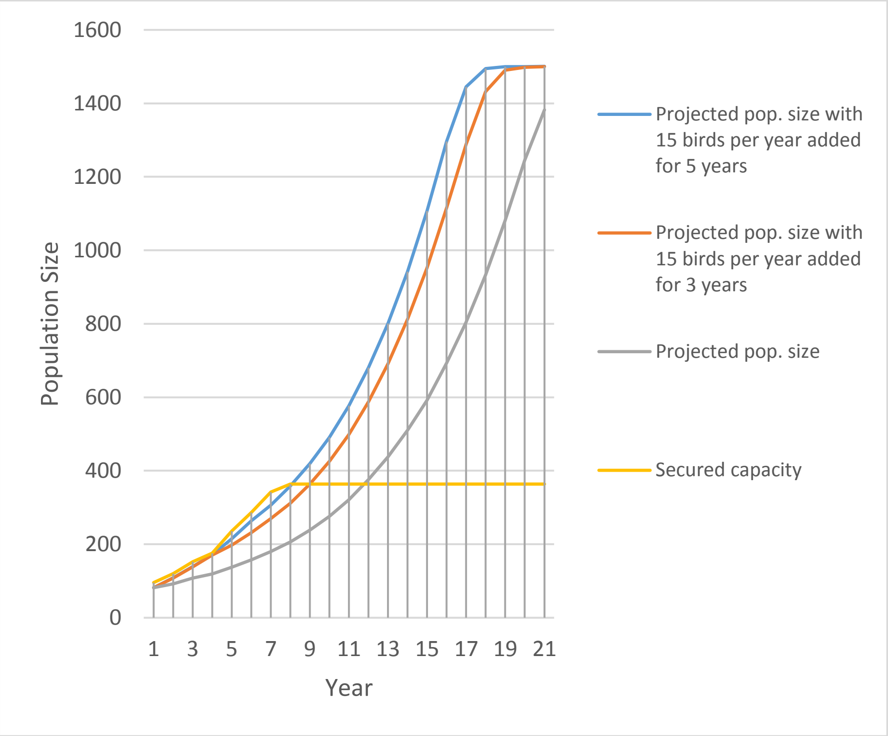


Figure 9. Comparison between secured capacity and projected population size in the North Island Meta-population for three management scenarios: 1) no further supplementation 2) 15 birds per year added for 3 years 3) 15 birds per year added for 5 years.

As illustrated, over the next ten years the carrying capacity estimated to have been secured to date should be sufficient to accommodate growth of the existing population in the absence of further supplementation from the Burwood breeding centre. Under this scenario capacity would be expected to be reached somewhere around year 12 of the program. However, further supplementation from Burwood is expected to be required in order to improve the genetic and demographic prospects of the North Island Meta-population. Both supplementation scenarios result in projected growth in excess of estimated carrying capacity by around years 8-9, that is, at around year 8-9 capacity constraints will begin to exacerbate loss of gene diversity.

SEX-RATIO SKEWS

A sex-ratio skew has been observed in the population which varies in direction (male-biased in the south, female biased in the north) and in magnitude (larger skews in some sites than in others). Some of this skew may be due to chance but overall at secure sites the historic sex-ratio measures 45:55 towards females.

To test the impact on meta-population performance of an underlying female sex-ratio bias, ratios ranging from 50 – 70% were modelled in VORTEX using as a starting point the demographic and genetic characteristics of the current meta-population and excluding any intensive management (i.e. no inter-site transfers and no further supplementation). The results are illustrated in Figure 10a. Over the period modelled, biases of 55% and 60% reduced mean meta-population size only slightly (from N=284.50 to N=279.83 and N=278.79 respectively, at 50 years), whilst 65% and 70% biases had larger impacts (down to N=262.5 and N= 231.66 respectively, at 50 years). The larger impacts of the more extreme skews in the modelled populations can mostly be explained by inbreeding. As the sex-ratio bias increases, the number of breeding pairs contributing to growth decreases, which over time raises the average level of relatedness across the population and leads to inbreeding depression Figure 10b Illustrates the relative importance of this inbreeding effect by showing growth projections in the absence of inbreeding.

There was no discernible impact on extinction risk at the meta-population level (P(Ex)=0.000 for all scenarios). This suggests that biases of the magnitude observed to date in the North Island will not on their own pose a risk to the meta-population. Should these skews become more extreme, greater attention to inbreeding management may be required. [Note that the models currently factor in only reduced productivity resulting from fewer pairs and do not consider any disruption of resident pairs as a result of surplus, single birds].

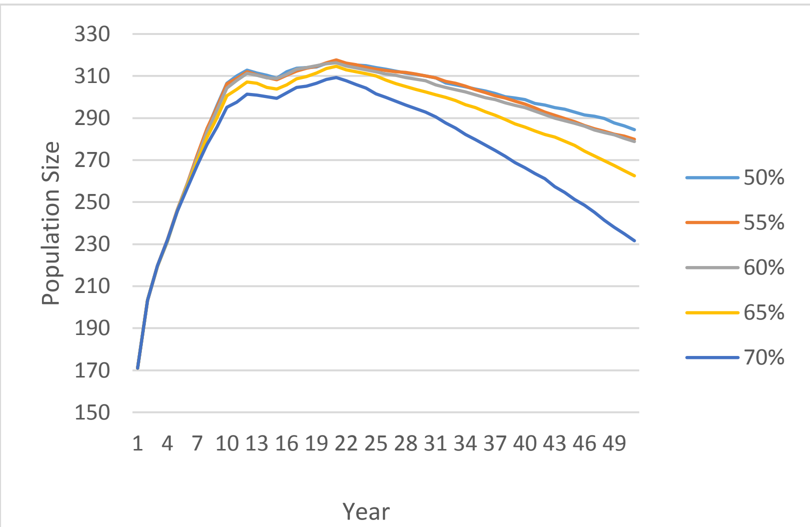


Figure 10a. Impact on expected population size of varying female sex-ratio from 50% - 70%; effect of inbreeding included.

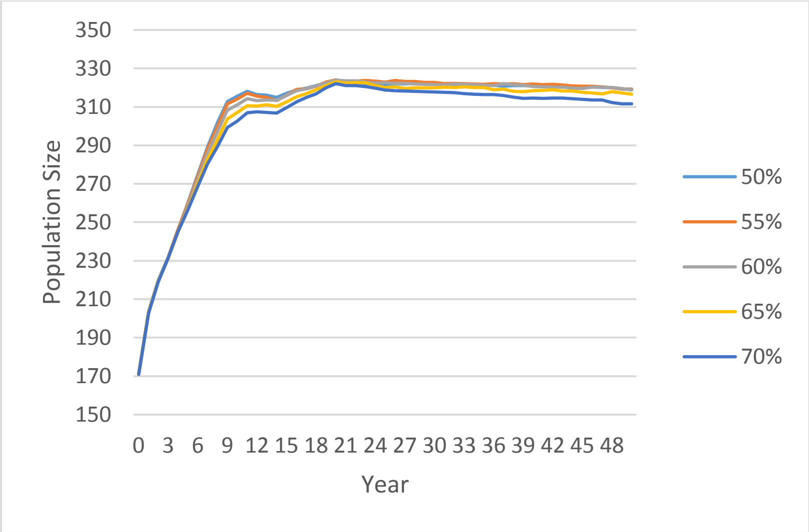


Figure 10b. Impact on expected population size of varying female sex-ratio from 50% - 70%; effect of inbreeding excluded.

VISION

The following VISIONARY GOAL has been developed by the Recovery Group to guide all aspects of recovery work for the taxon:

Takahë exist at numerous accessible sites across their historic range, are recognised as a national treasure valued by New Zealanders, and as a result are no longer at risk of extinction.

Though the planned North Island meta-population sits outside the historic range of the extant South Island takahë species (*Porphyrio hochstetteri*), carefully managed it has the potential to replace ecologically the extinct North Island takahë (*Porphyrio mantelli*).

NORTH ISLAND META-POPULATION

The following long-term aim has been proposed by the Recovery Group to guide development of the North Island Meta-population.

To build a self-sustaining, locally adapted meta-population of takahë in the North Island of New Zealand.

Self-sustaining is interpreted here as able to persist indefinitely without further recruitment of individuals from external sources.

Locally adapted is interpreted here as achieving vital rates equal to or better than, those observed in growing South Island populations.

STRATEGY

The following strategy takes into account current population characteristics, available resources (genetic, demographic and capacity-related), small population science, and the suite of management interventions currently considered feasible for takahë. It is designed to advance the goal of establishing a self-sustaining, locally adapted meta-population of takahë in the North Island.

PHASE I. 3-5 YEARS

- Establish the means to run an effective program of intensive population management towards agreed genetic and demographic targets.
- Secure as a base for the North Island Meta-population, a representative sample of wild source gene diversity, through supplementation from the Burwood breeding centre.
- Using small population biology theory and associated software tools, direct transfers and breeding within the North Island Meta-population to slow inbreeding accumulation and maximise gene diversity retention as the population is growing.
- When the population is sufficiently robust both genetically and demographically, move to Phase II.

PHASE II. 5 – 10 YEARS

- Accelerate adaptation to North Island conditions by isolating the North Island Meta-population from further supplementation from the south.
- Continue close management of transfers and breeding within the meta-population to slow inbreeding accumulation and maximise gene diversity retention.
- Continue expansion into currently secured capacity.
- Avoid curtailing population growth by anticipating the need for new capacity and mobilising new sites of the required size.
- For sites housing 50 birds or more and where maintenance of individual monitoring and management becomes onerous, transition to lower-intensity management.
- Review and revise strategy, targets and activities.

OBJECTIVES, TARGETS AND ACTIVITIES

The following objectives, targets and activities are for the next 10 years of the program. Implementation will involve collaboration between a number of project partners, coordinated through the recovery group.

PHASE I. 3-5 YEARS

Objective 1. Establish immediately an operational framework for running an effective program of intensive population management towards agreed genetic and demographic targets.

Activity 1. With site managers/coordinators, establish and implement the following intensive population management protocols:

- protocols for site-specific and program-wide data collection and management
- protocols for demographic and genetic analysis and the associated generation of breeding and transfer recommendations in line with program targets
- protocols for implementation of breeding and transfer recommendations and monitoring of results

(See next section of this document for further information on requirements)

Objective 2. Secure as a base for the North Island Meta-population, a representative sample of wild source gene diversity, through supplementation from the Burwood breeding centre.

Targets: secure as a genetic base at least 96% wild source gene diversity (as inferred from PMx pedigree analysis); complete this founding phase in 3 – 5 years, supplementing with up to 15 birds per year from the south.

Activity. Use *PMx Management Sets* and *Pairings* capabilities to recommend pairings at Burwood and offspring transfers from the Burwood breeding centre to the North Island Meta-population, towards increasing gene diversity in the North Island Meta-population without detriment to the south. Repeat annually until no further benefits accrue.

Objective 3. Manage transfers and breeding within the meta-population to slow inbreeding accumulation and maximise gene diversity retention.

Targets: for the next 10 years, retain at least 94% wild source gene diversity which, (from a starting GD of 96%) will require an average annual growth rate of lambda > 1.06 and Ne/N ratio of at least 0.41. Maintain average inbreeding coefficient below 0.125.

Activity: Use *PMx Pairwise Information*, and *Pairings* functions to identify potentially optimal and detrimental pairings with respect to gene diversity retention and inbreeding accumulation. Encourage optimal pairings and discourage detrimental ones using species and situation-appropriate interventions (see next section, this document). Monitor and report results annually.

Objective 4. Move to Phase II when the North Island Meta-population has captured sufficient initial gene diversity, carries a genetically effective population size of at least 50, and where vital rates are expected to support sufficient positive growth.

Targets: for transition to Phase II - gene diversity ≥ 96%; population size ≥ 120; lambda > 1.06

Phase II. 5 – 10 years

Objective 5. Isolate the North Island Meta-population from further supplementation from the south.

Activities: prevent further supplementation from south to north. North to south translocations can continue where required.

Objective 6. Identify and secure additional sites to allow growth to continue unconstrained.

Target 1: current models indicate an additional 50 – 100 additional spaces will be required by year 7-8 to take the population through to year 10. To take the population beyond that without constraining growth will require several hundred additional spaces (estimated targets only – need to couple this target to observed growth and any updated capacity estimates).

Target 2. Secure approximately 30 spaces for post-reproductive birds in the first 10 years (requirement should decline beyond this to around 25).

Activities: monitor population growth with respect to available capacity; anticipate additional capacity and secure as needed.

Objective 7. Ensure effort expended on intensive genetic management is proportional to expected benefits.

Activity: for sites housing 50 birds or more, where maintenance of individual monitoring and management becomes onerous, move to lower-intensity management in the form of periodic inter-site exchanges of birds. (Frequency of transfers and number of birds to be exchanged can be estimated using models).

Objective 8. Monitor and evaluate progress, and review regularly the relevance of Objectives, Targets and activities. Adapt accordingly.

Note that for the purpose of evaluation, baseline values for gene diversity retention and mean inbreeding will be the 2012 values: Gene Diversity = 92.6%; Mean Inbreeding Coefficient = 0.0523

Target 1. Annual review of progress towards targets and objectives (as part of the annual breeding and transfer recommendation review and analysis).

Target 2. Five-yearly review of Goal, Objectives, Targets and Activities to ensure ongoing relevance.

Activity: review the plan in light of population developments - complete an annual review of progress as part of the annual analysis and transfer/breeding recommendations. Complete a review of the strategy, objectives, targets and activities after 5 years and again after 10 years, and revise as appropriate.

Intensive Management of the North Island Meta-population: Principles, Assumptions and Protocols.

The following paragraphs present a summary of the broad principles and assumptions that underpin this plan for the intensive management of the North Island meta-population of takahë. In addition, protocols are provided for takahë data management, for the annual analysis of genetic and demographic meta-population characteristics, and for the development of pairing and transfer recommendations that fall from this.

Principles

Managing the gene pool

- The sample of founders taken from the wild and now represented at sites and facilities outside the Murchison Mountains is assumed to be a representative "snapshot" of wild gene diversity.
- The aim of genetic management will be to amplify this "snapshot" without changing its composition.
- In advance of its isolation, the North Island meta-population should be a replica of this "snapshot", as far as possible, given operational constraints.
- This requires manipulation of the living gene pool to equalise the contributions of founders, taking into account any lineage bottlenecks that would devalue a particular founder's contribution and reduce its "target share" of the gene pool.
- Ongoing management of this 'snapshot' to reduce deterioration requires rapid growth to capacity, maintenance of constant size once at capacity, and maximizing the number of individuals contributing (evenly) to the gene pool each generation – that is, maximizing the population's genetically effective population size[11].
- Manipulation of the gene pool will be carried out by allowing all birds the opportunity to breed whilst encouraging optimal pairings over less-optimal ones.
- Optimal pairings are considered to be those between birds carrying relatively low and similar mean kinship values[12] with respect to the wider population, and for which any offspring produced would be expected to carry an inbreeding coefficient[13] no higher than the population average. Additional factors relating to pair compatibility and logistical difficulty will also be accounted for (relative age, location, reproductive histories, program resources).
- Optimal pairings and their implications will be inferred from pedigree analysis, using studbook data collated through the SPARKS program (ISIS, 2013) and the population management software PMx (Ballou *et al*. 2013). The outputs of these analyses will be checked and modified on the basis of expert advice from managers on the additional factors referred to above.

[11] Genetically effective population size provides a measure of the efficiency with which the population is retaining gene diversity from one generation to the next.

[12] The mean kinship value of an individual signals how related it is to the rest of the population; individuals less related to the wider population are more likely to contain rarer alleles than those with many close relatives.

[13] The probability that an individual has obtained copies of the same ancestral gene from both its parents. High inbreeding coefficients may result in depressed fitness.

- Optimal pairings will be encouraged through one of the following methods, depending on circumstances:
    - "Forced pairings"; for single birds for which a new mate is required, housing a potentially optimal pair together until firmly bonded.
    - Assembling for translocation genetically favourable groups of unpaired birds within which several optimal pairings could be created.
    - Double-clutching; for existing, priority pairs. Less optimal pairs may be used to rear the extra eggs.
- During the growth phase of the meta-population, continuing population expansion will be a priority. Therefore, the primary routes to improving gene diversity will be through increasing the productivity of rare genetic lines (e.g. by double-clutching priority pairs) and through encouraging optimal pairings. Reducing productivity of common lines as a strategy for improving gene diversity will be avoided, except in instances where that productivity presents an obstacle to these primary strategies.
- Once components of the population become too large or inaccessible for the maintenance of pedigree data, pedigree information will be inferred from simulation models using the program VORTEX (Lacy *et al*, 2003). This will allow an ongoing strategy of island exchanges to be developed which specifies numbers and rates of exchange between specific locations for the ongoing management of gene diversity and inbreeding accumulation.

MANAGING CAPACITY

- To avoid placing constraints on breeding during the growth phase, capacity will be sought and mobilized at a rate tailored to expected growth of the population, which will be revised regularly on the basis of observed vital rates, using the population management software PMx.
- During the growth phase the input of genetically important birds from the south will be timed to ensure that those pairs have space to grow their offspring contribution once in the north.
- To maximize the resources for breeding birds at island sites at or nearing capacity, birds aged 15 years or more will be transferred to sites dedicated to that purpose.
- Island sites are likely to need ongoing management to ensure optimal results once carrying capacities are reached. More will be understood about this as sites reach capacity and the behaviour of populations in this state can be monitored. Over the long-term (beyond the scope of this plan) the aim will be to secure some protected sites of large capacity, from which birds can move into the surrounding landscape to alleviate population pressure. Such sites could provide repositories for birds that need to be removed from islands.

SITE ROLES AND PRIORITIES

- Due to their disproportionate contribution to meta-population viability, securing demographic viability and optimizing gene diversity on **larger islands will take priority**; small islands will play a supporting role.

ASSUMPTIONS AND RISKS

- That the sample of founders taken from the wild and now represented at sites and facilities outside the Murchison Mountains constituted a representative sample of remaining wild gene diversity.

- That the Burwood facility will continue to perform at its current level in terms of breeding success and capacity, for at least the next 3-5 years, and that no additional demands will be placed on it during that time that would prevent it from meeting the North Island targets.
- That the carrying capacities estimated for planned North Island sites are roughly accurate and reflect an expected average or minimum abundance of birds.
- That the vital rates observed at Burwood will be replicated in the North Island Meta-population over time, as the program progresses.

MANAGING TAKAHË DATA

Data on individual birds, on their locations, mates and reproduction, have been kept for 30 years by the Department of Conservation (DOC). The process of transferring these data to searchable databases was recently completed (Greaves, pers. comm). At present records from all sites are collated once each year (late September) for entry into the main database, with the aim of having complete and accurate records at the start of each breeding season (October 1). Events such as annual banding of new birds and translocations of large numbers of individuals may trigger an additional round of data entry but in general, throughout the rest of the year, paper records of individual birds and their breeding and movements are recorded and maintained separately by managers at the various sites.

To date this has not presented a significant problem as most records (perhaps 90%) are held at the Fiordland District Office. However, as the meta-population shifts further north and becomes more dispersed, and as pedigree analysis forms a regular precursor to management decisions, more formal data collation and reporting protocols will be important. However, site managers are resource poor and will be unlikely to be able to accommodate any significant increase in the frequency or complexity of data collection and reporting.

The following proposed measures aim to deliver a reasonable balance between data accuracy and labour intensity:

1. Twice yearly updates to the master database and to the SPARKS studbook. Once in March-April to coincide with the banding of new birds, and again in August – September prior to the breeding season.
2. Implementation of standardised data recoding conventions and protocols for use by all sites, to ensure consistent recording and interpretation of information.

PROTOCOLS FOR GENERATING PROGRAM RECOMMENDATIONS

On the basis of the management approach likely to be applicable to North Island takahë, the steps below are recommended for an **annual process of analysis and recommendation generation.** This is a guide only. Varying circumstances and unexpected developments will require year-to-year changes in approach.

REVIEW THE PREVIOUS YEAR'S ACTIVITY

1. Review pairing successes and failures from the previous year, agree what has been learned, recommend any changes to management practice in line with these advances in knowledge.

REFRESH STUDBOOK INFORMATION

2. Update studbook records to create a complete and accurate picture of:
    - which birds are known to be living
    - which birds are considered or assumed to be reproductively capable
    - where each bird is located, when it arrived there and where else it has been
    - dates of birth and parentage for all living birds

- dates of death for all birds deceased since the previous update.

Establish demographic needs and potential

3. Update information on:
   - which birds are paired and which unpaired
   - which birds are due for retirement
   - each island's carrying capacity
   - which birds (if any) need to be moved from their current location (for whatever reason)
   - which birds must not be moved (for whatever reason)
   - any new or potential facilities or islands able to house birds, and details of what kinds of birds they could usefully provide for (e.g. post reproductive or breeding)
4. Analyse demographic status and set target size for the year (where appropriate).
5. Use PMx to determine how many breeding pairs are required to meet population size targets for the year and revise targets if necessary.
6. Estimate the number of birds likely to be surplus to North Island capacity (if any).
7. Check population projections and flag any burgeoning capacity issues for the wider recovery team.

Establish genetic needs and potential

8. *Use PMx to partition the North Island meta-population from Burwood and the rest of the South Island population. Analyse the founder statistics of each to check the relative genetic quality of populations.*
9. *Use the PMx Management Sets feature to identify which individuals could be transferred into the North Island meta-population from Burwood and elsewhere, without undue detriment to the source population. Where detriment is expected as a result of a transfer, consider mitigating action (i.e. breeding from the targeted birds at Burwood to create a situation in which lines can be amplified and as a result distributed to multiple sites without detriment to any).*
10. Use the PMx Management Sets feature to identify which birds from the North Island meta-population (if any) could usefully be "retired" to another management subset (i.e. on the South Island via Burwood).

Identify priority pairs

11. Evaluate existing pairs using the PMx Mate Suitability Index (MSI), to establish which are good and which are least good.
12. Identify potentially optimal mates for single birds that need to be paired and for any birds that will be re-paired.
13. Use this to agree which genetically suitable pairs or groups of single birds, will be formed.
14. Agree which priority pairs will be double-clutched and which pairs (if any) will be separated or used to incubate eggs from a higher priority pair.

Identify transfer requirements

15. Determine where priority pairings should occur and, therefore, any transfer requirements that result from that.
16. Determine where any newly retired birds will be moved to (if applicable).

QUANTIFY THE EXPECTED BENEFITS

17. Enter the results into the Pairings window in PMx to check expected impact on population-wide gene diversity. Revise and fine tune as needed.
18. Check the expected impact on population growth. Fine tune as needed.

TAKE ACTION

19. Finalise, document and act on recommendations. Record the outcomes.

Once the benefits of further imports from Burwood and the South Island diminish, the North Island meta-population will be closed to imports (though not to exports) and steps 7 and 8 will no longer be required.

INTENSIVE MANAGEMENT SCHEDULE

The intensive management of the North Island meta-population will be most effective where pairing and transfer recommendations are based on accurate information and sound science, and where they are successfully enacted as recommended. Amongst other things, this will require careful scheduling of data collection, analysis, recommendation generation, implementation and monitoring. The following schedule is designed to include these elements in a way that articulates with known management commitments and resource constraints.

Oct	•STUDBOOK UPDATE COMPLETE - data current as of October 1 •Nests include 1 - 2 yearlings, hatching season begins
Nov	•Hatching season •Breeding management recommendations implemented
Dec	•Hatching season •Breeding management recommendations implemented
Jan	•Close of hatching season •FIRST PMx ANALYSIS to check selection of yearlings for translocation
Feb	•TRANSLOCATION 1: batch of yearlings to South Island sites - one from each nest with 2 yearlings plus any prescribed additions
Mar	•BANDING of new birds and entry into the system •Studbook update - all births, deaths, transfers
Apr	•STUDBOOK UPDATE COMPLETE - data current as of April 1
May	•Rearing
June	•Rearing
July	•Rearing
Aug	•SECOND PMx ANALYSIS to determine transfer recommendations for the North Island and priority pairings for the coming year
Sept	• TRANSLOCATION 2: Remaining yearlings distributed across to North Island sites •Studbook update - all recent deaths and transfers incorporated

2014-2015 PAIRING AND TRANSFER RECOMMENDATIONS

BACKGROUND AND RATIONALE

The focus of intensive management of the North Island Meta-population in the 2014-2015 season will be to increase abundance, to increase gene diversity and to maintain inbreeding below detrimental levels. In addition and in support of this, older birds (aged 15 years or more) will be removed from breeding sites and retired to other suitable areas and facilities.

For the next few years, the Burwood breeding centre (and the associated population on Rarotoka) will be the principal means through which manipulation of the North Island Meta-population's demography and gene pool is achieved. Therefore, the scope of the 2014-2015 pairing and transfer recommendations includes all three units (the North Island Meta-population, Burwood Breeding Centre and Rarotoka).

To encourage a rapid increase in abundance, all birds of breeding age (as far as possible) will be given an opportunity to breed. To improve the gene diversity of the population whilst keeping inbreeding below detrimental levels, genetically optimal pairings will be pursued and where possible, less optimal ones avoided. This year, particular attention will be given to ensuring that four founder lineages[14] currently unrepresented in the north but present in the south, are managed to ensure representation in both populations. These founder lineages stem from the following founders: #472 (Tumbles), #585 (Blaze), #676 (Larrivee) and #717 (Kuini)

The methods and strategies through which these aims will be achieved are described below.

ASSESSING THE GENETIC VALUE OF PAIRINGS

The value of genetic pairings is inferred from pedigree data using the MateRx feature in PMx (Ballou et al., 2013). The MateRx feature accords every current or potential pairing in the population a Mate Suitability Index (MSI) which reflects its genetic value relative to all possible pairings.

MSI is a composite score that integrates four genetic components into a single index:

1. Delta GD (dGD): change in gene diversity (GD) of the population if one offspring is produced by the pair. Positive dGD increases the GD of the population, while negative dGD decreases GD.

2. Differences in MK values (MKDiff): difference in the genetic value (mean kinship value) of the male and female. Breeding a pair with a large MKDiff is detrimental because it combines under-represented and over-represented genetic lines, making management towards founder line parity more difficult.

3. Inbreeding coefficient (F): inbreeding coefficient of any offspring resulting from the pair (i.e., the kinship value for the pair). Inbreeding is considered to be detrimental to the fitness of the resulting offspring.

4. Unknown ancestry: the amount of unknown ancestry in the male and female. Incomplete pedigree information means that the genetic value and relatedness of a pair cannot be accurately calculated.

These variables are combined using a default set of definitions (that can be modified) to assign a *MSI* score of 1 to 6 for each pair, which can be thought of as follows:
1 = very beneficial (genetically) to the population
2 = moderately beneficial

[14] Note that since initial analysis the sole representative of one of these lines has died (#585 – Blaze)

3 = slightly beneficial
4 = slightly detrimental
5 = detrimental, should only be used if demographically necessary
6 = very detrimental (should be considered only if demographic considerations override preservation of genetic diversity)
"-"= highly detrimental (should not be paired, due to high level of kinship of pair)

Alternative strategies

The priority for takahë is to increase abundance. Therefore, the main strategy for enhancing gene diversity will be to increase the representation of ALL genetic lines, but to increase the rarer ones at a faster rate so that they become more evenly represented. There are a number of alternative ways of achieving this, some requiring more time and effort than others. In discussion, the options were narrowed to two viable alternatives and these were tested to see which would produce the highest genetic gains. The results are shown in Table 6. Strategies A and B would be pursued as part of usual management and both will, if carried out as envisaged result in gene diversity improvements to the population. Strategies C and D would impose additional management requirements. As can be seen from the figures, the greatest gains are to be found in double-clutching the more valuable lines rather than in splitting and re-pairing less optimal pairs. As the latter strategy is not only less effective but more difficult to achieve, **double-clutching will be the principle strategy pursued for 2014-2015.** Only where it is convenient to do so, or where it also serves other program goals, will splitting and re-pairing low value pairs be pursued. The "Potential" figures at the bottom of the table show that further gains could be made, but this would require more onerous management intervention with no guarantee of success. This may be reviewed in subsequent years depending on the results of the 2014-2015 interventions.

Table 6. Impact of alternative management strategies on gene diversity and rate of inbreeding accumulation

Strategy	Gene Diversity	Founder Genome Equivalents	Population Mean Kinship
Current population outside the Murchison Mountains	0.9593	12.29	0.0407
A. Breed from currently established pairs only	0.9631	13.55	0.0369
B. Breed from currently established pairs plus optimally paired singletons	0.9634	13.66	0.0366
C. A & B plus worst pairings split and re-paired (MateRx 6s & 7s)	**0.9637**	**13.77**	**0.0363**
D. A & B plus best of established pairs double-clutched (MateRx 1s)	**0.9651**	**14.32**	**0.0349**
Potential of current population	0.9863	35.31	-

In summary, the following broad strategies will be applied to the intensive management of the North Island Meta-population (including Burwood-Rarotoka) in 2014-2015.

1. Continued population expansion will be prioritised by ensuring (as far as possible) that all birds of breeding age have the opportunity to breed
2. Gene diversity will be enhanced and inbreeding accumulation managed by:
   - using the PMx Pairwise Breeding function to identify optimal and detrimental pairings

- encouraging genetically optimal pairings of currently single birds (ideally to create pairings with MSI values of 1, 2, or 3 but certainly to avoid those where MSI >5)
    - double-clutching (at Burwood) those highly valuable pairings residing there (in order of priority those with MSI values of 1, 2 and 3)
    - Identifying representatives of the four lineages[15] currently unrepresented in the North and ensuring that birds from these lines are prioritised for translocation.
3. To a lesser extent, and only where it can be achieved conveniently and with relatively little effort, particularly disadvantageous pairings (those ranked "-" and in some cases 6) will be separated and the birds re-paired.
4. As a result of double-clutching efforts, some pairs will be needed to incubate the resulting additional eggs. Where possible the pairs used for this will be those identified as of low genetic value.
5. In considering new pairings consideration will be given to:
    - the current location of the birds (to reduce the number of transfers and the distances or difficulty involved)
    - the relative ages of birds (i.e. pairing young with old birds was avoided to reduce the need for re-pairing downstream)

Table 7. below provides a full list of birds in the population and the recommendations generated for each for the 2014-2015 season. The impact of these recommendations on the North Island Meta-population will be assessed in 2015, once breeding and transfers are complete and the relevant information added to the studbook. This revised starting point will become the basis for the 2015-2016 pairing and transfer recommendations.

[15] Since analysis the sole representative of one of these lineages has died #585 – Blaze)

DRAFT 2014 – 2015 PAIRING AND TRANSFER RECOMMENDATIONS (TABLE 7.)

Green shading indicates representatives of four founder lineages currently unrepresented in the North Island Meta-population (note #585 – Blaze has died since initial analysis leaving 3 unrepresented lines). The 2014-2015 recommendations and their implementation should be seen as a trial of this new phase of intensive management. Feedback from this will inform refinements to the generation and presentation of the 2015-2016 recommendations.

UniqueID	Location	LocalID	HouseName	Sex	AgeYears	Disposition	Current Mate	MSI	New Location	Breed?	With	New MSI
229	AUCKLAND	B30140	Ahikaea	Female	16	Hold	Montague	6		Retire		
291	AUCKLAND	B30141	Montague	Male	14	Hold	Ahikaea	6		Retire		
357	BURWOOD	NONE	Whata	Female	11	Hold	-			?	?	
466	BURWOOD	NONE	Widget	Female	9	Hold	-			Re-pair	441 Maata	2
479	BURWOOD	NONE	Miharo	Female	8	Hold	Nuinea	1		D/C		
520	BURWOOD	NONE	Catlin	Female	8	Hold	Shadowfax	1		D/C		
547	BURWOOD	NONE	Weydon	Female	7	Hold	Ananda	1		D/C		
616	BURWOOD	NONE	Rusby	Female	5	Hold	Tihaka	5		Breed		
636	BURWOOD	NONE	Princhester	Female	4	Hold	Takurua	4		Breed		
642	BURWOOD	NONE	Lily	Female	4	Hold	Rerehu	4		Breed		
644	BURWOOD	NONE	Maka	Female	4	Transfer	-		MURCHIES			
645	BURWOOD	NONE	Ngaire	Female	4	Hold	Hopi	6		X foster?		
675	BURWOOD	NONE	Arnie	Female	4	Hold	Taramea	2		D/C		
676	BURWOOD	NONE	Larrivee	Female	4	Hold	Elwyn	4		Breed		
681	BURWOOD	NONE	Navi	Female	4	Hold	Turnbull	1		D/C		
686	BURWOOD	NONE	Tintin	Female	3	Hold	Jekyll	5		Breed		
687	BURWOOD	NONE	Hyde	Female	3	Hold	Tametame	5		Breed		
689	BURWOOD	NONE	Pipper	Female	3	Hold	Matariki	4		Breed		
694	BURWOOD	R60589	Te Maka	Female	3	Transfer	-		MURCHIES			
708	BURWOOD	NONE	Hoheria	Female	3	Hold	Tuatahi	3		Breed		
734	BURWOOD	NONE	Te Uatorikiriki	Female	2	Hold	Aparima	4		Breed		
736	BURWOOD	NONE	George	Female	2	Hold	Wal	4		Breed		
742	BURWOOD	R60527	Maaka	Female	2	Transfer	-		MURCHIES			
744	BURWOOD	NONE	Waiorua	Female	2	Hold	Pahi	4		Breed		
745	BURWOOD	NONE	Uruau	Female	2	Hold	Langley	4		Breed		
746	BURWOOD	NONE	Hine Pou Pou	Female	2	Hold	Charles	6		X foster?		
759	BURWOOD	NONE	Tapui	Female	1	Transfer	-		MURCHIES			
761	BURWOOD	R60541	Peti	Female	1	Transfer	-		MURCHIES			

UniqueID	Location	LocalID	HouseName	Sex	AgeYears	Disposition	Current Mate	MSI	New Location	Breed?	With	New MSI
763	BURWOOD	NONE	Reina	Female	1	Transfer	-		New Site	Re-pair	741 Hori	4
766	BURWOOD	R63365	Watson	Female	1	Transfer	-		MURCHIES			
768	BURWOOD	NONE	Autahi	Female	1	Hold	He Maipi	4		Breed		
769	BURWOOD	NONE	Pleiades	Female	1	Transfer	-		MURCHIES			
770	BURWOOD	NONE	Joan	Female	1	Transfer	-		MURCHIES			
279	BURWOOD	NONE	Ananda	Male	15	Hold	Weydon	1		D/C		
444	BURWOOD	NONE	Tuatahi	Male	9	Hold	Hoheria	3		Breed		
484	BURWOOD	NONE	Aparima	Male	8	Hold	Te Uatorikiriki	4				
532	BURWOOD	NONE	Matariki	Male	7	Hold	Pipper	4		Breed		
585	BURWOOD	NONE	Blaze	Male	6	Hold	-				DEAD	
614	BURWOOD	NONE	Shadowfax	Male	5	Hold	Catlin	1		D/C		
619	BURWOOD	NONE	Nuinea	Male	5	Hold	Miharo	1		D/C		
634	BURWOOD	NONE	Rerehu	Male	4	Hold	Lily	4		Breed		
638	BURWOOD	NONE	Elwyn	Male	4	Hold	Larrivee	4		Breed		
639	BURWOOD	R60600	He Maipi	Male	4	Hold	Autahi	4		Breed		
646	BURWOOD	NONE	Takurua	Male	4	Hold	Princhester	4		Breed		
647	BURWOOD	NONE	Taramea	Male	4	Hold	Arnie	2		Breed		
669	BURWOOD	NONE	Hopi	Male	4	Hold	Ngaire	6		X foster?		
672	BURWOOD	NONE	Turnbull	Male	4	Hold	Navi	1		D/C		
688	BURWOOD	NONE	Jekyll	Male	3	Hold	Tintin	5		Breed		
696	BURWOOD	NONE	Tametame	Male	3	Hold	Hyde	5		Breed		
704	BURWOOD	NONE	Langley	Male	3	Hold	Uruau	4		Breed		
706	BURWOOD	NONE	Wal	Male	3	Hold	George	4		Breed		
735	BURWOOD	NONE	Pahi	Male	2	Hold	Waiorua	4		Breed		
740	BURWOOD	NONE	Charles	Male	2	Hold	Hine pou pou	6		X foster?		
762	BURWOOD	NONE	Tihaka	Male	1	Hold	Rusby	5		Breed		
551	CAPE KIDN	NONE	Catseye	Female	7	Hold	Isra	1		D/C		
718	CAPE KIDN	NONE	Orehou	Female	3	Hold	Oraka	2		D/C		
774	CAPE KIDN	NONE	Rautangi	Female	1	Hold	Asterope	4		Breed		
781	CAPE KIDN	NONE	Puiaki	Female	1	Hold	Hone	3		Breed		
492	CAPE KIDN	NONE	Oraka	Male	8	Hold	Orehou	2		D/C		
588	CAPE KIDN	NONE	Isra	Male	6	Hold	Catseye	1		D/C		
760	CAPE KIDN	NONE	Hone	Male	1	Hold	Puiaki	3		Breed		
773	CAPE KIDN	NONE	Asterope	Male	1	Hold	Rautangi	4		Breed		

UniqueID	Location	LocalID	HouseName	Sex	AgeYears	Disposition	Current Mate	MSI	New Location	Breed?	With	New MSI
318	KAPITI I	NONE	Ra	Female	13	Transfer	Blitzen	6	New Site	Breed		
351	KAPITI I	NONE	Mingi	Female	12	Transfer	Bellamy	4	New Site	Retire		
405	KAPITI I	NONE	Ihi	Female	10	Hold	Bargie	7		Re-pair	671 Haeata	4
530	KAPITI I	NONE	Hoppie	Female	7	Hold	-			TBD		
182	KAPITI I	NONE	Beaker	Male	18	Hold	-			Retire		
253	KAPITI I	NONE	Bellamy	Male	15	Transfer	Mingi	4	New Site	Breed		
254	KAPITI I	NONE	Bargie	Male	15	Hold	Ihi	7		Retire		
280	KAPITI I	NONE	Ahoake/ Aho Ake	Male	14	Hold				Retire		
328	KAPITI I	NONE	Otakou	Male	13	Hold				TBD		
677	KAPITI I	NONE	Blitzen	Male	4	Transfer	Ra	6	New Site	Breed		
304	MANA ISL	NONE	Tua	Female	13	Hold	Kakau	6		Breed		
356	MANA ISL	NONE	Moro	Female	11	Hold				TBD		
427	MANA ISL	NONE	Fomi	Female	10	Hold	Sir Ed	4		Breed		
461	MANA ISL	NONE	Nio	Female	9	Hold	Orbell	4		Breed		
477	MANA ISL	NONE	Flotsom	Female	9	Hold	Grant	5		Breed		
519	MANA ISL	NONE	Kat	Female	8	Transfer			Rarotoka	Re-pair	Mo?	4
529	MANA ISL	NONE	Raewyn	Female	7	Hold	Rodney	6		Breed		
589	MANA ISL	NONE	Tussie	Female	6	Hold	Waitohi	6		Breed		
637	MANA ISL	NONE	Buddy	Female	4	Hold	Noam	5		Breed		
703	MANA ISL	NONE	Astelia	Female	3	Hold	Port			Breed		
733	MANA ISL	NONE	Mccaw	Female	2	Hold	Santi	5		Breed		
321	MANA ISL	NONE	Orbell	Male	13	Hold	Nio	4		Breed		
362	MANA ISL	NONE	Grant	Male	11	Hold	Flotsom	5		Breed		
386	MANA ISL	NONE	Sir Ed	Male	11	Hold	Fomi	4		Breed		
401	MANA ISL	NONE	Kakau	Male	10	Hold	Tua	6		Breed		
423	MANA ISL	NONE	Noam	Male	10	Hold	Buddy	5		Breed		
436	MANA ISL	NONE	Santi	Male	9	Hold	McCaw	5		Breed		
437	MANA ISL	NONE	Uncle Aka	Male	9	Hold				Retire		
465	MANA ISL	NONE	Port	Male	9	Hold	Astelia	?		Breed		
557	MANA ISL	NONE	Rodney	Male	7	Hold	Raewyn	6		Breed		
572	MANA ISL	NONE	Waitohi	Male	6	Hold	Tussie	6		Breed		
700	MANA ISL	NONE	Nohorua	Male	3	Hold				Re-pair	690 Raumati	

UniqueID	Location	LocalID	HouseName	Sex	AgeYears	Disposition	Current Mate	MSI	New Location	Breed?	With	New MSI
741	MANA ISL	NONE	Hori	Male	2	Transfer			New Site	Re-pair	763 Reina	4
228	MAUD ISL	NONE	Rangi	Female	17	Hold	The Captain	4		Retire		
586	MAUD ISL	NONE	Pitt	Female	6	Hold	Roy	6		Breed		
667	MAUD ISL	NONE	Harper	Female	4	Hold	Kowhai	1		Breed		
685	MAUD ISL	NONE	Pango	Female	3	Hold						
385	MAUD ISL	NONE	The Captain	Male	11	Transfer	Rangi	4	Mana	Re-pair	Mahuika	
518	MAUD ISL	NONE	Roy	Male	8	Hold	Pitt	6		Breed		
701	MAUD ISL	NONE	Kowhai	Male	3	Hold	Harper	1		Breed		
301	MEIT NZ	NONE	Matariki/ Kelly	Female	13	Hold	Kina/ Hauhanga	5		Breed		
737	MEIT NZ	NONE	Tawa	Female	2	Hold	Toa	4		Breed		
739	MEIT NZ	NONE	Nancy	Female	2	Hold	Geoffrey	4		Breed		
772	MEIT NZ	NONE	Marlee	Female	1	Hold	Te Wero	2		Breed		
474	MEIT NZ	NONE	Kina/ Hauhanga	Male	9	Hold	Matariki/ Kelly	5		Breed		
556	MEIT NZ	NONE	Geoffrey	Male	7	Hold	Nancy	4		Breed		
568	MEIT NZ	NONE	Te Wero	Male	6	Hold	Marlee	2		Breed		
695	MEIT NZ	NONE	Toa	Male	3	Hold	Tawa	4		Breed		
T791	MEIT NZ	R60534	Turutu	Male	0	Transfer			New Site	Re-pair	T792 female Tiri	4
567	MOTUTAPU	NONE	Tarawera	Female	6	Hold				Re-pair	635 Te Rangi	4
674	MOTUTAPU	NONE	Ella	Female	4	Hold	Hemi	1		Breed		
679	MOTUTAPU	NONE	Tautari	Female	4	Hold	Bligh	4		Breed		
680	MOTUTAPU	NONE	Pearl	Female	4	Hold				Re-pair	723 Ariki	1
690	MOTUTAPU	NONE	Raumati	Female	3	Hold				Re-pair	700 Nohorua	
707	MOTUTAPU	NONE	Charlie	Female	3	Hold	Bradshaw	1		Breed		
727	MOTUTAPU	NONE	Chalky	Female	2	Hold						
729	MOTUTAPU	NONE	Bowen	Female	2	Hold	Beacon	4		Breed		
731	MOTUTAPU	NONE	Emelius	Female	2	Hold				Re-pair	725 Westy	3
635	MOTUTAPU	NONE	Te Rangi	Male	4	Hold				Re-pair	567 Tarawera	4
671	MOTUTAPU	NONE	Haeata	Male	4	Hold				Re-pair	405 Ihi	4
723	MOTUTAPU	NONE	Ariki	Male	2	Hold				Re-pair	680 Pearl	1

UniqueID	Location	LocalID	HouseName	Sex	AgeYears	Disposition	Current Mate	MSI	New Location	Breed?	With	New MSI
724	MOTUTAPU	NONE	Beacon	Male	2	Hold	Bowen	4		Breed		
725	MOTUTAPU	NONE	Westy	Male	2	Hold				Re-pair	731 Emelius	3
726	MOTUTAPU	NONE	Bligh	Male	2	Hold	Tautari	4		Breed		
728	MOTUTAPU	NONE	Bradshaw	Male	2	Hold	Charlie	1		Breed		
730	MOTUTAPU	NONE	Hemi	Male	2	Hold	Ella	1		Breed		
196	MT BRUCE	A50001	Blossom/ Bud	Male	18	Hold	Natural			Retire		
281	MT BRUCE	A80001	Natural	Male	14	Hold	Blossom/ Bud			Retire		
442	OROKONUI	NONE	Paku	Female	9	Hold	Quammen	6		Retire		
350	OROKONUI	NONE	Quammen	Male	12	Hold	Paku	6		Retire		
380	RAROTOKA	NONE	Puku	Female	11	Hold	Puna	2		Breed		
566	RAROTOKA	NONE	Roroa	Female	6	Hold	Kaitai	3		Breed		
633	RAROTOKA	NONE	Celie	Female	4	Hold	Rex	4		Breed		
640	RAROTOKA	NONE	Inaka	Female	4	Hold	Tia	4		Breed		
641	RAROTOKA	NONE	Kura	Female	4	Hold				TBD		
692	RAROTOKA	NONE	Ani/ Oni	Female	3	Hold	Maika	1		Breed		
693	RAROTOKA	NONE	Heni	Female	3	Hold				Breed		
717	RAROTOKA	NONE	Kuini	Female	--	Hold				Breed		
767	RAROTOKA	NONE	Tekau	Female	1	Hold	Kingi	4		Breed		
303	RAROTOKA	NONE	Mo	Male	13	Transfer			Rarotoka	Re-pair	Kat?	4
395	RAROTOKA	NONE	Puna	Male	11	Hold	Puku	2		Breed		
441	RAROTOKA	NONE	Maata	Male	9	Hold				Re-pair	466 Widget	2
486	RAROTOKA	NONE	Kaitai	Male	8	Hold	Roroa	3		Breed		
569	RAROTOKA	NONE	Tia	Male	6	Hold	Inaka	4		Breed		
598	RAROTOKA	NONE	Morehu	Male	5	Hold				TBD		
643	RAROTOKA	NONE	Maika	Male	4	Hold	Ani/ Oni	1		Breed		
764	RAROTOKA	NONE	Kingi	Male	1	Hold	Tekau	4		Breed		
771	RAROTOKA	NONE	Rex	Male	1	Hold	Celie	4		Breed		
87	TE ANAU	NONE	Hebe	Female	22	Hold				Retire		
244	TE ANAU	NONE	Monty	Female	16	Hold				Retire		
558	TE ANAU	NONE	Kawa	Female	7	Hold	Tumbles			Retire		
472	TE ANAU	NONE	Tumbles	Male	9	Hold	Kawa			Retire		
358	TIRITIRI	NONE	Mahuika	Female	11	Hold				Re-pair	The Captain?	

UniqueID	Location	LocalID	HouseName	Sex	AgeYears	Disposition	Current Mate	MSI	New Location	Breed?	With	New MSI
471	TIRITIRI	NONE	Cheesecake	Female	9	Hold	Te Mingi	6		Breed		
543	TIRITIRI	NONE	Edge	Female	7	Hold	Mungo	1		Breed		
743	TIRITIRI	NONE	Nohoa	Female	2	Hold	Ranfurly	6		Breed		
T792	TIRITIRI	NONE		Female	1	Transfer			New Site	Breed	T791 Turutu	4
361	TIRITIRI	NONE	Mungo	Male	11	Hold	Edge	1				
534	TIRITIRI	NONE	Te Mingi	Male	7	Hold	Cheesecake	6				
668	TIRITIRI	NONE	Ranfurly	Male	4	Hold	Nohoa	6				
359	WILLOWBAN	NONE	Abel/ Maarooroo	Female	11	Hold	Teebee			Retire		
181	WILLOWBAN	NONE	Teebee	Male	18	Hold	Abel/ Maarooroo			Retire		
183	ZEALANDIA	NONE	Puffin	Female	18	Hold	T2	5		Retire		
159	ZEALANDIA	NONE	T2	Male	19	Hold	Puffin	5		Retire		

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. The first step in model construction is to compile these values and anomalies into a "baseline" population designed to emulate, in this case, a generic population under "normal" island conditions. In discussion it was agreed that the Murchison Mountains population has sufficiently different vital rates due to its interaction with predators and the local environment, that its values should be excluded from calculations of baseline vital rates for other island populations.

The results of baseline analyses are described below.

The Island Baseline Model

[Note that the baseline does not assume any particular grouping of birds or management scenario. Its purpose is to establish a suitable model of general island takahë dynamics and to explore the relative impact of different population characteristics on population performance].

Parameters for the Island Baseline Model are shown at the end of this document. Parameters were provided by Glen Greaves and Daryl Eason based on analysis of real data and, where absent or incomplete, their expert opinion.

Population performance is described through the following characteristics:

Lambda (ʌ) – the growth rate per annum

Ro – the growth rate per generation

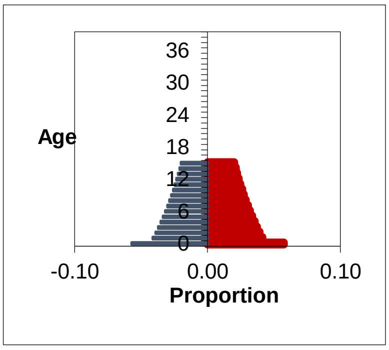
r – the exponential growth rate

T – the generation time defined as average age at reproduction and measured in years

Deterministic characteristics

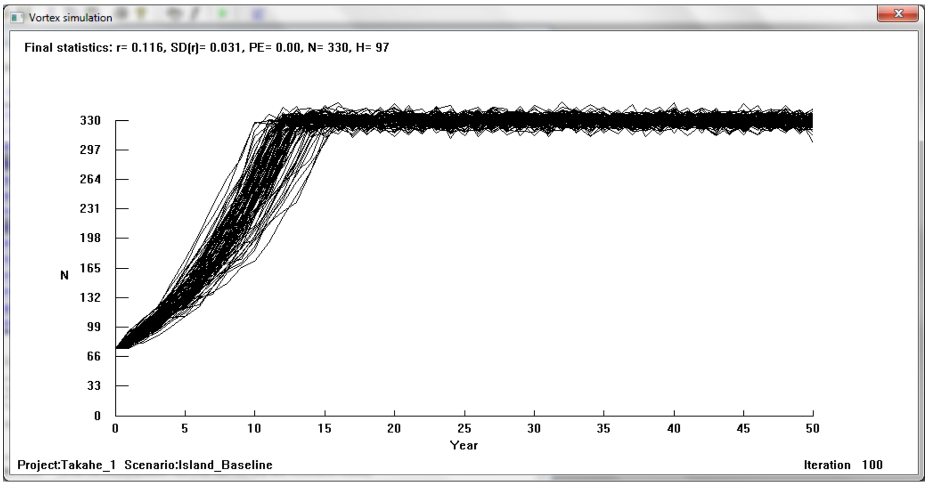
In the absence of chance variation in base rates, the values included in the model produce a population that grows at an annual rate (ʌ) of around 13% per year, has a generation time (T) of 8.29 years and an age-structure comprising 72% adults (aged 3 years or more).

Summary Statistics:			
		Females:	
% Adults	72%	Ro=	2.53
% Males (adult pop.)	50%	T=	8.29
		Lambda=	1.132
		r=	0.124



Stochastic simulations

The figure below shows the results of 100 simulations of the Island Baseline model with stochastic or chance elements included and in the absence of catastrophes. As can be seen, with relatively little variation simulated populations grow at a rate of approximately 12% per year, only slightly less than that predicted by the deterministic calculations. The population grows to capacity over an 8-15 year period and retains a high level of gene diversity at 50 years (0.975 down from 0.993). Note that this is likely to paint an optimistic picture as unless otherwise instructed, the model treats all individuals in the starting population as unrelated "founders", exaggerating starting gene diversity and underestimating inbreeding accumulation with respect to the living population under study. Though this model is sufficient to proceed with sensitivity testing, to test scenarios the starting genetic profile will require modification using pedigree information drawn from the studbook.



Sensitivity Testing

Tests were carried out on a range of parameters to identify which have the greatest impact on population performance when varied across a plausible range. The values used in the tests are included in the table at the end of the document.

Two types of parameter were selected for testing:

- Those where there is parameter uncertainty.
- Those where values show inter-island variation.

Figure 1. illustrates the relative impact on growth rate of the various manipulations compared with the baseline. The table in Appendix I summarises the values tested.

Female Mortality Rates

Varying mortality in the 0-1 year age-class by as much as 5% in either direction had a relatively modest impact compared to the equivalent shift in adult mortality rates. Accurately assessing the latter is therefore more important (though harder to do).

Inbreeding

The sensitivity of the model to inbreeding was modelled at 3.14, 4.5, 6.0, 9.0, 12.0 and 16.0 lethal equivalents per diploid genome. Unless instructed otherwise, Vortex will assume that individuals in the starting population are unrelated. From a starting population of 75, a generation time of 8.29 years and a 50-year program period, relatively little inbreeding would be expected to accumulate and this is reflected in the marginal susceptibility of the modelled population to this factor. However, the actual starting population is known to be inter-related.

[Further tests have been carried out with the aim of more closely modelling the inter-generational distribution of the impact of lethal equivalents described in (Grueber *et al*., 2010) and the smaller founder numbers and carrying capacities of individual sites within the North Island Meta-population. The resulting model scenarios flagged inbreeding depression as an important risk factor for populations at smaller sites (N<50)].

Carrying capacity

Though varying carrying capacity across the range considered (300 – 1000) makes little impact on growth rate, it has a noticeable effect on allele retention. This is to be expected (loss of allelic diversity through drift is directly related to population size). Quantifying the expected loss may be useful when considering alternative management interventions.

Table 1. Alleles retained at 50 years for carrying capacity varied from 300 to 1000 (note these allele numbers are for comparison only, to indicate the relative impact of different carrying capacities on allelic retention – the model infers starting number of alleles from the initial number of founders (N=75 in this case).

Carrying capacity	**Alleles Retained at 50 years**
K=300	64.16
K=400	74.5
K=500	82.25
K=600	87.66
K=700	91.76
K=800	95.15
K=900	97.52
K=1000	99.41

Initial Population Size

The poor performance of populations beginning with 10-20 individuals is likely due to the exacerbating forces of demographic and environmental stochasticity, and inbreeding (in the tests performed no supplementation is carried out beyond the founder phase).

Catastrophes

No meta-population-wide catastrophes were identified by collaborators and so none are included in the baseline model. The takahë population is highly fragmented and catastrophes may be more likely to operate at the local, island level rather than across the entire population at once.

Work by Reed *et al* (2003) provided a rule of thumb generated from a study of 88 vertebrate species, which suggests that on average, wildlife populations have a 15% chance each generation, of experiencing a severe catastrophe (defined as a loss of at least 50% of the standing population). In the absence of other information, island-specific catastrophes will be introduced into the models at this rate, for scenario testing.

Sensitivity test results summary:

The left hand figure (Fig.1) illustrates the results of the sensitivity tests with respect to population growth rate (r). The red line marks the baseline value of r=0.116

The biggest shifts in growth rate were seen as a result of varying:

- Juvenile and adult mortality rates in females.
- Percentage of females breeding annually.
- Ages at first and last breeding.
- Starting population size.

Note that the negative impact of reducing age at last breeding is larger than the positive impact of the corresponding increase due to the reduced number of animals in the later age-classes.

Variations showing little impact across the range considered were:

- Inbreeding.
- Environmental variation in the percentage of females breeding annually.
- Male mortality rates.
- Male age at first breeding.
- Carrying capacity.

SUMMARY OF VORTEX PARAMETERS

Vortex Parameter	Best Guess	NOTES
# of populations	1 to many 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 (Murchieson Mts)
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	No	Mortality events mainly related to old age and aggression. These are not coupled to good years for reproduction.
EV correlation among populations	No	No - 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.
Annual % adult females breeding	80%	Based on real data
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.

Vortex Parameter	Best Guess	NOTES
Clutch size	Max size 2. Distribution 1=70%; 2=30%	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 sex ratio	0.5	Birds are sexed at 3-4 months of age - at that point sex-ratio is 50:50
% annual mortality (♂ / ♀)	SD= 10% of mean	Baed on Burwood captive records but expected to be a reasonable proxy for island rates. 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)
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)

Vortex Parameter	Best Guess	NOTES
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	TBD	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	Frequency 2%; Survival *0.5; Reproduction*1.0	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 takahë generation time of 8.3 years)
Timeframe	20 and 50 years	Though these were used in most trials, when inbreeding was considered in detail the effects of small founder base and/or constrained growth did always become apparent until much later (50 – 100 years).

APPENDIX II: PMX DATA TABLES FOR THE NORTH ISLAND META-POPULATION

FEMALE MEAN KINSHIP TABLE

UniqueID	HouseName	MKdynamic	MKRank	KVdynamic	Location	Known	AgeYears	ReproStatus
586	Pitt	0.0053	1	0.0055	MAUD ISL	1	6	Fertile
729	Bowen	0.0071	2	0.0084	MOTUTAPU	1	2	Fertile
551	Catseye	0.0115	3	0.0118	CAPE KIDN	1	7	Fertile
589	Tussie	0.0123	4	0.0136	MANA ISL	1	6	Fertile
567	Tarawera	0.0125	5	0.0126	MOTUTAPU	1	6	Fertile
718	Orehou	0.0143	6	0.0166	CAPE KIDN	1	3	Fertile
727	Chalky	0.0146	7	0.017	MOTUTAPU	1	2	Fertile
543	Edge	0.016	9	0.0168	TIRITIRI	1	7	Fertile
781	Puiaki	0.016	8	0.0183	CAPE KIDN	1	1	Fertile
737	Tawa	0.0164	10	0.0189	MEIT NZ	1	2	Fertile
304	Tua	0.0191	11	0.0185	MANA ISL	1	13	Fertile
471	Cheesecake	0.0195	12	0.0197	TIRITIRI	1	9	Fertile
674	Ella	0.0211	13	0.0227	MOTUTAPU	1	4	Fertile
680	Pearl	0.0213	14	0.025	MOTUTAPU	1	4	Fertile
739	Nancy	0.0231	15	0.0269	MEIT NZ	1	2	Fertile
667	Harper	0.024	16	0.0278	MAUD ISL	1	4	Fertile
707	Charlie	0.024	16	0.0279	MOTUTAPU	1	3	Fertile
T792		0.0258	18	0.0255	TIRITIRI	1	1	Fertile
772	Marlee	0.037	19	0.0367	MEIT NZ	1	1	Fertile
703	Astelia	0.0395	20	0.0379	MANA ISL	1	3	Fertile
318	Ra	0.0476	21	0.0444	KAPITI I	1	13	Fertile
774	Rautangi	0.0477	22	0.0468	CAPE KIDN	1	1	Fertile
477	Flotsom	0.0487	23	0.0449	MANA ISL	1	9	Fertile
690	Raumati	0.0495	24	0.049	MOTUTAPU	1	3	Fertile
427	Fomi	0.0544	25	0.0502	MANA ISL	1	10	Fertile
358	Mahuika	0.0562	26	0.052	TIRITIRI	1	11	Fertile
519	Kat	0.0569	27	0.052	MANA ISL	1	8	Fertile
685	Pango	0.0583	28	0.056	MAUD ISL	1	3	Fertile
679	Tautari	0.0586	29	0.0564	MOTUTAPU	1	4	Fertile
731	Emelius	0.0586	29	0.0564	MOTUTAPU	1	2	Fertile
301	Matariki/ Kelly	0.059	31	0.0554	MEIT NZ	1	13	Fertile
733	Mccaw	0.06	32	0.0578	MANA ISL	1	2	Fertile
465	Port	0.062	33	0.0556	MANA ISL	1	9	Fertile
529	Raewyn	0.0627	34	0.0587	MANA ISL	1	7	Fertile
356	Moro	0.0634	35	0.0583	MANA ISL	1	11	Fertile
530	Hoppie	0.0642	36	0.0594	KAPITI I	1	7	Fertile
405	Ihi	0.0676	37	0.0626	KAPITI I	1	10	Fertile
637	Buddy	0.0696	38	0.0667	MANA ISL	1	4	Fertile

UniqueID	HouseName	MKdynamic	MKRank	KVdynamic	Location	Known	AgeYears	ReproStatus
743	Nohoa	0.0723	39	0.0692	TIRITIRI	1	2	Fertile

MALE MEAN KINSHIP TABLE

UniqueID	MKdynamic	MKRank	KVdynamic	HouseName	Location	Known	AgeYears	ReproStatus
328	0.0036	1	0.0004	Otakou	KAPITI I	1	13	Fertile
588	0.0115	2	0.0122	Isra	CAPE KIDN	1	6	Fertile
668	0.0122	3	0.0138	Ranfurly	TIRITIRI	1	4	Fertile
568	0.0125	4	0.0125	Te Wero	MEIT NZ	1	6	Fertile
492	0.0134	5	0.0128	Oraka	CAPE KIDN	1	8	Fertile
730	0.0135	6	0.015	Hemi	MOTUTAPU	1	2	Fertile
677	0.0142	7	0.0151	Blitzen	KAPITI I	1	4	Fertile
728	0.0152	8	0.0173	Bradshaw	MOTUTAPU	1	2	Fertile
701	0.0172	9	0.0197	Kowhai	MAUD ISL	1	3	Fertile
773	0.0231	10	0.0266	Asterope	CAPE KIDN	1	1	Fertile
760	0.0239	11	0.0244	Hone	CAPE KIDN	1	1	Fertile
723	0.0258	12	0.0256	Ariki	MOTUTAPU	1	2	Fertile
361	0.0297	13	0.0277	Mungo	TIRITIRI	1	11	Fertile
726	0.037	14	0.0368	Bligh	MOTUTAPU	1	2	Fertile
695	0.0381	15	0.0387	Toa	MEIT NZ	1	3	Fertile
671	0.0411	16	0.0394	Haeata	MOTUTAPU	1	4	Fertile
724	0.0414	17	0.0409	Beacon	MOTUTAPU	1	2	Fertile
725	0.0429	18	0.0421	Westy	MOTUTAPU	1	2	Fertile
385	0.0451	19	0.0425	The Captain	MAUD ISL	1	11	Fertile
386	0.0487	20	0.0441	Sir Ed	MANA ISL	1	11	Fertile
474	0.0513	21	0.0493	Kina/ Hauhanga	MEIT NZ	1	9	Fertile
401	0.0565	22	0.0527	Kakau	MANA ISL	1	10	Fertile
572	0.0578	23	0.053	Waitohi	MANA ISL	1	6	Fertile
436	0.0585	24	0.0531	Santi	MANA ISL	1	9	Fertile
T791	0.0586	25	0.0559		MEIT NZ	1	0	Fertile
534	0.0596	26	0.0567	Te Mingi	TIRITIRI	1	7	Fertile
321	0.0614	27	0.0543	Orbell	MANA ISL	1	13	Fertile
556	0.0615	28	0.0556	Geoffrey	MEIT NZ	1	7	Fertile
461	0.0617	29	0.057	Nio	MANA ISL	1	9	Fertile
518	0.0629	30	0.0563	Roy	MAUD ISL	1	8	Fertile
635	0.0634	31	0.0597	Te Rangi	MOTUTAPU	1	4	Fertile
362	0.0635	32	0.0565	Grant	MANA ISL	1	11	Fertile
741	0.0667	33	0.0633	Hori	MANA ISL	1	2	Fertile
557	0.0672	34	0.0637	Rodney	MANA ISL	1	7	Fertile
291	0.0673	35	0.0622	Montague	AUCKLAND	1	14	Fertile
700	0.0683	36	0.0651	Nohorua	MANA ISL	1	3	Fertile
423	0.0706	37	0.0663	Noam	MANA ISL	1	10	Fertile

FEMALE LIFE TABLE DATA

Age (years)	Px	Mid Px	Qx	Risk Qx	Lx	Mid Lx	Mx	Risk Mx	Ex	Vx	Cx
0	0.85	0.86	0.15	150.5	1	0.92	0	150.5	8.94	1.08	0.11
1	0.88	0.88	0.12	133.7	0.85	0.79	0.029	133.7	9.23	1.25	0.09
2	0.88	0.9	0.12	113.1	0.74	0.7	0.081	113.1	9.33	1.38	0.08
3	0.92	0.93	0.08	100.1	0.66	0.63	0.161	100.1	9.25	1.44	0.07
4	0.93	0.94	0.07	87.7	0.6	0.58	0.23	87.7	8.9	1.37	0.07
5	0.94	0.95	0.06	81	0.56	0.55	0.186	81	8.44	1.21	0.07
6	0.96	0.94	0.04	74.5	0.53	0.52	0.199	74.5	7.84	1.07	0.06
7	0.92	0.91	0.08	67.1	0.51	0.49	0.14	67.1	7.28	0.93	0.06
8	0.9	0.89	0.1	59.6	0.47	0.44	0.112	59.6	6.91	0.86	0.05
9	0.87	0.86	0.13	50.2	0.42	0.39	0.216	50.2	6.67	0.84	0.05
10	0.84	0.84	0.16	40.3	0.37	0.34	0.198	40.3	6.62	0.72	0.04
11	0.84	0.9	0.16	32.7	0.31	0.28	0.067	32.7	6.68	0.62	0.04
12	0.96	0.92	0.04	27.9	0.26	0.25	0.253	27.9	6.32	0.61	0.03
13	0.88	0.94	0.12	23.3	0.25	0.23	0.126	23.3	5.77	0.39	0.03
14	1	0.88	0	21	0.22	0.22	0.097	21	5.1	0.28	0.03
15	0.76	0.72	0.24	19.3	0.22	0.19	0.089	19.3	4.65	0.21	0.02
16	0.67	0.71	0.33	13.7	0.17	0.14	0.102	13.7	5.05	0.16	0.02
17	0.78	0.8	0.22	8.8	0.11	0.1	0	8.8	5.69	0.08	0.01
18	0.83	0.82	0.17	6.2	0.09	0.08	0.102	6.2	5.84	0.1	0.01
19	0.8	0.89	0.2	4.7	0.07	0.07	0	4.7	5.92	0	0.01
20	1	1	0	4	0.06	0.06	0	4	5.53	0	0.01
21	1	0.88	0	4	0.06	0.06	0	4	4.53	0	0.01
22	0.75	0.85	0.25	3.3	0.06	0.05	0	3.3	4.04	0	0.01
23	0.99	0.92	0.01	2.9	0.04	0.04	0	2.9	3.56	0	0.01
24	0.85	0.83	0.15	2	0.04	0.04	0	2	2.79	0	0.01
25	0.82	0.8	0.18	2	0.04	0.03	0	2	2.15	0	0
26	0.78	0.44	0.22	2	0.03	0.03	0	2	1.44	0	0
27	0	0	1	0	0.02	0.01	0	0	1	0	0
28	0	0	1	0	0	0	0	0	0	0	0
29	0	0	1	0	0	0	0	0	0	0	0

MALE LIFE TABLE DATA

Age (years)	Px	Mid Px	Qx	Risk Qx	Lx	Mid Lx	Mx	Risk Mx	Ex	Vx	Cx
0	0.85	0.88	0.15	166.1	1	0.93	0	166.1	8.96	1.08	0.1
1	0.91	0.91	0.09	151.4	0.85	0.82	0.01	151.4	9.05	1.2	0.09
2	0.91	0.9	0.09	132.9	0.78	0.74	0.093	132.9	8.85	1.28	0.08
3	0.89	0.91	0.11	113.8	0.71	0.67	0.091	113.8	8.72	1.28	0.07
4	0.93	0.94	0.07	101.1	0.63	0.61	0.199	101.1	8.46	1.28	0.07
5	0.95	0.95	0.05	94.9	0.59	0.57	0.162	94.9	7.93	1.12	0.07
6	0.96	0.92	0.04	88.6	0.56	0.55	0.167	88.6	7.28	0.99	0.07
7	0.89	0.91	0.11	79.5	0.53	0.5	0.194	79.5	6.79	0.87	0.06
8	0.93	0.91	0.07	69.2	0.48	0.46	0.154	69.2	6.37	0.72	0.06
9	0.89	0.91	0.11	60.2	0.44	0.42	0.207	60.2	5.89	0.61	0.05
10	0.93	0.9	0.07	53.2	0.39	0.38	0.118	53.2	5.39	0.43	0.05
11	0.87	0.86	0.13	44.1	0.36	0.34	0.103	44.1	4.9	0.34	0.05
12	0.86	0.87	0.14	36.7	0.32	0.29	0.158	36.7	4.51	0.27	0.04
13	0.87	0.82	0.13	29.3	0.27	0.25	0.038	29.3	4.06	0.13	0.04
14	0.76	0.79	0.24	22.1	0.24	0.21	0.048	22.1	3.73	0.11	0.03
15	0.83	0.87	0.17	15.4	0.18	0.16	0.039	15.4	3.46	0.08	0.02
16	0.92	0.74	0.08	12.4	0.15	0.14	0.042	12.4	2.83	0.04	0.02
17	0.54	0.68	0.46	9.3	0.14	0.11	0	9.3	2.48	0	0.02
18	0.93	0.71	0.07	4.3	0.07	0.07	0	4.3	2.19	0	0.01
19	0.46	0.49	0.54	2.4	0.07	0.05	0	2.4	1.69	0	0.01
20	0.53	0.38	0.47	1	0.03	0.02	0	1	1.42	0	0
21	0.11	0.1	0.89	1	0.02	0.01	0	1	1.1	0	0
22	0	0	1	0.1	0	0	0	0.1	1	0	0
23	0	0	1	0	0	0	0	0	0	0	0
24	0	0	1	0	0	0	0	0	0	0	0
25	0	0	1	0	0	0	0	0	0	0	0
26	0	0	1	0	0	0	0	0	0	0	0
27	0	0	1	0	0	0	0	0	0	0	0
28	0	0	1	0	0	0	0	0	0	0	0
29	0	0	1	0	0	0	0	0	0	0	0

REFERENCES

Baber, M. J.; Craig, J. L. 2003. Home range size and carrying capacity of the South Island takahe (*Porphyrio hochstetteri*) on Tiritiri Matangi Island. *Notornis* 50: 67-74.

Ballou, J.D., Lacy, R.C., Pollak, J.P. (2013). PMx: Software for demographic and genetic analysis and management of pedigreed populations (Version 1.2.20130621). Chicago Zoological Society, Brookfield, Illinois, USA. Available from http://www.vortex10.org/PMx.aspx

BirdLife International 2012. *Porphyrio mantelli*. The IUCN Red List of Threatened Species. Version 2014.2. <www.iucnredlist.org>. Downloaded on 02 September 2014.

Bunin, J. S., Jamieson, I. G. and Eason, D. (1997). Low reproductive success of the endangered Takahe *Porphyrio mantelli* on offshore island refuges in New Zealand. Ibis, 139: 144–151.

Frankham R, Ballou J.D. and Briscoe D.A.(2010). Introduction to conservation genetics, second edition. Cambridge University Press.

Frankham, R., Brook, B.W. Bradshaw, C.J.A. Traill, L.W. Spielman D. (2013). 50/500 rule and minimum viable populations: response to Jamieson and Allendorf. Trends in Ecology and Evolution. **28**(4): 187–188. Cell Press.

Franklin, I.R. (1980) Evolutionary change in small populations. Pp 135-140 in: M.E. Soulë ad B.A. Wilcox (eds), Conservation Biology: An Evolutionary-Ecological Perspective. Sunderland, Mass.: Sinauer Associates.

Grueber C.E., Maxwell J.M. and Jamieson I.G. (2012). Are introduced takahë populations on offshore islands at carrying capacity? Implications for genetic management. New Zealand J. Ecol. **36**(2): 223-227.

Heather, B. D.; Robertson, H. A. (1997). *The field guide to the birds of New Zealand*. Oxford University Press, Oxford, UK.

ISIS (2012) Single Population Analysis & Records Keeping System (SPARKS) version 1.66. ISIS, MN.

Jamieson, I.G. and Ryan, C.J. (1999). Causes of low reproductive success of translocated Takahe (Porphyrio mantelli) on predator-free islands. Science for Conservation. Vol 125, 65pp, Department of Conservation, Wellington.

Jamieson, I. G.; Roy, M. S.; Lettink, M. (2003). Sex-specific consequences of recent inbreeding in an ancestrally inbred population of New Zealand Takahe. *Conservation Biology* 17: 708-716.

Jamieson, I.G. and Allendorf, F.W. (2012) How does the 50/500 rule apply to MVPs? Trends in Ecology and Evolution. **27**(10): 578–584. Cell Press.

Joustra. T. & G. Greaves, (2014) SPARKS Studbook Database for Takahë. *Porphyrio hochstetteri*. International Species Information System, MN.

Lacy, R.C., M. Borbat, and J.P. Pollak. (2003). VORTEX: A Stochastic Simulation of the Extinction Process.Version 9. Brookfield, IL: Chicago Zoological Society.

Marshall D.R., Brown A.H.D. (1975). Optimum sampling strategies in genetic conservation. In: Frankel O.H., Hawkes J.G., (editors). Crop Genetic Resources for Today and Tomorrow. Cambridge University Press, Cambridge, UK.

Meyer, A. B., (1883) Abbildungen von Vogel-Skeletten IV and V Lieferung, Dresden.

Owen, R. (1848). On *Dinornis* (Part III): containing a description of the skull and beak of that genus, and of the same characteristic parts of *Palapteryx*, and of two other genera of birds, *Notornis* and *Nestor*, forming part of an extensive collection of ornithic remains discovered by Mr Walter Mantell at Waingongoro, North Island of New Zealand. *Transactions of the Zoological Society of London 3*: 345-378, pls 52-56.

Schaffer, M. (1981) Minimum Viable Populations: Coping with Uncertainty In: Viable Populations for Conservation. Soule, M.E. (Ed). Cambridge Univ. Press. 1987.

Trewick, S. A. (1996). Morphology and evolution of two Takahe: flightless rails of New Zealand.*Journal of Zoology (London)* 238: 221-237.

Trewick, S. A. (1997). Sympatric flightless rails *Gallirallus dieffenbachia* and *G. modestus* on the Chatham Islands, New Zealand; morphometrics and alternative evolutionary scenarios. J. Royal Soc. New Zealand. 27(4): 451-464.