DEPARTMENT OF CONSERVATION INVESTIGATION

DEFINING THE PARAMETERS FOR A SUSTAINABLE, ADVOCACY-DIRECTED, CAPTIVE POPULATION OF KEA (*NESTOR NOTABILIS*)

Department of Conservation
Te Papa Atawhai

CONSERVATION BREEDING SPECIALIST GROUP

Acknowledgements

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A contribution of the IUCN/SSC Conservation Breeding Specialist Group

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Introduction

The IUCN/SSC/Conservation Breeding Specialist Group was commissioned to complete this study, by the Otago Conservancy of the New Zealand Department of Conservation. Both organisations value transparency and stakeholder inclusivity as key facets of any cooperative program and, in-keeping with this ethic, it is intended that this report be given a wide circulation amongst stakeholders as a precursor to a more formal planning process.

The aim of the study was to define the parameters necessary for a sustainable, advocacy-directed, captive kea population in New Zealand. The report does not aim to provide definitive answers, but to provide a tool to help shape and inform the necessary discussions between policy-makers, captive managers, resource-providers and other relevant stakeholders.

This report is written with the expectation that institutions holding birds as part of an advocacy program, will be brought together under a single management plan. This is a long-lived species with complex social and behavioural needs. Meeting those needs, as well as the population-level demographic and genetic targets of the program, and the exhibit requirements of advocacy facilities, will be challenging. Success will be most likely where available resources are mobilized behind a single, well-designed, well-coordinated and well-supported program.

Aims

The Investigation Brief calls for the design of a captive population of kea which:

- *Delivers effective advocacy.*
- *Provides for a demographically robust population.*
- *Meets international standards of gene diversity retention and inbreeding management.*
- *Is managed so that required wild recruitment rates are achievable, sustainable, minimal and, as far as possible, from injured birds only.*
- *Is managed so as to eradicate any risk to wild populations, of Parrot Beak and Feather Disease (PBFD).*
- *Is maintained to the highest standards of husbandry with particular consideration given to group size and composition.*
- *Retains the capacity to shift to an insurance or breed to release role, should this be required.*

Strategies and targets

Based on analyses of studbook data (Behrens & Pullar, 2011), population biology theory and information provided in the husbandry manual (Orr-Walker, 2010), **a population size of at least 70 birds is recommended.**

This would be expected to require an annual birth rate of around 3 – 5 hatchlings per year and a founder recruitment rate of either around **15 birds at the start of the program**, or a **supplementation rate of around 1 bird every 4 or 6 years,** to meet a target of 90% wild source gene diversity retention for 100 or 40 years respectively.

Management interventions that succeed in **increasing Ne/N ratios or in extending generation length,** should allow targets to be met at lower rates of founder recruitment.

Though the preferable avenue of wild recruitment is **injured or rehabilitated birds,** these **may not meet the criteria for recruitment,** which will require that a bird can contribute genetically to the population. This issue will require further discussion.

Biological and behavioural considerations

Population-level management is more likely to succeed, and to be sustained, where it works with and not against, the species' biology. As far as is reasonable then, the design of captive programs should support seasonal and throughout-life shifts in individual and group behaviour and biology.

Based on the social groupings and management recommended in the husbandry manual, the typical annual and life-time changes described there, and the need for close management of genetics and demography at the population-level, the following program management scheme is proposed as a starting framework for discussion:

Population characteristics

A population of 70 birds containing: 15-20 juveniles; 50-55 adult birds; approximately 3 – 5 hatchlings bred each year (due to stochastic events the range could be larger in practice); at least 8-10 breeding/holding institutions.

Annual/life-time management

1. **Post breeding season:** adult birds are maintained as mixed-sex flocks of around 4 - 8 birds.
2. **Towards breeding season:** recommended pairs are separated from the flock and transferred to breeding enclosures (unless breeding can be closely controlled within the flocking aviary).
3. **Pairs are, in general, allowed to rear only a single chick**: though this will be determined, annually by the Species Coordinator. Initially the focus is likely to be on correcting founder skew, such that genetically valuable birds maybe required to rear more than this.
4. **Non-recommended pairs**: have their eggs replaced with dummy eggs as the preferred method of contraception.
5. **Hatchlings:** spend the first 4-5 months with their parents in the breeding aviary, after which they are sent to a creching aviary to be with other, similar aged birds until aged 3-4 years.
6. **Parents:** are reintegrated into the flock according to introduction protocols.
7. **Sub-adults (aged 3-4 years):** are either encouraged to bond with a suitable mate and integrated into a suitable flock OR are housed in an appropriate social group until breeding (and therefore pairing) is required.

In terms of supporting "national" infrastructure, this scheme requires:

- that each flocking aviary has **at least one associated breeding aviary.**
- that the program has **at least three or four creching aviaries** associated with it, each to accommodate a year's cohort of juveniles on a three or four-year rotation.
- that the program has access to **additional accommodation** able to accommodate birds that are unable to be integrated into an existing mixed-sex flock, for whatever reason.

Note that this is provided as a starting framework, and as a potential long-range plan only. Its purpose is to provide a basis for discussion with facility managers and husbandry experts, who will be able to bring greater depth of kea management experience as well as knowledge of currently and potentially available facilities and resources, to the design of the program.

Potential of current population

The current ZAA-managed population of approximately 40 birds (as of December 2011) has the potential to form a sound base for a long-term advocacy program only if current weaknesses in its genetic and demographic composition can be resolved. Other birds are held in captive facilities in New Zealand but the ZAA-managed subset was selected for analysis because these are the birds for which most accurate data were immediately available. Future analyses should consider all potential program candidates. Issues identified in this preliminary analysis were:

- The sex-ratio skew in potential founders – most are male and so cannot be paired with each other, which would be the ideal. This issue will limit the ability of the population to reach its genetic potential.
- General founder skew – some founder lines have bred well at the expense of others. Attempts will need to be made to correct this.
- Lack of pedigree information – recommendations for genetic management would ideally be based on better pedigree information (current percentage known is 70%).
- Recent breeding success has been limited by greater than expected mortality, though the sample is small. It may indicate problems in resuming breeding after a long hiatus (resulting from the breeding current breeding moratorium). Demographic rates may need to be revised if this trend continues.

These issues are discussed in the text and remedial measures suggested. These will need to include, though are not limited to, additional recruitment from the wild.

Other considerations

Delivering effective advocacy

This aspect is beyond the scope of this study but would ideally be centrally coordinated as part of the captive program so that materials, methods and results can be shared.

Parrot Beak and Feather Disease

There is currently a national ban on translocations of parrots from areas with known PBFD exposure to areas of unknown PBFD status (Bell & McInnes, 2012). At present this is not explicitly extended to captive parrots, though this may change in future. This situation should be monitored carefully and, in the meantime, collections should aim to maintain PBFD-free status through appropriate screening and quarantine (Jackson, pers. comm.).

Shifting to an insurance or breed to release role

The Investigation Brief refers to the possibility that an advocacy program could be required to change its purpose to insurance or breed for release, should observed population declines in wild kea populations continue.

Provided that the advocacy program is managed to retain at least 90% gene diversity, to maximize its genetically effective size, and to sustain its numbers primarily through breeding, it will be in a good position to shift to an insurance or breed for release role as needed. The only change likely to be required, depending on circumstances in the wild, is an increase in population size to compensate for reduced access to new founders and/or to facilitate a regular harvest for release.

Introduction

The aim of this study was to define the parameters necessary for a sustainable, advocacy-directed, captive kea population in New Zealand. There are a number of ways in which this could be achieved and the challenge will be to find the model which best fits the goals of the program, the biological and behavioural needs of the species, and the resources, expertise and commitment available within the captive sector.

The study was not designed to provide definitive answers, but to provide a tool to help shape and inform the necessary discussions between policy-makers, captive managers, resource-providers and other relevant stakeholders. Ultimately this should lead to a captive management plan for the species, supported by all involved, in which specific goals, targets, actions, time-lines and responsibilities are detailed.

The IUCN/SSC Conservation Breeding Specialist Group (CBSG) supports conservation planning through the application of expert facilitation and science-based planning tools. It specialises in planning for small populations, and in integrating *in situ* and *ex situ* conservation efforts. CBSG was commissioned to complete this study, by the Otago Conservancy of the New Zealand Department of Conservation. Both organisations value transparency and stakeholder inclusivity as key facets of any cooperative program and, in-keeping with this ethic, it is intended that this report be given a wide circulation amongst stakeholders as a precursor to a more formal planning process.

Though the species is fairly widely held in captive facilities in New Zealand, some of the analyses presented here focus on a sub-set of the wider population; that managed by the Zoo and Aquarium Association as of December 2011. This is an arbitrary starting point only, chosen because this is the subset of captive birds in New Zealand for which most data are readily available. Many of the conclusions and recommendations in the report would be equally applicable to any starting population. The section explicitly analyzing the ZAA population's potential is to be read mainly as a guide to the kinds of analyses that will be required during program planning, and to the kinds of obstacles likely to be encountered in shaping any future advocacy population.

Finally, this documented is written with the expectation that institutions holding birds as part of an advocacy program, will be brought together under a single management plan. This is a long-lived species with complex social and behavioural needs. Meeting those needs, as well as the population-level demographic and genetic targets of the program, and the exhibit requirements of advocacy facilities, will be challenging. Success will be most likely where available resources are mobilized behind a single, well-designed, well-coordinated and well-supported program.

Aims

The Investigation Brief directing this study (see Appendix I) describes or implies a number of desirable characteristics for a captive population of kea in New Zealand. These have been developed into the following list of attributes which, together, describe a desired future state for a kea captive management program in New Zealand.

- *Delivers effective advocacy.*
- *Provides for a demographically robust population.*
- *Meets international standards of gene diversity retention and inbreeding management.*
- *Is managed so that required wild recruitment rates are achievable, sustainable, minimal and, as far as possible, from injured birds only.*
- *Is managed so as to eradicate any risk to wild populations, of Parrot Beak and Feather Disease (PBFD).*
- *Is maintained to the highest standards of husbandry with particular consideration given to group size and composition.*
- *Retains the capacity to shift to an insurance or breed to release role, should this be required.*

Not all of these attributes are addressed in this report as they require more extensive stakeholder consultation and the involvement of additional subject-matter experts. It is expected that these areas will be dealt with as part of the broader planning initiative.

Data and Models

General

In addition to the DOC Investigation Brief (see Appendix I), the following sources of information were used to develop the analyses and recommendations contained in this report. Should the advice or information in these documents or data sets change over time, the corresponding analyses and any recommendations arising from them, will require review.

Atwell, K. (2007) European Studbook Database for Kea, *Nestor notabilis*. 2008 ISIS Studbook Library CD-ROM. International Species Information System, MN.

Behrens, S. & Pullar, A. (2011) Australasian Studbook Database for Kea, Nestor notabilis. ISIS Studbook Library. International Species Information System, MN.

Bell, P. & McInnes, K. (2012) New Detections of Psittacine Beak and Feather Disease. DOC.

Collen, R. (2011) Review of captive management of kea (*Nestor notabilis*) – report on initial consultation with stakeholders. DOC.

Orr-Walker, T. (2010) Kea (*Nestor notabilis*) Husbandry Manual. Kea Conservation Trust.

ZAA (2006 – present) Kea Annual Report and Recommendations. Zoo and Aquarium Association internal reports.

SPARKS and PMx

Two programs were used to complete the analyses contained here: SPARKS (ISIS 2004a) and PMx (Ballou *et al*., 2011). SPARKS allows managers to record, analyse and export for further analysis, small population pedigree and demographic data. It exports in a format compatible with and designed for, PMx. PMx allows more detailed exploration of genetic and demographic information derived from studbook data and includes the ability to project forward certain population characteristics.

SPARKS is available from the International Species Information System (ISIS): www.isis.org and PMx is available from Dr. Robert Lacy's web-site: www.vortex9.org/**PMx**.html

Studbook data

For quantitative data relevant to population viability analyses, two sources of information are potentially relevant: the Australasian Regional Studbook for Kea (Behrens and Pullar, 2011) and the European Regional Studbook for Kea (Atwell, 2007).

An evaluation of these sources was carried out and is summarized in Table 1.

Table 1. Comparison of data quantity and quality in the Australasian and European studbook data sets.

	Australasian Studbook	European Studbook
Total specimen records	250.133.37 (420)	288.243.156 (687)
Records date back to:	1938	1932
Data current to:	24/11/2011	31/12/2007
% of all specimens with dam unknown	25%	15%
% of all specimens with sire unknown	28%	15%
% of all specimens captive hatched	70%	85%
Living specimens (excl. ltf)	40	139
% known pedigree for living specimens	70%	27%

The European data set is larger (N=687 versus N=420 for Australasia), but is also the least complete with respect to the pedigree of the living population (missing pedigree=73% versus 30% for Australasia).

As these were the only sources of captive data for kea available at time of writing, they have been used, with modification, for the analyses presented here, accompanied by the appropriate caveats and cautions. Treatment of the data for use in the models is described below.

Model input parameters

Age-specific Survivorship and Fecundity

Age-specific values for survivorship and fecundity are used in the models to predict growth and changes in age-structure over time. Age-specific survivorship is particularly important for setting required annual breeding rates.

Studbook data are used to create life-tables for these values. It is important, wherever possible, to filter the values incorporated so that the figures calculated are most likely to represent the future behavior of the population under management, rather than, for example, the results of historic husbandry practices.

Age-specific survivorship curves for the two regional populations (see Figure 1.) indicate higher mortality rates in Europe, especially in the earlier age-classes. Little can be gleaned from either data set about age-specific fecundity (see Figure 2).

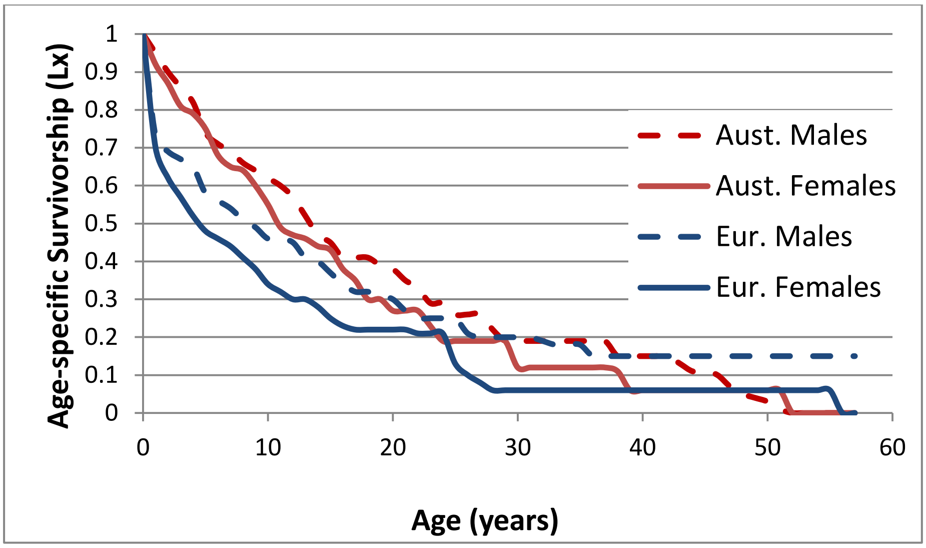

Figure 1. Age-specific survivorship in the Australasian and European captive kea populations.

The Australasian population has been subject to a breeding moratorium since the early 1990s and the European population has been under close management for at least two decades. The rates observed for both then are more likely to reflect captive circumstances than biological potential. This is likely to account for apparently early reproductive senescence in Europe (breeding for both sexes ends in the mid-twenties), and for generally low levels of reproduction in many of the age-classes.

The spikiness of the curves in both cases is indicative of small age-class sample sizes. This is a particular problem in the older age-classes, where breeding or the lack of it by one or two individuals can considerably exaggerate underlying trends. Smoothing routines can be used to dampen this effect but are statistical rather than biologically-based interpretations of the data and so must be applied with caution.

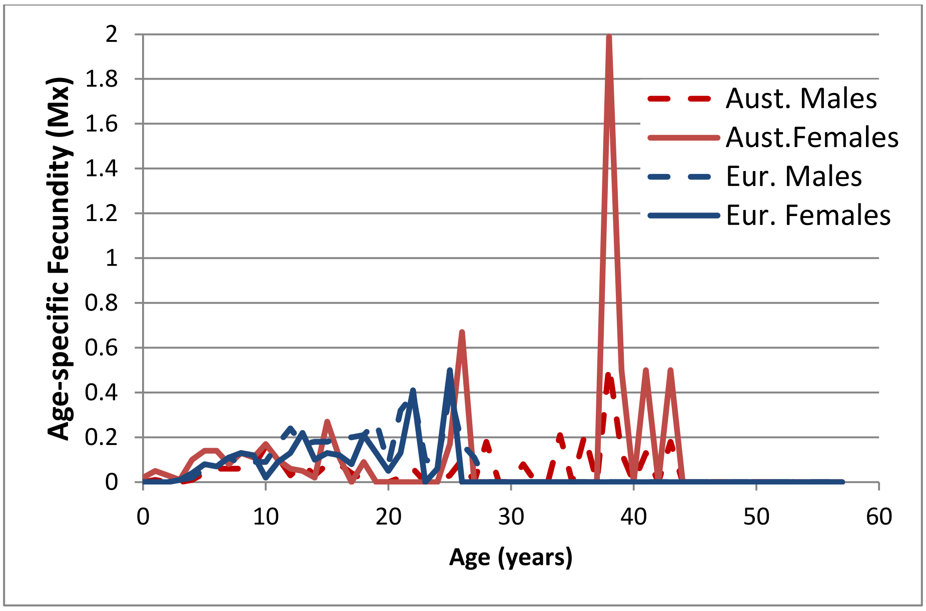

Figure 2. Age-specific fecundity in the Australasian and European captive kea populations.

Though the European data set carries larger sample sizes, the Australasian survivorship trends are likely to be a better predictor of what can be achieved in the New Zealand program. Similarly, though potential age-specific reproductive rates are likely to be underestimated in the Australasian data, the reproductive life-span is likely to be a more accurate representation of biological potential.

The Australasian demographic data were used for both age-specific survivorship and fecundity calculations in this study. Data were smoothed twice using the PMx smoothing routine, to dampen the distortions due to small sample size. Though the resulting curves are still relatively "spiky" they should be adequate for the purpose to which they are put here.

In line with reported observations (Orr-Walker, 2010), breeding rates for males and females were set to zero in the first three age-classes so that breeding begins at age three years for both sexes. Reflecting the studbook data collected to date, breeding is curtailed at 41 years for males and 43 years for females. Though it may go on for longer in both, only a small number of birds are expected to reach these age-classes and so in practice it makes little difference to model outcomes. Longevity is curtailed at 50 years for both sexes, though again, a small number of birds may exceed this.

The resulting curves are shown below:

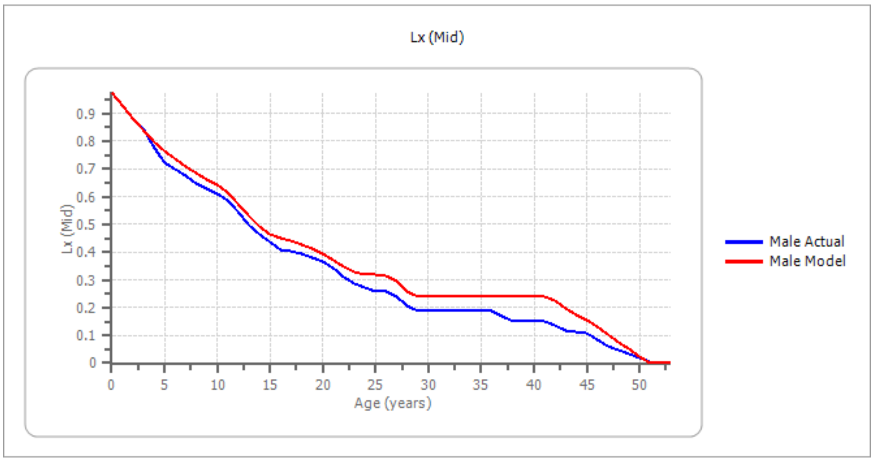

Figure 3. Age-specific survivorship data for male captive kea in Australasia.

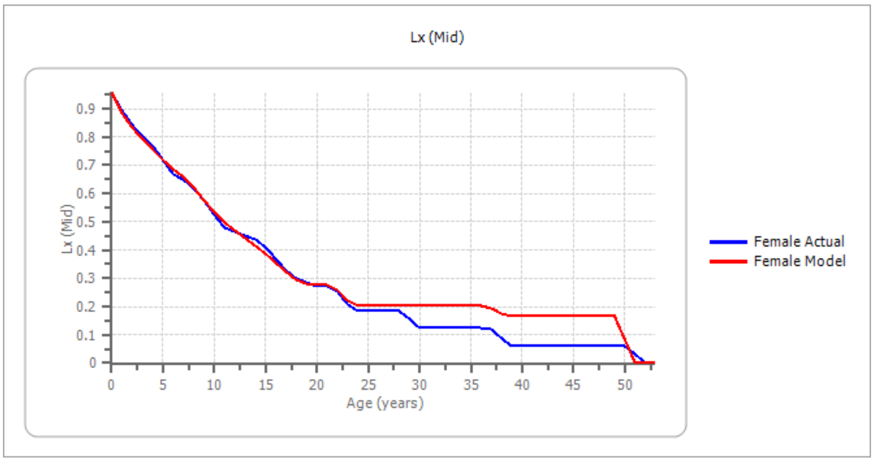

Figure 4. Age-specific survivorship data for female captive kea in Australasia.

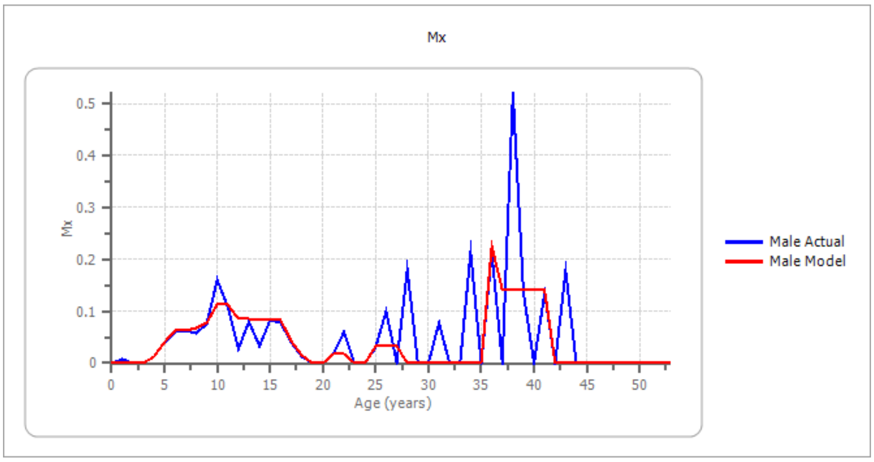

Figure 5. Age-specific fecundity data for male captive kea in Australasia.

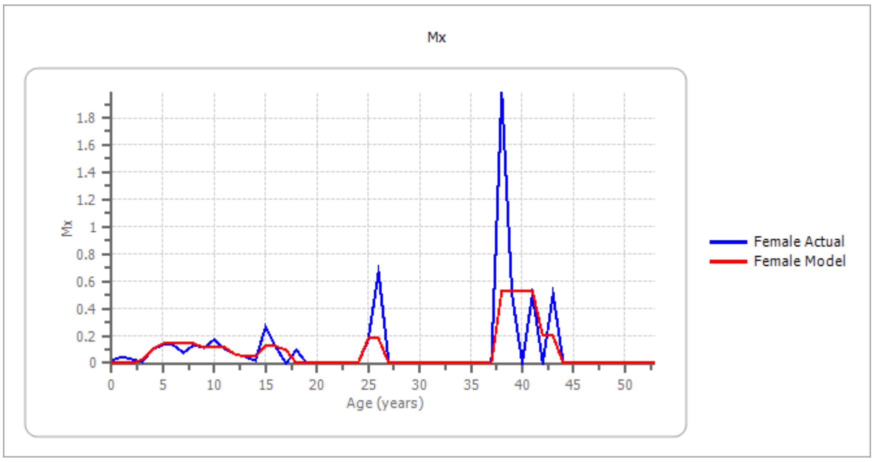

Figure 6. Age-specific fecundity data for female captive kea in Australasia.

Generation Length

Gene diversity is lost at each generation event. Therefore, during a given period of time, and all other things being equal, species with longer generation lengths will lose less gene diversity than those with shorter ones.

Generation length is defined here as the average age at breeding, so it is expected to fall somewhere within the peak breeding years for the species.

PMx calculates generation length using the age-specific reproductive data available from the studbook. The results for the Australasian population are as follows:

Table 2. Generation length in captive kea in Australasia

	Generation length (years)
Males:	19.5
Females:	15.8
Average:	17.7

Note that management practice may have obscured biological generation length in the data sets used and future management may shift it again. **The combined value of 17.7 years is used in the models.**

Growth Rate

The growth rate parameter required for the model is the maximum potential *lamda* or annual growth rate. Potential growth rates can be difficult to estimate for captive populations in which growth is often deliberately constrained and observed rates do not reflect what could be achieved.

Figure 7. shows the census figures for the Australasian kea population since 1932. As can be seen, the population grew quickly in the years prior to the breeding moratorium, which began in the early 1990s. Those early years should provide some insight into achievable annual growth rates, for use in the models.

[Note that the contraction to 40 individuals is not solely the result of attrition post breeding moratorium. It includes the exclusion, from the current studbook data, of a number of birds which are still alive in captive facilities but which are not part of the population currently managed through ZAA].

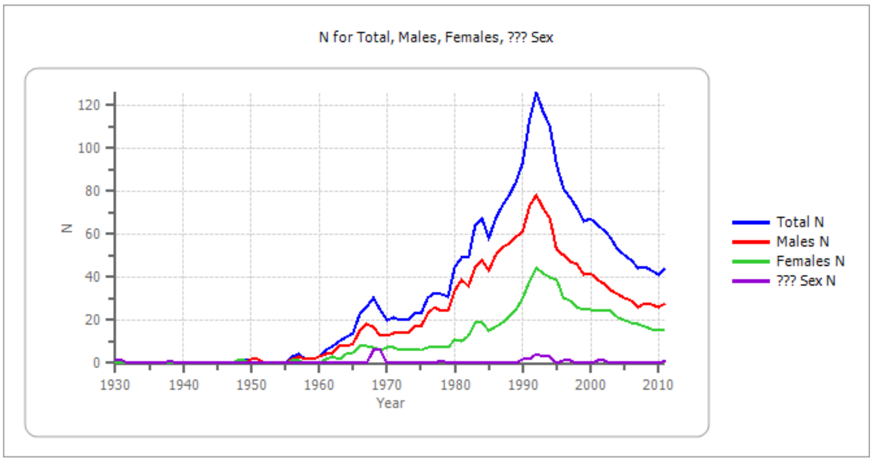

Figure 7. Population census for the Australasian captive kea population.

The period between 1975 and 1991 was selected for further analysis. This was a period of roughly continuous growth. PMx was used to separate the growth attributable solely to reproduction from that achieved through other means (e.g. recruitment from the wild or from another external source). The results are shown in Figure 8.

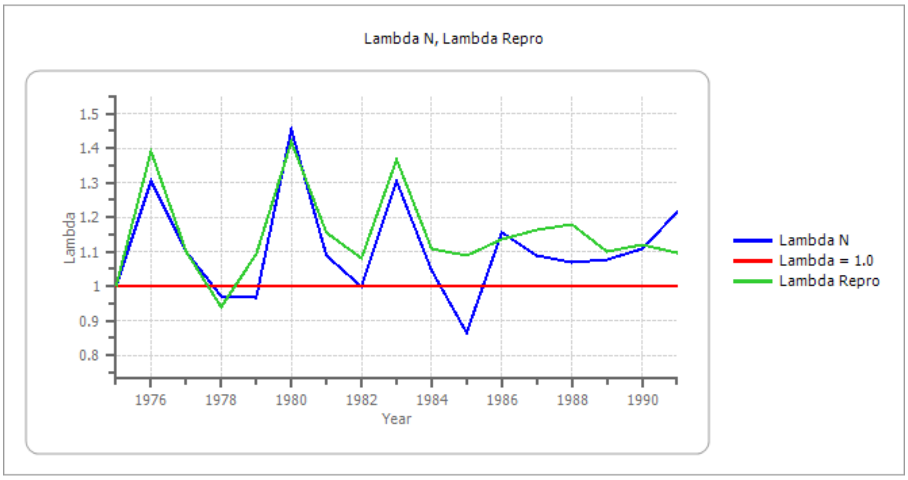

Figure 8. Annual growth rate (λ) for Australasian captive kea , showing total growth (Lamda N) against growth due to reproduction alone (Lamda Repro) and showing the line of zero growth (Lamda=1.0)

The analysis shows that most of the growth in this period was attributable to captive breeding and suggests that a breeding rate of around 10% per year should be achievable on an ongoing basis. **A value of λ = 1.10 is applied in the model.**

Current Population Size

The models require the input of a starting population size. This cannot be known at this point and so various options are modelled.

It is likely that some or all of the individuals in the currently managed population of around 40 birds, will be used as a basis for future management. At the very least these birds will need to be housed at the outset of the program. **Therefore, 40 is set as the smallest starting population size.**

In various places, starting population sizes of 70, 150 and 250 are also modelled, representing the span between the current population size and the largest population size held just prior to the breeding moratorium.

Ratio of Effective Population Size to Actual Size (Ne/N)

The genetically effective size of a population is a measure of how efficiently that population retains gene diversity over time. For populations of fixed size, effective to actual size ratio is key to gene diversity retention over time. In captive populations, Ne/N ratios of 0.2 - 0.4 are common (Mace, 1986). For wild populations, to the extent known, the value may be as little as 0.10 (Frankham, 1995c). Populations that show high levels of conformity to the characteristics of an idealised population (constant size, random breeding, equal sex-ratio, roughly equal life-time family sizes) have larger Ne/N ratios and management interventions in captivity are often aimed at enhancing this conformity.

The genetically effective size of the Australasian captive kea population was calculated in PMx to be 3.11, based on the number of males and females in the population that have bred, using this equation:

$$\mathbf{Ne = 4(Nfemales*Nmales)/(Nfemales + Nmales)}$$

PMx calculated the Ne/N ratio as 0.182 by dividing this calculated effective size by the total number of living descendants traceable to founders (N=17).

The potential Ne/N ratio may be larger, as the breeding moratorium may have reduced the number of breeders that would otherwise be in the population. The amount of missing pedigree may also have distorted this value, though this could result in both under- and over-estimation. For the models, a precautionary approach is taken of applying **a value of Ne/N= 0.2.** This is slightly higher than the calculated value but still at the bottom end of the values expected for managed captive populations. This should be readily achievable (though the ability to evaluate this will rely on improvements in the quality of pedigree records).

Current Gene Diversity

PMx calculates the amount of wild source gene diversity expected to have been retained in a captive population from the portion of the population's pedigree traceable to founders. Gene diversity figures calculated for captive kea then, will not reflect the whole population, only a portion of it and could over- or underestimate the "real" values.

However, as these are the only data available at time of writing they are applied in the model and should be sufficient to generate broad values for the parameters required.

The population includes nine potential founders which have not yet produced offspring. It is possible that they will not. Excluding them from the calculations sets gene diversity at 87.63%. Including them increases **gene diversity to 94.43%.** The latter is used for analyses as it leaves open the opportunity to test scenarios for retaining 90% gene diversity in which no new founders are added but where genetic retention is instead manipulated by incremental increases in, for example, carrying capacity.

Carrying Capacity (K)

Carrying capacity(K), or maximum population size, is critical to gene diversity retention. As population size increases so does effective population size (assuming the same regime of management can be maintained).

Capacity values of 40, 70, 150 and 250 were modelled, to emulate the range between current managed population size and the largest size achieved prior to the breeding moratorium.

Model Results

Target size and founder acquisition strategy

The goal-setting facility in PMx was used to establish the basic requirements for a genetically healthy population, in terms of population size and founder acquisition strategy. Table 3. shows the baseline input parameters and the range of alternative management scenarios considered.

Two goals were considered:

1) **Retention of 90% gene diversity at 40 years.**
2) **Retention of 90% gene diversity at 100 years.**

Table 3. Input parameters for the PMx goal analysis

Input parameter	Baseline	Other scenarios
Generation length	17.7 years	-
Maximum potential lambda	1.10	-
Current N	40	-
Ne/N	0.2	0.2, 0.3, 0.4
Current gene diversity	94.42%	-
Maximum N (carrying capacity)	40	70, 150, 250
Founders added year 1	0	0 - 40
Ongoing supplementation rate (from year 1)	No supplementation	1 every 1 – 20 years
Founder Genome Equivalents captured per founder	0.4 (PMx default)	-

Each of the parameters was varied in turn and the results are shown in the following tables:

Table 4. Varying carrying capacity

K Value	GD at 40 years	GD at 100 years	90% retained for:
40	81.6%	65.6%	13 years
70	86.5%	76.5%	20 years
150	89.5%	84.5%	33 years
250	90.3%	87.2%	45 years

With baseline population parameters and no further supplementation from the wild, the population cannot meet 40 year genetic targets without constant and significant growth (to a population size of at least 250). **[Note that this assumes that the potential founders in the population that have not yet bred, can be mobilised].**

Table 5. Adding founders in year 1 only (only scenarios successful in at least one case are shown)

Number added in year 1	**GD at 40 years**				**GD at 100 years**			
K	***40***	***70***	***150***	***250***	***40***	***70***	***150***	***250***
0	81.6%	86.5%	89.5%	**90.3%**	65.6%	76.5%	84.5%	87.2%
2	82.1%	87.1%	**90.1%**	**90.9%**	65.9%	77.0%	85.1%	87.8%
15	84.8%	**90.1%**	**93.7**	**94.7**	68.1%	79.7%	88.5%	**91.6%**
40	85.0%	**91.3%**	**95.2%**	**96.4%**	68.3%	80.7%	89.9%	**93.2%**

With baseline population parameters and K=40, 90% gene diversity cannot be retained for 40 years through the sole strategy of importing additional founders at year 1. At least 15 additional founders would be required in year 1, to meet targets at K=70. This assumes that this number of birds could be successfully integrated and propagated within the available carrying capacity, which may not be a feasible proposition. Only a population size of 250, under the supplementation regimes modelled, was able to meet targets for 100 years, and was able to meet 40 year targets with no further supplementation, though again this relies on remaining gene diversity within the population being fully mobilised, which may not be possible.

Table 6. Periodic supplementation with founders

K=40	**GD at 40 yrs**	**90% retained for**	**GD at 100 yrs**	**90% retained for**
1 per 3 years	89.1%	27 years	88.5%	27 years
1 per 2 years	**91.1%**	>40 years	**90.9%**	>100 years
1 per year	**93.3%**	>40 years	**93.3%**	>100 years
K=70	**GD at 40 yrs**	**90% retained for**	**GD at 100 yrs**	**90% retained for**
1 per 7 years	89.7%	34 years	88.3%	34 years
1 per 6 years	**90.1%**	>40 years	88.6%	43 years
1 per 4 years	**91.0%**	>40 years	**90.3%**	>100 years
K=150	**GD at 40 yrs**	**90% retained for**	**GD at 100 yrs**	**90% retained for**
1 per 20 years	**90.3%**	>40 years	87.0%	51 years
1 per 15 years	**90.9%**	>40 years	89.0%	58 years
1 per 10 years	**91.2%**	>40 years	**90.0%**	>100 years
K=250	**GD at 40 yrs**	**90% retained for**	**GD at 100 yrs**	**90% retained for**
1 per 20 years	**91.1%**	>40 years	**90%**	100 years

As shown, to retain 90% gene diversity for 40 years, starting with a current population of 40 individuals and carrying 94.42% wild source gene diversity, requires the assimilation of approximately one additional founder every 2 years. This rate will also meet targets over the 100 year time-span. Approximately one founder every 4 years is required to meet targets at both 40 and 100 years, for K=70. This is reduced to one in 10 years and to 1 in 20 years, for K=150 and K=250 respectively.

Table 7. Increasing Ne/N ratio for K=70
To illustrate the impact of increasing Ne/N ratio, ratios were varied from 0.2 – 0.4 for K=70 only. All other baseline values were left unchanged.

	GD at 40 years	90% retained for	GD at 100 years	90% retained for
Ne/N = 0.2	86.5%	20 years	76.5%	20 years
Ne/N = 0.3	89.1%	32 years	82.1%	32 years
Ne/N = 0.4	**90.4%**	44 years	85.1%	44 years

As shown, increasing Ne/N ratio through appropriate management intervention can considerably improve genetic performance over the time-frames considered.

Annual breeding rates

Required annual breeding rates to grow, sustain or reduce population size, can be calculated using the PMx software. The rates take account of the current age-structure, and the age-specific mortality rates calculated from studbook data an edited as described under *Model input parameters.*

Required annual breeding rates were calculated for maintaining population sizes at 40, 70, 150 and 250 and are shown in Table 8. The birth rates calculated are predicated on the number of animals expected to die in each age-class, during the year, according to the age-specific mortality rates provided. These rates are average figures and are expected to vary stochastically (through chance), such that some years may see unexpectedly high or low rates. The magnitude of likely distortion of required breeding rates due to chance is a function of population size and can be calculated. The ranges calculated by PMx, for the first year only, are shown in Table 8. As can be seen, chance can have a significant impact on population dynamics in populations of these sizes.

Table 8. Annual breeding rate required to sustain populations of various sizes.

Target size	Annual breeding rate (average)	Stochastic range for year 1
40	1 – 3 hatchlings	0.0 - 5.6
70	3 - 5 hatchlings	0.7 – 8.6
150	6 – 11 hatchlings	4.2 – 15.7
250	11 - 18	9.0 – 24.0

If the population is set to grow, higher birth rates will be required during the growth phase and these can be calculated as needed. The number of births required will need to be discounted by the number of new birds acquired from other sources.

Discussion and recommendations

The results show that the targets of retaining 90% gene diversity for 40 and 100 years can be met through various combinations of population size, founding strategy, effective population size and other management interventions.

The strategy that is the best fit for the proposed kea program will depend to a large extent on the resources available. Population sizes of 150 and 250 require particularly low rates of founder supplementation, but it may be difficult to access sufficient, high quality care for such a large population. Population sizes of 40 and 70 may be a better fit for the available volume of high quality captive space in New Zealand, but would require higher rates of supplementation from the wild.

From a demographic perspective, larger populations are more stable and more predictable, than smaller ones. A population of only 40 birds is likely, at any one time, to comprise approximately 10 pre-reproductive individuals, 5 or so post-reproductive and 5 or more “surplus” as a result of sex-ratio skews or the presence of mal-adapted individuals (pers. obs.). This leaves a breeding pool of perhaps 10 pairs at any one time; a relatively small and vulnerable resource. A captive population of at least 70 presents a more robust prospect, though only in the context of periodic supplementation from the wild.

A further consideration is the behavioural needs of the species. The husbandry manual (Orr-Walker, 2010) recommends that juvenile birds be raised with a group of similar-aged conspecifics. Table 8. indicates that annual breeding rates in a population capped at 40 might be too low to allow for this, and that even in a population of 70 it may at times be difficult to balance the need to avoid surplus production, with the need to produce well-socialised birds.

On the basis of all of these considerations, **a population size of at least 70 birds is recommended.**

A population of 70 birds is expected to require around 3-5 hatchlings each year to maintain its size, and approximately 1 founder every 4 – 6 years to meet gene diversity targets over 100 and 40 years respectively. In practice this rate might be more usefully delivered through fewer, larger recruitment events.

Though for demographic reasons care should be taken in reducing the target population size to anything lower than 70 (and a larger size would be preferable if standards can be met) the rate of wild recruitment could be further reduced through management interventions which successfully increase Ne/N ratio and/or increase generation time.

Biological and Behavioural Considerations

Background

Population-level management is more likely to succeed, and to be sustained, where it works with and not against, the species' biology. As far as is reasonable then, the design of captive programs should support seasonal and throughout-life shifts in individual and group behaviour and biology.

Guidance on the husbandry and management aspects of program design have been taken from the husbandry manual (Orr-Walker, 2010). As husbandry knowledge advances, aspects of program design should be reviewed.

At present, the husbandry manual advises:

- Mixed-sex groups with either an equal sex-ratio or a male bias, are considered ideal.
- Single-sex female groups are not the preferred social grouping and should be closely monitored and managed until it can be demonstrated that such situations do not cause unnecessary stress.
- Single-sex male groupings are considered appropriate.
- Juveniles are to be moved out of the natal group before the following breeding season and housed with similar-aged conspecifics.
- Pair bonds are to be left intact where possible
- Introductions to potential mates and to group situations can be problematic and should follow the protocols provided.

Information included in the husbandry manual suggests that a typical year for wild kea involves a period (roughly January to July) where birds aggregate as large flocks (13-20 birds), of mixed-sex, which break up into smaller flocks of 6-8 in autumn (August to September). These smaller groups further separate into pairs or groups of three, during October – December, coinciding with the peak egg-laying period (laying begins in July but can extend into January). Large flocks are re-constituted by January-February.

This annual "cycle" should provide insights into the best time to introduce potential mates to maximise chances of success, for creating flocks, and for introducing new birds (such as 3-4 year-olds) to existing flocks. Manipulating these dynamics will be key to a successful program.

Alongside this annual cycle are the throughout-life needs of individual birds, which require that young remain with their parents for the first 4-5 months, are then removed to a creching aviary where they need to be housed with conspecifics for the next 3-4 years, after which they are paired and/or integrated into flocks or other appropriate social groups.

Discussion and recommendations

Program design should support seasonal and throughout-life needs, but must also accommodate the additional requirements of the captive program to:

- **Breed only at the rate required to maintain the population at target size;** this will require that only a fraction of the available breeding pairs are mobilised for breeding in any one year.
- **Prioritise breeding from genetically optimal pairs;** to maximize gene diversity and manage inbreeding rates.
- **Track parentage of every bird;** by closely monitoring and controlling all breeding events and, where necessary, DNA testing to confirm parentage.
- **Provide long-range advice on infrastructure requirements;** to help participants to plan their involvement in the program.

Suggested scheme

To provide a framework for discussion, the following broad scheme is suggested as a starting point for planning. The scheme is based on:

A population of 70 birds containing: 15-20 juveniles; 50-55 adult birds; approximately 3 – 5 hatchlings bred each year (due to stochastic events the range could be larger in practice); at least 8-10 breeding/holding institutions.

It assumes that all holding institutions participating in the program will manage their birds and facilities towards a single set of agreed goals, sharing facilities and moving and managing birds as required by the program, to ensure that, as far as is possible, the demographic and genetic goals of the program are met, the biological and behavioural needs of the species are met, and the exhibit requirements of the advocacy facilities are met.

The suggested scheme would work as follows:

1. **Post breeding season:** adult birds are maintained as mixed-sex flocks of around 4 - 8 birds.
2. **Towards breeding season:** recommended pairs are separated from the flock and transferred to breeding enclosures (unless breeding can be closely controlled within the flocking aviary).
3. **Pairs are, in general, allowed to rear only a single chick**: though this will be determined, annually by the Species Coordinator. Initially the focus is likely to be on correcting founder skew, such that genetically valuable birds maybe required to rear more than this.
4. **Non-recommended pairs**: have their eggs replaced with dummy eggs as the preferred method of contraception.
5. **Hatchlings:** spend the first 4-5 months with their parents in the breeding aviary, after which they are sent to a creching aviary to be with other, similar aged birds until aged 3-4 years.
6. **Parents:** are reintegrated into the flock according to introduction protocols.

7. **Sub-adults (aged 3-4 years):** are either encouraged to bond with a suitable mate and integrated into a suitable flock OR are housed in an appropriate social group until breeding (and therefore pairing) is required.

Supporting infrastructure requirements

In terms of supporting infrastructure, this scheme requires:

- that each flocking aviary has **at least one associated breeding aviary.**
- that the program has **at least three or four creching aviaries** associated with it, each to accommodate a year's cohort of juveniles on a three or four-year rotation. This is necessary because once the program is operational, no one institution would be expected to breed enough offspring in a single year to allow for the housing of multiple juveniles. If multiple cohorts can be successfully introduced and housed together, the number of "national" creching aviaries can be reduced.
- that the program has access to **additional accommodation** able to accommodate birds that are unable to be integrated into an existing mixed-sex flock, for whatever reason.

Note that this is provided as a starting framework, and as a potential long-range plan only. Its purpose is to provide a basis for discussion with facility managers and husbandry experts, who will be able to bring greater depth of kea management experience as well as knowledge of currently and potentially available facilities and resources, to the design of the program.

Further research

Listed below are outstanding husbandry questions relevant to demographic and genetic management, the answers to which will greatly facilitate the successful management of kea at population level:

1. To what extent can pair bonding be manipulated and what is/are the most appropriate methods of manipulation? That is, to what extent can the "attractiveness" of one bird to another be controlled?
2. Is there an appropriate time of year or set of conditions in which breaking and re-forming pairs can be done without excessive stress caused to the birds involved?
3. Can multiple juvenile cohorts be introduced to each other and subsequently housed together? And if so, under what conditions?
4. To what extent can first breeding be delayed, and for how long can breeding be prevented, before damage is done to the future breeding/rearing potential of birds?

Current Population Potential

The following section assesses the potential of the current ZAA-managed kea population (as of December 2011) to provide a base for a future advocacy population. It provides general insight into the strengths and weaknesses of the current population and of measures that might be taken to address the latter. It should be noted that there are other captive birds in New Zealand; this subset was used because it is the group of birds for which data were most complete and most readily available. Many of the issues raised here would be equally applicable to a different subset of captive birds.

The living population registered in the Australasian Kea Studbook (Behrens & Pullar, 2011) shows 8 founders (i.e. wild-caught birds that have contributed offspring to the current population), two of which are still alive. In addition the population includes 9 potential founders - wild-caught birds that do not have offspring in the living population. It is possible that they will not. Analyses were run with and without the contributions of these founders and are summarised in Table 9. Note that these analyses are only able to incorporate the known portion of the genome (70%) but are the best data available at time of writing.

Table 9. Genetic attributes of the current, managed captive population of kea in Australasia analysed both with and without, potential founders.

Attribute	Potential founders included	Potential founders excluded
Founders	17	8
Living Animals	40	40
Living Descendants (i.e. sum of known portions of the genome)	28	17
% Ancestry Known	70%	70%
Gene Diversity	94.42%	87.63%
Founder Genome Equivalents	8.96	4.04
Mean Inbreeding	0.00	0.00
Average Mean Kinship	0.0558	0.1237

As can be seen in Table 9., with potential founders included, the population shows relatively high gene diversity retention (94.42%), no inbreeding (mean inbreeding = 0.00; range = 0.00) and a low average mean kinship coefficient (Average MK = 0.0558). Without potential founders, the population begins below the advocated gene diversity target (at 87.63% gene diversity) and, although there is no current inbreeding in the population, the average mean kinship value, which provides an indication of the average level of inbreeding expected in the next generation under random breeding, is close to the recommended maximum threshold of 0.125 (current average MK = 0.1237). This is a relatively young population, carrying mostly wild-caught (9 out of 40) and F1 generation (19 out of 40) individuals. If the remaining potential founders can be encouraged to breed, the population could form a reasonable basis for a long-term managed population; if not, it will require some short-term management intervention to shape it into a useful resource including, though not limited to, the recruitment of additional founders.

There are a number of additional aspects to this population which may prevent it from achieving its apparent potential and these are considered below.

Founder sex-ratio skew

All but one of the living founders that have not yet bred, are male (see Figure 9). Ideally, these highly valuable individuals would be paired with each other, rather than with individuals from existing, well-represented lineages.

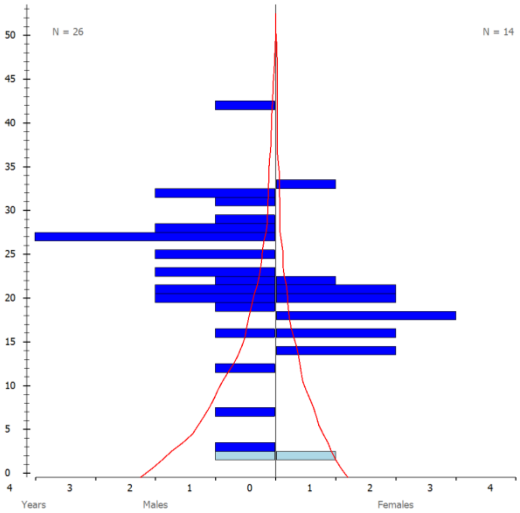

Figure 9. Age pyramid depicting the managed population of captive kea (as of 24/11/2011). Pale blue indicates juveniles.

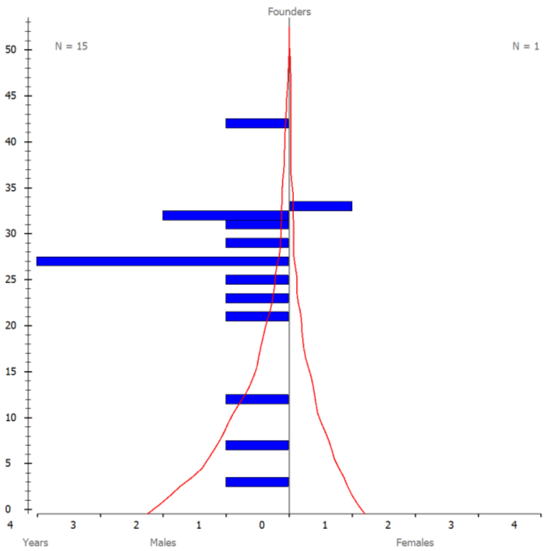

Figure 10. Age pyramid depicting living founders within the managed population of captive kea (as of 24/11/2011)

This is done to prevent the inextricable linking of over- and under-represented genetic lines which would prevent the population from achieving its potential. Further recruitment from the wild would be the ideal way of addressing this from a genetic perspective.

Founder representation skew

Genetic management aims to maintain the representation of founders in the descendent population at parity. Founder lines # 123 and # 124 have been particularly prolific in this population, at the expense of other lines and this is illustrated in Figure 11. Moving founder representation back towards parity (corrected for any irreversible loss of gene diversity from individual founders as a result of pedigree bottlenecks), through a combination of management by mean kinship (wherein individuals with low and similar mean kinship values are preferentially paired), combined with the retirement of some individuals from the breeding pool, could improve gene diversity. However, this may prove extremely difficult given the current sex-ratio skew in the most valuable animals (potential founders). This may be further exacerbated by differences in reproductive competence between remaining individuals in the breeding pool, though this is not known at time of writing.

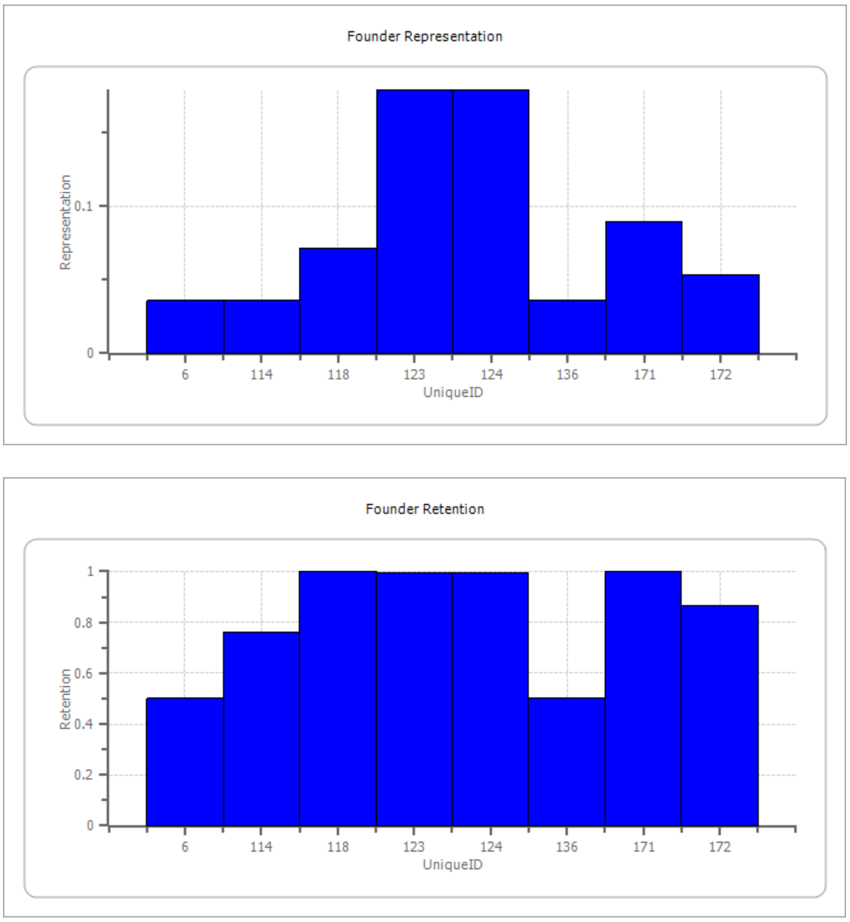

Figure 11. Comparison of founder representation and founder retention. Ideally representation would follow the pattern of retention. It does not in this case as a result of some lines multiplying at the expense of others.

Poor juvenile survival rates post breeding moratorium.

[The following analysis was provided by S. barlow, Kiwi Captive Coordinator, using studbook data (Behrens & Pullar, 2011 and ZAA Annual Reports and Recommendations]

A review of breeding in the population since 2006 shows that five pairs have been recommended to breed. Of these, two pairs were reformed (with different mates) during the period. Although breeding was reported, the success of these pairings in terms of rearing offspring (or offspring reaching breeding age) was minimal. There is no record of the numbers of eggs produced (rather of chicks hatched and their fate), and chick survival was low. Of 13 chicks recorded as hatched, only two are known to be still alive, with two recorded as lost-to-follow-up. It is possible that following the prolonged breeding hiatus (as a result of the moratorium) it will take a few breeding seasons for kea pairs to begin reliably rearing their offspring. Some pairs appear to have taken a year or so of practice to successfully rear (e.g. eggs laid but offspring not reared, or offspring died in the first year recommended to breed after the long break).

The following table of data taken from the Australasian SPARKS dataset shows the results of the limited breeding recommended since 2006. These data should be treated with caution given the small sample size.

Table 10. Kea chicks hatched in the Australasian captive population (and their fate) from Behrens & Pullar, 2011)

Studbook ID	Sex	Hatch date	Sire	Dam	Comment
326	M	22 Oct 2006	107	86	Lost to follow up
327	F	22 Oct 2006	107	86	Lost to follow up
328	unk	22 Oct 2006	107	86	Died same day
336	unk	22 Oct 2006	107	86	Died same day
325	F	25 Sep 2007	249	317	Died at 2 yr 7 mths
329	M	15 Sep 2008	288	296	Died at 12 days
332	unk	17 Oct 2008	249	317	Died same day
333	unk	17 Oct 2008	249	317	Died same day
330	M	30 Oct 2008	100	312	Died at 1 yr 7 mths
331	M	1 Nov 2008	100	312	Died at 10 mths
337	M	13 Aug 2009	288	297	Alive
338	F	13 Aug 2009	288	297	Alive
421	unk	7 Oct 2011	100	312	Died at 4 mth
Total	**5.3.5 (13) hatches**; 2 alive; 2 lost to follow up; 4 died same day as hatch; 5 died before they reached 3 years old (e.g. breeding age).				

The model demographic data (from historic kea datasets) shows 5% mortality in the 0-1 year age-class, with 14% of the male offspring and 20% of female offspring dying before they reach 3 years of age (breeding age). Given the recent reproductive history of the NZ captive kea population (since 2006) it is unlikely that the modelled level of breeding success could be immediately achieved. This would be expected to improve over time, but should be a consideration when setting short-term breeding targets.

This analysis highlights the value of producing accurate "Annual Report and Recommendations" documents and of reviewing data annually, so that breeding rates may be adjusted where needed.

Discussion and recommendations

Due to the demographic and genetic challenges of this current population of 40, the following actions are likely to be required, to shape it into a healthy base for a long-term advocacy program:

Auditing population potential

The analyses in this document are based solely on studbook data. They do not take account of the physiological and behavioural idiosyncrasies of individual birds. If not already known, an audit should be carried out of the breeding potential of all birds in the population, and of those currently sitting outside it where these are candidates for inclusion, and the analysis of demographic potential revisited in that light.

In particular, the higher than expected mortality in births that have taken place in recent years should be investigated, in case this warrants temporary modification of the age-specific mortality rates that underpin annual breeding rate calculations. If recent experiences are indicative of a current trend then current life-tables will underestimate the annual birth rate required to sustain the population. This situation should be monitored and managed in an ongoing way.

Optimising genetic composition

At present there is an unfortunate sex-ratio skew towards males, in potential founders. If not addressed, this will require that they be paired with less valuable females, resulting in the linking of under- with over-represented founder lines – a situation which can be difficult and often impossible to address in later generations. Ideally, founder composition would be re-configured using a combination of:

- additional female founder recruitment so that founder males can be paired with founder females
- preferential pairing of individuals with low and similar mean kinship values
- the strategic retirement of some individuals from the breeding pool, to reduce the level of representation of some of the more prolific founder lines, to move founder representation closer to parity.

The best time to attempt to accomplish this reconfiguring of genetic composition is during a growth phase when some space can be provided to allow prolific breeding from under-represented lines and, where necessary, to incorporate new founder lines.

Stabilising demography

The current population of 40 birds is smaller than normally recommended for demographic stability and growth to at least 70 is recommended in previous sections. Should growth be pursued it will be important to set appropriate annual birth rates aimed at accommodating expected mortality in the population and also the intended growth towards target population size. Any wild recruitment should avoid the acquisition of large numbers of same-aged birds, which could cause significant fluctuations in captive population size downstream. Note that the total number of hatches required each year will need to be discounted by the number of founders to be acquired that year, should recruitment be part of the strategy.

Ongoing management

Breeding rates should be set each year to take account of the conditions on the ground at the time, though estimates for several years ahead can be projected to assist forward planning. On an ongoing basis, individuals with low and similar mean kinship coefficients should be prioritised for pairing and pair selection should keep offspring inbreeding coefficients below 0.125. This can be facilited through PMx and is standard practice for regional programs such as that operated through the Zoo and Aquarium Association (ZAA).

Other Considerations

Delivering effective advocacy

The delivery of effective advocacy will be informed by:

- An understanding of the advocacy messages important to kea conservation and management and of where those messages need to be delivered.
- An understanding of the target audience and its access to captive facilities.
- An evidence-based theory of change (where behavioural change is the aim).
- A professional approach to the content and delivery of advocacy messages.
- Baseline and subsequent regular assessments, of advocacy impact.

These aspects are beyond the scope of this study but would ideally be centrally coordinated as part of the captive program so that materials, methods and experiences can be shared.

Wild recruitment from injured birds

At the population sizes likely to be sustainable within New Zealand, occasional recruitment of wild founders will be necessary to maintain genetic health. Injured keas are periodically available to captive collections and at first sight this would seem like the ideal avenue of recruitment. However, "recruitment" in the context of the managed program requires the successful integration into the population of a bird which:

- after appropriate screening is considered to pose no health or disease risk to the existing population;
- is physically and physiologically capable of breeding;
- is of the right age and sex for successful pairing with genetically suitable singletons.

Injured birds will not necessarily meet these criteria.

The acquisition of wild birds as part of a long-term supplementation strategy will require further discussion to ensure that all the relevant issues are considered thoroughly. A review of the subsequent breeding success (or assessed breeding competence) of previously acquired rehab birds would assist discussions.

Parrot Beak and Feather Disease

The Investigation Brief requires that program design take into account the need to eradicate any risk to wild populations, of Parrot Beak and Feather Disease (PBFD).

There is currently a national ban on translocations of parrots from areas with known PBFD exposure to areas of unknown PBFD status (Bell & McInnes, 2012). At present this is not explicitly extended to captive parrots, though this may change in future.

At present then, any captive population would not need to consider the implications of sub-division, which would require careful planning to ensure viability.

This situation should be monitored carefully and, in the meantime, collections should aim to maintain PBFD-free status through appropriate screening and quarantine (Jackson, pers. comm.)

Shifting to an insurance or breed to release role

The Investigation Brief refers to the possibility that an advocacy program could be required to change its purpose to insurance or breed for release, should observed population declines in wild kea populations continue.

Provided that the advocacy program is managed to retain at least 90% gene diversity, to maximize its genetically effective size, and to sustain its numbers primarily through breeding, it will be in a good position to shift to an insurance or breed for release role as needed. The only change likely to be required, depending on circumstances in the wild, is an increase in population size to compensate for reduced access to new founders and/or to facilitate a regular harvest for release.

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Appendix 1 – Investigation Brief

Investigation Brief: Defining the parameters for a sustainable advocacy based Captive population of kea (*Nestor notabilis*)

1. INTRODUCTION

The Department of Conservation has embarked on a process to engage with the holders of captive kea to establish on what basis the future of any captive kea population in New Zealand should be established. The reasons for doing this are covered in a recent report commissioned by the Department[1]. The policy and social implications of maintaining a captive kea population are covered in this report. What is missing is an analysis of the technical parameters that must be considered in developing a future for a captive kea population. Modeling options of a potential captive population is one method to identify the practicalities of how to structure a population so that it is sustainable and can meet husbandry standards and policy expectations of the Department of Conservation.

There is no justification for a captive population for direct conservation purposes (eg breed for release or as an insurance population). The reason for having a captive kea population currently relates to advocacy and education. The captive population needs to be managed to reflect this policy direction although on-going wild declines may change the priority in the future.

2. BACKGROUND

There currently exists an up to date stud book for the captive population. In 1991 a PVA exercise was completed for wild and captive kea. The PVA was based on the premise that the captive population would contribute directly to the conservation of kea in the wild. The PVA report made the following recommendations for captive kea:

> **"2.5.3. Recommendations for Management of Captive Population:**
> 1. Establish a captive population to protect against catastrophic loss of the species.
> Comments
> Results of the PVA Workshop indicate in accordance with IUCN Policy a captive population needs to be established.
> A nuclear Captive Population of up to 60 needs to be established to provide for the retention of more than 90% Heterzygosity over a 200 year period.
> (a) Rationalise the existing and reduce numbers to a nucleus of 60 birds.
> (b) 204 captive spaces currently available sufficient to accommodate programme target."

[1] Review of captive management of kea (*Nestor notabilis*) – report on initial consultation with stakeholders July 2011. Rose Collen Contractor to DOC Otago Conservancy 14 September 2011.

Since the 1991 workshop Departmental policy has evolved to require more clarity about the overall purpose of captive management programmes. In terms of the Captive Management Policy captive kea support advocacy goals not direct conservation outcomes. The potential for a "captive breeding for release" programme has been discussed with scientists undertaking kea research in the Department of Conservation. The consensus view is that based on current information there is not a role for captive bred kea in supporting the management of wild populations (i.e. breeding for release), for the following reasons:

- There is little point in releasing captive-bred kea into areas where the threats to kea still exist; and releasing captive-bred kea does not address the issue of females then being killed by predators when they come of nesting age.
- In areas under intensive predator control, many more chicks can be raised in-situ per year than the captive population could produce for release (Josh Kemp *pers. comm.*), unless the captive population was very large. Efforts are better directed towards predator control at suitable sites in the wild rather than releasing captive-bred birds.
- Currently kea are still found throughout their habitat range, so there is not yet a need to introduce new populations into new areas.

An implication of this emphasis on advocacy is that an advocacy population will probably not be as large as it would if it were an insurance population. Another implication is that any advocacy population needs to be self-sustaining long term so that there is not a constant demand to get more birds from the wild to prevent in-breeding.

3. OUTCOMES

The overall outcome is to develop a robust picture of what a future captive population will look like in 2110.

The following parameters are to be considered:

- Heterzygosity > 90%
- Proportion able to either be used for captive breeding: 90%
- Expected longevity in captivity 35-50 years
- Mean kinship to be managed at 0.125 or below
- Rate of wild recruitment through rehabilitation after injury to the captive population: to be modeled at the following rates 1 individual per year up to 5 per year (either sex).
- "Parrot Beak and Feather Disease" can be managed so that potential spread of this virus into native wild populations of parrots is eliminated.
- The appropriateness of either:
    - Focus on breeding for the population from wild caught birds or

- Focus on breeding from carefully selected pairs to sustain maximum genetic diversity within the captive population

3. OBJECTIVES

The objective of this work is to:

3.1. Model the parameters in Section 2 to confirm that they are achievable.

3.2. Define the necessary size of a captive population to maintain:

- genetic diversity over a period of 40 years (one life cycle)
- appropriate frequency of breeding to maintain this population
- sensitivity analysis of assumptions relating to rate of wild recruitment
- Identify whether such a population can be maintained without further introductions from the wild or if not what supplementary introductions from the wild in terms of size and frequency will be required.

3.3. Identify options for the best group size based on needs of the captive population and husbandry standards as laid out in the Kea husbandry Manual[2].

4. DELIVERABLES

4.1. Critically evaluate the stud book to establish degree of inbreeding

4.2. Undertake appropriate modelling to meet the objectives of this investigation.

4.3. Preparation of a suitable report that details what a captive kea population (maintained for advocacy purposes) will look like/how it will be structured.

5. TIME FRAME

Report to be delivered in May 2012

[2] http://www.keaconservation.co.nz/pdfs/2010_kea_husbandrymanual_final.pdf